IMPLEMENTING TRADABLE EMISSIONS PERMITS FOR SULFUR OXIDES EMISSIONS IN THE SOUTH COAST AIR BASIN

VOLUME II

FINAL REPORT

ARB Contract No. A8-141-31

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Environmental Quality Laboratory
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ABSTRACT

Tradable emissions permits have important theoretical advantages over source-specific technical standards as a means for controlling pollution. Nonetheless, difficulties can arise in trying to implement an efficient, competitive market in emissions permits. Simple workable versions of the market concept may fail to achieve the competitive equilibrium, or to take account of important complexities in the relationship between the pattern of emissions and the geographical distribution of pollution. Existing regulatory law may severely limit the range of market opportunities that states can adopt.

This report examines the feasibility of tradable permits for controlling particulate sulfates in the Los Angeles airshed. Although the empirical part of the paper deals with a specific case, the methods developed have general applicability. Moreover, the particular market design that is proposed -- an auction process that involves no net revenue collection by the state -- has attractive features as a general model.

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SUMMARY AND RECOMMENDATIONS

As the controlled trading options of the Environmental Protection Agency become more widely adopted, the concept of a market for emissions permits becomes closer to reality -- and less an academic exercise. This project has examined the issue of the feasibility of tradable emissions permits (TEP) as a means for controlling particulate sulfates in the South Coast Air Basin. It is intended to be a test case of the general approach of a relatively unfettered market in emissions permits. The methods of analysis employed are intended to provide a guide for attacking similar feasibility problems in other regions and/or for other pollutants.

The controlled trading options of EPA can be regarded as allowing some transactions within the framework of traditional command-and-control regulation. The focus of our work has been a system in which primary reliance in deciding the pattern of abatement among sources is placed upon the market, with regulators using the standards approach to set an overall emissions ceiling in a region and, on occasion, to deal with specific sources that require some constraints on their acquisition of permits (and hence emissions) through the market.

The desirability of the market approach depends on its performance according to several different criteria. First, TEP must realize their principal design advantages: reduce the costs of compliance with environmental standards and increase the flexibility with which firms in the region can enter or expand. Second, this must be accomplished within the constraint that overall environmental objectives are not sacrificed — that is, that the implementation of TEP does not degrade air quality. Third, the effects on the distribution of wealth and the industrial structure of the region must be politically acceptable. While we offer no index of political acceptability, an analysis of any major regulatory reform must provide decisionmakers with useful information about these impacts which they can use to assess this element of feasibility. Fourth, the reform must be made to fit into the body of law regarding regulation and administrative processes. Reforms must either be legal under current law, or must be accommodated by changes in law that are regarded as reasonable in the sense that they do not violate the spirit of public policies towards environmental protection, due process, etc.

To attack these issues, we have assembled the following information: abatement cost data for major source categories of sulfur oxides emissions in the air basin, an emissions inventory under current standards, a working model of the relationship between emissions and air quality, and the relevant statutory and case law in both environmental and public utility regulation. We have used the data on costs, emissions and air quality to simulate the results of different market designs to determine the properties in terms of costs and air quality of several different approaches to a TEP system. We have used work in economic theory and small group experiments to check whether the hypothetical market institutions that we have considered can be expected to work in practice. And, we have assessed the important legal barriers to implementing a relatively full-blown tradable emissions permit system.

A number of technical and economic questions need to be addressed explicitly to demonstrate the feasibility of the TEP concept. Can a competitive market in TEP be established — one that has the desirable features of flexibility and cost-minimization of competitive equilibrium in economic theory? Or will the market be monopolized, or have so few traders, that it does not produce an efficient result? And, if competitive allocations of permits are attained, what effect will this have on air quality? Assuming that the result is acceptable from both an efficiency and an environmental point of view, what will be the effect on abatement costs, the profitability of local industry, and the structure of the regional economy? Finally, assuming that these other questions can be answered in an acceptable fashion, what exactly has to be done -- in law and in working out the details of the market — in order actually to implement the plan?

The results of the work on this project indicate that, indeed, a system of tradable emissions permits is feasible -- but that it must be carefully designed to avoid some pitfalls. Moreover, there are some legal and regulatory policy issues that need to be worked out to adopt the form of a permits market that is likely to work the best. Selecting a design for TEP in Los Angeles is in part a matter of technical and economic analysis, but it is also partly a matter of judgment. It requires an assessment of the political realities constraining reform, and of the types of risks that a regulatory agency is more and less willing to run.

In Los Angeles, the possibility of monopolistic practices and thin markets apparently are a far more important design issue than is the possibility of undermining environmental objectives. Theoretically, any environmental objective can be obtained by creating a large enough number of different kinds of permits, each of which relates to pollution at a specific geographical location. Practically, fine-tuning the system in terms of multiple markets for sulfur oxides emissions promises gains, yet presents formidable problems of transactions costs and market structure. Consequently, a system in which permits are simply stated in terms of allowable quantities of SO_2-equivalent emissions anywhere in the region appears to be the most desirable.

The Los Angeles airshed has a relatively large number of sources producing a small quantity of emissions, but only ten firms account for about 85 percent of the total. Consequently, imperfectly competitive and thin markets are a potential problem for large transactions. The implication is that the method selected for initializing and maintaining the system should encourage an active, competitive market.

The most attractive method for the initial allocation is an auction. This provides a thick market (all permits are transacted in the initial distribution) and, because all polluters are placed on the same side of the market, it minimizes the likelihood of monopolistic imperfections. The mechanics of the proposed mechanism are as follows. Each source would be asked to write down the number of permits it would seek to purchase at each of several prices. The firm would be free to choose as many price gradations as it wanted. It could write down one price-quantity pair (e.g., X tons per day at any price up to $Y per ton). It could provide a step function of several jumps, such as X tons per day for prices between $Y and $Z ($Y being larger), and X+W tons for prices below $Z. Permits would then be allocated to the highest bidders at the quantities requested, descending down the price bids until the permits were completely allocated. The final price could be determined by either of two methods. The simplest to understand is a "first-price auction," in which the price is the lowest successful bid. The alternative is a "second-price auction," in which the price is the highest unsuccessful bid. The second-price auction is slightly superior theoretically because it is more likely to produce a competitive allocation and be free of strategic manipulation by a participant with a large share of the market.

A separable equity issue accompanying the auction is the allocation of the net costs of the permits. Whereas the permit price determined above could actually be paid to the state, an alternative is to pay the revenues according to a previously arranged provisional permit allocation. As a political matter, the chances of implementing a tradable permits system may be greater if the revenues do not accrue to the governmental treasury, and if the provisional allocation of the rights to receive the revenues from the permit auction does not reward firms who have been most resistant to current environmental regulations. For example, one possible alternative is to base allocations on an amended list of existing emissions, with the few remaining uncontrolled sources being put through an emissions standard process before the initial allocation of tradable permits is made.

In any case, the provisonal allocation would be used solely for allocating auction revenues. Each polluting firm would make bids on permits, and thereby receive a final allocation of emission permits according to its bids at the price of the highest excluded bid. The firm would pay for these permits at the established price, and receive revenues at the same price for the permits which it held provisionally. The net payment for a particular source would be the product of the auction price and the difference between its final allocation based upon the bidding procedure and its provisional allocation based upon its emissions baseline. For all firms taken together, the net payment would be zero.

It is worth noting that in this type of auction, if a firm reports its true cost-minimizing demand for permits, any difference between the final and provisional allocations is a net financial gain. A firm will end up buying permits only if these permits allow an even greater savings in abatement costs, and will sell permits only if the revenues from the sale exceed the costs of the additional abatement that the sale will require. Hence, participation in an auction that reallocates all auction revenues in this way can harm a firm only if it is not truthful in stating its demand for permits. This is true even if the market is not competitive.

To provide a continuing opportunity for entry and expansion, the initial permits could be separated into vintages according to useful life and periodically reissued by the same process. A predesignated portion of the permits would expire every few years -- for example, permits could be valid for nine years, with one-third expiring every three years. Prior to the expiration date, the regulators would determine how many permits would be issued to replace the expired ones, based upon considerations of cost and air quality. The new permits could be allocated by the same auction procedure as was used for the initial allocation. Provisional allocations for purposes of distributing auction revenues would be based upon holdings of the expiring permits, but the final allocation would be based upon an auction. Meanwhile, between auctions businesses could negotiate trades if they so chose.

The system of permits with sequenced expiration introduces flexibility into the regulatory process while still retaining a substantial amount of stability. More risk-averse firms, or firms seeking to pursue abatement strategies involving long-term capital investments, could adjust their portfolio to hold permits with late expiration dates. Each three-year regulatory review would introduce the opportunity for altering total emissions in response to new information or political changes.

The system described above addresses the major questions about a tradable permits approach.

1. An auction process for sequentially expiring permits guarantees regularized transactions that involve all sources in the airshed and, in addition, appears capable of producing a stable, competitive price for permits.

2. There is no significant loss in efficiency or air quality if the entire region is treated as a single, homogeneous market.

3. The Cass model of the relationship between emissions and air quality provides a good basis for establishing the air quality impact of an initial quantity of total emissions, and the sequential expiration of permits easily accommodates further adjustments to account for whatever errors might be present in the model's predictions.

4. Sequenced expiration of permits can also provide the possibility for long-term stability for firms that desire it, facilitating capital investments in abatement methods for firms that want to use them, while still letting the regulatory system adjust to changes in information or political values.

5. The sequenced expiration dates for permits plus the auction method for allocating them facilitate easy entry and expansion of emissions sources without altering environmental quality.

6. Even using the abatement cost information available to us, which is likely to overstate abatement costs, implementation of tradable permits will cause no dislocations in the local economy, in part because the cost-minimizing abatement strategy does not impose costs on any industry that would cause a significant reduction in output, and in part because the auction mechanism avoids the problems of temporary, distorted prices that create false incentives to industry.

Thus, tradable emissions permits are an attractive alternative to command and control regulation for the specific case of particulate sulfates in the Los Angeles area. We also believe that the analysis contained in this report has wider applicability. First, the most important questions about the feasibility of tradable permits are likely to be pretty much the same for all pollutants in all regions. Second, the design concepts that have been developed for this particular problem do not appear to us to be idiosyncratic. This project, then, provides a methodological guide for examining the prospects for this approach in other areas for other pollution problems.

A comprehensive TEP program faces two important legal barriers before it could be implemented. Although the Clean Air Act apparently does allow markets for emissions among old sources, it is quite specific in requiring that major new sources use up-to-date control technology, even if to do so causes significant differences to emerge in compliance costs between old and new sources. Thus, a limited TEP system — confined to old sources — could be implemented with minor changes in state and local laws and practices, but a TEP system that included new sources would violate Section 111 and Section 116 of the Clean Air Act. This is unfortunate, for one of the major advantages of TEP is the ease with which entry and expansion of new sources can occur without undermining air quality goals. Thus, a most effective system requires amendment of the Clean Air Act. Most promising would be to authorize a special experiment in innovative regulatory methods, limited to this one case, with provision for later evaluation. But even if such an amendment is not feasible, a TEP system that is constrained by new source performance standards is both useful and feasible.

A second legal issue has to do with the methods and practices of public utility regulation. Electric utilities are a major source of emissions in Los Angeles, and therefore can be expected to be a major force in a permits market -- assuming that they can and will participate. Unfortunately, their participation is not a foregone conclusion. Methods for regulating prices and profits of utilities in California are not particularly harmonious with the idea of an intangible asset in pollution permits that can enter the calculations of allowable costs for a utility. To cause the incentive effects of a permits market to be appropriately imposed on a utility requires that permits enter the allowed cost calculations of the firm, and that revenues from the sale of permits be available for abatement expenditures or other uses, rather than returned to ratepayers in lower prices. Current regulatory practice in California would not lead to this result for some of the alternatives to structuring a permits market that we have examined -- including the EPA's controlled trading options.

There are ready solutions to the utility rate-making problem, the details of which are described in Chapter 5. The general recommendation we have is that the Public Utilities Commission should use the authorization for experiments in rate regulation in the Public Utilities Regulatory Policies Act to treat tradable emissions permits in a somewhat novel fashion that will apply "replacement cost" valuation methods (even though California is an "original cost" state) and that will use the legal analogy of long-term leases to determine whether permits expenditures will be regarded as capital or operating expenses.

CHAPTER 1

INTRODUCTION

Roger G. Noll

One of the reforms of environmental regulation that has received considerable attention in the past few years is to replace source-specific standards with a system of tradable emissions permits (TEP). The theoretical case for the proposal is strong; however only recently have analysts devoted much attention to developing a strategy for implementing such a system. A synopsis of the research on TEP is contained in Appendix A.

This report addresses the problems of setting up an efficient market in emissions permits. We first develop the case for using tradable permits to solve environmental problems. Then we raise and attempt to answer some of the implementation questions that decisionmakers raise about the proposal. Because this is essentially a feasibility study, our answers to these implementation problems are presented in the context of a particular problem: the case of particulate sulfates in the Los Angeles airshed. The results of the empirical work for this case study are also included.

THEORETICAL ADVANTAGES OF MARKETABLE PERMITS

Decentralized, market-oriented methods for abating pollution have several theoretical advantages. Before discussing these advantages, it is useful to separate the methods available to regulate air pollution into four general categories. One is <u>input standards</u>: regulators tell polluters what kind of equipment or abatement strategies to adopt, such as requiring a utility to install stack gas scrubbers and/or burn low-sulfur fuel at a generation facility. A second is <u>output standards</u>, in which each polluter is told the quantity of emissions allowed at each source. Here the polluting firm is allowed to select the method for achieving the emissions target as long as the result is in compliance with the standard. A third method is <u>tradable permits</u>, whereby a target rate of emissions is set for a region and a market mechanism is relied upon to determine how these permits are allocated among emissions sources. A fourth approach is <u>monetary incentives</u>, which includes abatement subsidies and emissions taxes. Under such schemes a polluter is charged some amount for each unit of emissions and/or subsidized for each unit of emissions reductions beyond a specified baseline.[1] Subsequent discussion focuses on taxes. Emissions taxes seem more likely to be implemented than subsidies because the former do not have to confront the problems of seeming to reward pollution, encouraging entry of polluting industries, and raising revenues for subsidizing industrial abatement efforts. Nevertheless, subsidies are now used in one case -- grants for sewage treatment facilities -- and might prove politically more attractive if coupled with an emissions tax as the source of revenues for the subsidies.

In all cases, the purpose of environmental regulation is to achieve some overall reduction in pollution; for the case of air pollution, the target is an ambient air quality standard. In each case, an emissions target is selected that is thought to be consistent with the overall objective in terms of pollution reduction, although the link between environmental quality and emissions is often subject to considerable uncertainty. But in principle, input standards, output standards, emissions taxes and the number of tradable permits all can be chosen to achieve some target level of environmental quality.

In practice, environmental regulation has become a hybrid of all four approaches. In the Los Angeles airshed, for example, both input standards and emissions limits are used, a relatively low emissions fee is charged, and emissions permits can be traded according to the "controlled trading methods" that have been developed through the Environmental Protection Agency (EPA) in the late 1970s. Moreover, nationally there is relatively little difference in the way that input standards and output standards are adopted. An input standard is imposed upon a firm because regulators anticipate that it is the best feasible strategy for reducing emissions; an output standard is imposed on the basis of analysis of the technical abatement alternatives, and is normally set after a demonstration that a particular technical alternative can achieve the standard. In fact, standards are often really a combination of the two: an output target is set, and an acceptable technical approach is identified.

All standards must be adopted in a quasi-judicial process that is subject to judicial review on the basis of the procedures that were followed and the adequacy of the evidentiary basis for the decision. In the process of setting the standard, the regulatory authority bears the burden of proving that the regulations are reasonable with respect to cost and effectiveness; hence the tendency to deal with both inputs and outputs in setting standards for a particular source. Once a standard is adopted, if a polluting firm wishes to adopt another method of abating the emissions, it then bears the burden of proving that the other technical option will work at least as well. In both cases, the process of adopting a standard requires considerable time and expense, especially if regulated firms or environmentalists elect to challenge the standards in the courts. Thus, a key feature of the system of source-specific standards is that they are costly -- in dollars and time -- to establish and to change.

One factor influencing the choice of a standard is ease of enforcement. When the technology of choice is a specific piece of capital equipment, enforcement is the simple task of inspection to see if the equipment is present and working. Emissions taxes, tradable emissions permits and output standards require monitoring to determine compliance. Monitoring performance is usually more costly and technically more difficult than inspecting inputs. In the long run all regulatory approaches will be evaluated in terms of their performance with respect to pollution, and experience to date suggests that input regulation is too crude a control on performance to make worthwhile its lower enforcement costs. In Los Angeles, performance monitoring is relatively sophisticated already, so that no special problems are associated with a possible switch to tradable permits. Some questions about the design of fines in enforcement are considered in Appendix B.

The standard-setting approach to environmental regulation has several important shortcomings.[2] A regulatory system that deals with each specific source of emissions -- sometimes several at a particular plant -- requires that regulators must learn enough about the production process that they are regulating and the abatement opportunities available to it that they can determine the optimal emissions reduction for it. Because of the adversarial nature of the process, firms are likely to be reluctant to go to great lengths to provide accurate information to regulators. Moreover, some abatement strategies may involve changes in the production process that, if revealed in a public regulatory process, would give away economically significant trade secrets. Consequently, the standards that are adopted are not likely to be the set of cost-minimizing steps to achieve the overall air quality objective. Significant differences among firms in the costs of complying with regulation not only are inefficient, but also can upset competition among firms in the same industry.

Standards also provide blunted incentives for technological innovation in abatement. In the current regulatory system, industries that produce abatement equipment have a strong incentive to invent new equipment that reduces emissions; however, the firms that are the objects of regulation lack that incentive, and indeed can be expected to fight the adoption of better performing but more expensive abatement technologies. In addition, the case-by-case regulatory approach raises the cost of any technical change by requiring preimplementation approval by the regulators.

Finally, standards inhibit the entry of new firms into an area. Before a firm may enter any area, it must obtain approval of its emissions from the regulatory authority. And, if the area is not in compliance with ambient air quality standards, entry can be foreclosed if the new or expanded facility generates <u>any</u> emissions at all. In general, emissions standards for new plants tend to be substantially more rigorous -- and expensive -- than are standards for established plants in the same industry using the same production technology.[3]

In sum, standards do not lead to the most cost-effective abatement strategies, are promulgated in a costly, time-consuming process, and impede technological change and new business investments. Given these problems, the question naturally arises as to whether taxes and tradable permits are better ways of meeting a prescribed set of environmental policy objectives.

The purpose of a marketable permits system is to achieve the ambient air quality standard for a particular pollutant at minimum total cost, including both the direct abatement cost and the cost associated with the regulatory process. This is achieved by relying on decentralized decisions to rationalize abatement strategies at all sources. Each firm faces an abatement cost function — that is, a relationship between the amount of emissions that it will produce and the costs it will face. If the tradable permits market works efficiently (an issue that is examined in the next section), the best strategy for each firm is to abate emissions to the point at which the price for additional emissions (either the actual price of buying more permits or the opportunity cost of keeping, rather than selling, the permits it already has) equals its marginal abatement cost. If this solution holds for all firms, then all firms will pay the same amount for the last unit of pollution that they abate, and all firms together will achieve at minimal total cost the air quality standard that is implicit in the number of permits that are issued.[4] Moreover, this cost-minimizing abatement strategy will emerge without the necessity of a regulatory review of the costs and performance of the abatement strategies available to the sources and a formal approval of the technical approaches that are selected.

Emissions taxes have many of the same theoretical virtues as tradable permits. If firms are cost minimizers, effluent taxes also can lead to the cost-minimizing solution.[5] Like tradable permits, they provide a continuing incentive for cost reductions. Moreover, because taxes do not entail the introduction of a market, they avoid the implementation problems of permits, assuming that an efficient, competitive market will emerge.

While the theoretical case for taxes is strong, they have seldom been implemented. One reason is political — they confer benefits on the general public, but they force firms to pay both abatement costs and emissions taxes. The extent to which firms pay taxes out of profits depends on whether the increase in taxes can be passed along to consumers. Nevertheless, it is usually in industry's interest to oppose taxes in comparison with standards because the latter avoid the tax. Tradable permits also can avoid net payments to the government if licenses are initially given away rather than auctioned.

Emissions taxes also present some difficulties in dealing with the entry of new sources of pollution. Unless taxes adjust upward, they will lead to ever-worsening environmental quality; however, if taxes are to be adjusted when entry occurs, something like a regulatory process must be used to examine the implications of each new entry and set an appropriate new tax. By contrast, entry under a permits regime requires only the acquisition of the necessary permits from other sources, neither posing a threat to environmental standards nor requiring a formal review of the entrant's likely emissions and abatement opportunities.

As mentioned above, all performance-related regulatory approaches raise questions of enforcement costs because of the difficulty of monitoring pollution. Emissions fees, however, are somewhat more difficult to enforce because they require continuous monitoring to estimate total emissions for the purpose of determining tax liabilities. An emissions fee is normally some price per unit of emissions; hence total emissions during a tax period need to be estimated. Moreover, for the tax to be collectable, the monitoring process must be accurate enough to withstand legal challenges.

Performance standards and emissions permits can be enforced by intermittent monitoring. The key issue in either case is if a firm is in compliance with its emissions ceiling, whether the ceiling is established by a regulatory process or by acquisition of permits through a market. Noncompliance fines need not be based upon the extent to which the firm is out of compliance (e.g. on total measured emissions), although the fines must be high enough and the probability of detection great enough so that a firm prefers to emit within its ceiling rather than to run the risk of being caught with excess emissions.

Another characteristic of taxes that has caused opposition to them is that the consequence of uncertainties over the cost-effectiveness of abatement techniques emerges in an emissions tax system as unpredictability in the quantity of emissions. By contrast, both output standards and a permits scheme would specify the overall quantity of emissions in advance, and the uncertainties in the system are with respect to cost. Input standards suffer from both uncertainties, because the use of a technology, not its effectiveness in reducing emissions, is the measure of compliance.

The reforms of environmental regulation pursued by EPA since the enactment of the Clean Air Act amendments of 1977 foresee a limited role for emissions fees in the context of traditional standard-setting methods. This role entails the use of "noncompliance fines" for firms that fail to meet the standards, with the fees designed to be high enough to provide incentives to comply before all legal avenues for fighting compliance are exhausted. This, of course, avoids some of the political and technical problems of emissions taxes, but it also sacrifices their principal advantages in terms of minimizing abatement costs and providing an incentive to beat the standards.

The theoretical advantages of a tradable permits system make them worthy of further serious investigations. Indeed, both federal and state regulators have expressed considerable interest in this method. As mentioned above, EPA has developed several limited variants of a tradable permit system that are being applied experimentally around the nation. These so-called "controlled trading methods" are:

1. Bubbles. A single plant that has several emissions sources may be permitted to increase emissions beyond the current standard at one location if it makes a greater reduction in emissions somewhere else at the same facility;[6]

2. Offsets. A firm may add new emissions in a geographic area if it pays for a greater reduction in emissions somewhere else in the same area; and

3. Banks. A firm that reduces its emissions below the applicable standard may deposit as a credit some fraction of its excess emissions reductions in an emissions bank. These banked emissions credits can then be sold to some other firm that seeks emissions permits.

All of these policies are designed to introduce some flexibility into the means by which firms comply with environmental regulations by introducing the possibility of trading emissions at one place for emissions somewhere else. In this sense they are conceptually similar to tradable permits. But all retain important elements of the standard-setting approach as well. Each trade requires regulatory approval, and the source using the traded permit assumes a burden of proof that the trade is consistent with overall environmental policy.

Current distinctions in the stringency of regulations between new and old sources are retained in all of these policies. Thus, firms seeking to locate an environmentally significant new source of emissions by acquiring tradable permits must still operate at lowest attainable emissions rates. For new sources, the trading policies are regarded as a means for providing the possibility for entry when compliance with new source standards would still not be sufficient to comply with ambient air quality standards.

As of early 1982, the new policies did not yet have completely defined rules and procedures governing transactions, nor in most cases a convenient institutional arrangement for facilitating them. The offset policy has no formal process for informing prospective participants in an offset about the identity of potential partners, the likely cost of reducing their emissions, or the expected price of their emissions permits. Each offset transaction is the result of bilateral negotiations outside of any formal institutional structure established by the government. Emissions banks do have a formal record-keeping method for tracking the amount and source of marketable emissions credits, but at present the formal rules and procedures regarding trades are still being worked out. For both offsets and banks, trades must be approved by local regulatory authorities, although formal approval from the EPA can now be avoided if the trading system is established according to EPA guidelines.

A final problem with all three methods is that the long-term status of traded permits is not clear in any program. If environmental quality in any area falls short of the policy target, all permits — traded or not — are subject to revision; however, traded permits and banked credits from sources that reduced emissions below standards appear more likely to be confiscated or severely reduced in value than other permits do. For example, in listing the options available to a local air pollution control authority should a revision be necessary in the amount of emissions that is allowed, the EPA manual for setting up an emissions bank cites four alternatives:

1. A moratorium on the use of permits obtained from the emissions reduction credit bank;

2. On a source by source basis, a revision in the number of permits from the bank that are necessary to produce a unit of emissions at that source;

3. An across the board reduction in the amount of emissions permitted for a permit acquired through the bank; or

4. A forfeiture of all traded permits.[7]

Thus, a traded emissions permit may have secondary regulatory status in comparison with an untraded permit, making the former less valuable. The possibility that traded permits will be treated this way will make firms reluctant to reduce emissions beyond current requirements in order to create marketable permits out of concern that their additional emissions reductions will be confiscated rather than made available to others. Potential trading partners will be equally reluctant to make long-term capital investments on the basis of emissions permits that have such an uncertain status.

The tradable permits system examined here is a more radical institutional change than has thus far been contemplated by regulatory authorities. It would eliminate distinctions among sources because of age, ownership, industry or method of acquiring permits. It would simply establish a ceiling on total emissions within a geographic area, and it would allow the allocation of emissions among sources in the area to be determined solely by the market. No regulatory review of the methods used by any source nor of the distribution of emissions permits among the sources would be undertaken. Policy issues relating to the differential air quality effects of different geographical distributions of emissions permits would be dealt with by the way in which trading regions were defined, and by the rules for trading across regional boundaries, as will be discussed below. The role of the government would be reduced to the following activities: (1) establish ambient air quality standards; (2) determine the total amount of emissions that is consistent with the air quality standard; (3) issue permits and maintain a record of their ownership and a market for them; and (4) enforce the emissions limits by ascertaining whether each source is producing no more emissions than the quantity of permits it holds and by imposing noncompliance penalties.

DESIGN PROBLEMS FOR TRADABLE PERMITS

The main purpose of a tradable permits system is to convey to polluters — new and old — appropriate price signals about the social cost of emissions so that each can select a combination of capital investments, operating practices and emissions releases that minimize the sum of abatement costs and permits costs. The economic efficiency of the system depends on firms being able to buy and sell permits relatively easily, with incidental transactions costs, at competitive prices. The principal implementation problems associated with a tradable permits system are related to the question of whether these conditions for an efficient market can be satisfied in a manner that is equitable, legal and politically feasible.

One problem is the possibility of "thin" markets — that is, markets in which transactions are rare, and in which few firms are willing to buy or sell. In such a situation, the transactions costs of trading permits can prevent the market from being much of an improvement over source-specific standards. If a firm that seeks to buy permits must invest substantial time and resources in finding a potential trading partner, and then engage in bilateral negotiations to determine a price, the ability of the permits market to find a cost-minimizing total cost of achieving ambient air quality standards is undermined. Moreover, infrequent trades arranged through negotiations are less likely to convey clear price signals to potential entrants, firms contemplating expansion, or sources considering further abatement and the sale of some emissions permits.

A second problem is related to the structure of the permits market. In some airsheds, one or two firms can account for a very large share of emissions. Moreover, there is some tendency for regulators to require somewhat greater abatement efforts from the largest firms. In this situation, if a tradable permits system is initiated by making tradable the emissions permits that are implicit in current standards, it is conceivable that only one or two firms will be seeking to buy permits, with all other firms seeking to be sellers. If so, the market may not settle on the competitive equilibrium price, but a monopsonistic price instead. More generally, the degree to which a market diverges from the competitive ideal depends on the initial allocation of permits, and in any situation it is technically possible to pick an initial allocation that produces a monopoly or a monopsony. Thus, a design problem for a tradable permits market is to avoid an initial allocation that has this property.

A third problem has to do with the definition of markets and permits. As discussed briefly above, the relationship between emissions and pollution is often very complex. Pollution at any given receptor point is the consequence of emissions from several locations, and often depends on their interactions as well. Similarly, every source of pollution has a unique pattern of polluting effects, which, because of interactions, may also depend on emissions from other sources. In general, to achieve theoretical efficiency (ignoring transactions costs and possible market imperfections) requires a separate transformation function for each source of pollution that maps its holdings in pollution permits at any source to its emissions allowances. Of course, this degree of complexity is impractical to implement. Hence, an important design problem is to make simplifications in the definition of permits and regions in which permits are valid that do not sacrifice too much in the way of the potential efficiencies of a market mechanism. At one extreme, a large geographic region can be treated as one market, with the implication that the region will be treated as one large mixing bowl in which emissions from all sources are uniformly spread across the region. As a description of reality, no pollution problem -- not even emissions into standing bodies of water -- has this fully mixed property; however, as a practical matter it may be a workable assumption. A somewhat more complicated strategy is to define a few receptor points at which pollution is measured and require firms to purchase emissions permits for pollution at each receptor point where their emissions cause pollution.

The best way to organize the market -- the definition of a permit and the sources that must hold it -- depends only in part on the physical aspects of the pollution problem. It also depends on the economic incentives operating upon sources. If abatement cost functions for all sources lead to more or less the same degree of abatement (e.g., they are all reducing emissions by roughly the same proportion), a permits market that is defined crudely, even wildly incorrectly, as a mixing bowl may still be workable. In the worst case -- in which each receptor point is polluted by only one source -- the cost-minimizing distribution of emissions may still produce approximately the same amount of abatement at all sources.

In most regions, pollution problems exhibit both kinds of characteristics: localized, single-source pollution, and effects from the combined emissions of many sources. A plume from a smokestack may be the primary cause of pollution on receptors a few miles downwind, but as distance from the stack increases its emissions will mingle with the releases from other facilities. To take an extreme example, the problem of acid rain in Canada, New York and New England is probably the cumulative effect of emissions from literally thousands of sources, some more than a thousand miles away. Whether a tradable permits market is workable, then, depends on the relative importance of the local versus long-distance effects, and on the likely pattern of abatement that will emerge from the market.

A fourth issue in the design of a tradable permits system is its flexibility with respect to changes in ambient air quality or total emissions targets. Because the relationship between emissions and air quality and the effect of air quality on health are not well understood, there is a good chance that new knowledge will cause regulators to want to change emissions levels. A decision to create more permits is relatively straightforward to deal with; regulators can give away or sell some net increment to the total emissions rights in an area. But a decision to reduce the number of permits raises potential difficulties. The heart of the issue is still another dimension of the definition of an emissions permit. Is its lifetime perpetual, or of fixed duration? Can it be redefined by fiat, or as an outcome of a regulatory process, or must changes in the number of permits be accomplished by purchase of the state? Obviously, the ease with which the number of permits can be changed depends on the answers to these questions. Moreover, a constraining factor on building into the permits system a mechanism for changing the number of permits is the effect of the mechanism on the willingness of firms to hold permits. If polluting entities are made to believe that the value of an emissions permit is subject to significant change at the whim of the state, abatement strategies -- in terms of both the amount of abatement and its distribution between long-term capital investments and changes in operating methods -- are likely to be affected.

Fifth, the implementation of a tradable emissions permits system can have an important effect on the distribution of income in a region. The permits themselves have economic value, so that the choice of methods for distributing them initially will make the recipients of the permits wealthier. Moreover, the costs of the system of air pollution regulation to polluting industry will also be affected. On the one hand, industry in general will face lower total abatement cost and lower costs of participating in the regulatory process. But firms that are required to purchase permits may face more than offsetting expenses on permits -- depending on how the permits are distributed initially. Regulators can affect these distributional consequences, for the method of implementing TEP will be an important factor in determining how and by how much the TEP system will immediately alter the industrial structure of the region and the distribution of wealth. This issue is not only a matter of equity, but affects the political feasibility of the system as well, since these economic impacts will play an important role in the decisions of key groups to support or to oppose the reform. A more complete discussion of the source of political resistance to the TEP approach is contained in Appendix B.

Sixth, an element of system design is the state of the law that surrounds regulatory policy. Three important areas of regulatory law are important: environmental law, as represented by the Clean Air Act; administrative law, which establishes the bounds on the procedures and methods that a regulatory agency can adopt; and public utility law, by which the prices and profits of electric utilities are regulated, including the accounting practices for passing through to ratepayers the costs of environmental regulation. None of these areas of law has developed with the idea of dealing with the use by regulators of decentralized market forces to achieve social objectives. Consequently, the concept of tradable emissions permits does not fit comfortably into the body of established law. An important question for regulators is how existing law constrains the design of a tradable emissions permits system, and how law needs to be changed to accommodate the most attractive system.

Finally, some account needs to be taken of so-called air pollution episodes: periods when meteorological conditions are exceptionally unfavorable, and so air pollution builds up over a number of days. To limit emissions to a level consistent with good air quality on these worst days is irrational; it is far less costly to curtail economic activity for a few days a year than to build in abatement capacity that would keep air quality high regardless of the weather. The current practice is to announce the degree of unfavorability of conditions a day in advance, and to invoke special regulations when conditions look especially bad. To do something much more complicated than this is of dubious value, because the frequency and magnitude of air pollution episodes is not very high, and will be lower still as limits on emissions are lowered.

The tradable permits systems could easily adopt the present approach to episodes, with the emissions permits applying only in the vast majority of days when there is no special condition. Alternatively, separate emissions permits markets could be implemented, one for normal conditions, and one or more for episodes, with regulators announcing each day which permits apply tomorrow. Because this problem is relatively easy compared to the others it will not be addressed in the remainder of this report.

VARIANTS IN SYSTEM DESIGN

The design features available to construct a workable permits market are as follows.

1. Permit Life. Regulators could elect to make the durability of emissions permits uncertain by stating that they were valid until a formal regulatory procedure declared them to be invalid or changed the amount of emissions allowed by a single permit. Such a system would create incentives among firms to adopt production methods with some flexibility in emissions, and to hold more permits than were actually used. Alternatively, regulators could define the time period in which a permit is valid. At one extreme, permits could be perpetual, requiring regulators to buy them back to reduce total emissions. Or, regulators could assign a fixed life. If regulators decided to alter the number of permits, they could do so by allowing firms to trade in old permits for new at a specified exchange rate. Finally, regulators could have several different kinds of permits: some perpetual, some of a fixed, long-term duration, and some with a short life (e.g., one year). Some periodic variability in the number

of permits could be accomplished through the process of reissuing the permits with the short life; somewhat greater variability could be introduced as the intermediate-duration permits expired.

2. Market Definition. An emissions permit pertains to a particular geographic area. The size of the region and the variety of permits a source must hold for a given emissions allowance is a design feature of the system. Regulators could define emissions permits as freely tradable among all sources in a wide geographic area. Alternatively, a region could be subdivided into smaller areas, with trades between areas either barred or permitted according to some transformation of the value of a permit across area boundaries. Or, markets could be defined according to the location of receptors. In each area of the region, a coefficient would be estimated that related the effect of a unit of emissions on ambient air quality at a receptor point. Sources could then be required to hold permits to pollute at a receptor point equal to their quantity of emissions multiplied by the corresponding coefficient.

3. Market Initialization. Regulators must select a method for initially distributing the permits. One possibility is to give them away according to some rule. Examples of allocation rules are: in proportion to precontrol emissions, in proportion to emissions allowed under existing standards, or equal to the expected equilibrium distribution of emissions if abatement costs were minimized. Alternatively, permits could be given to entities other than sources of pollution: the poor, schools, etc., presumably any of which would then elect to sell them. Or the government could allocate the permits by auctioning them. The latter two options suggest that sources of pollution would have to pay for permits; however, this is not necessarily the case for a state auction. Ownership of permits could be conferred on sources according to one of the rules for giving permits aways, but sources could then be required to use an auction process to allocate the permits among themselves, with the revenues from the auction divided among the sources in proportion to their ownership shares.

4. Market Operations. Once an initial allocation has been made, provisions must also be adopted for later transactions. Government could leave the problem of organizing a continuing market to the private sector. Alternatively, given the recordkeeping requirements of the government for purposes of enforcement, the government could act as a marketplace by providing information about potential buyers and sellers to anyone requesting it. Or the government could be more than a passive marketing agent by actually requiring regular opportunities for reallocation of permits. This could be accomplished by forcing periodic reauctioning (with proceeds redistributed among the sources) of some fraction of the permits. A reauctioning process fits naturally with a system in which permits have fixed durations, for then the replacement of old permits by new ones can be accomplished through an auction of the same sort as used to accomplish the initial allocation.

SOLVING THE DESIGN PROBLEM: A CASE STUDY

The following report uses a particular example -- the control of sulfate particulates in Los Angeles — to illustrate how the implementation problems can be addressed. This analysis is based upon relatively complete information about abatement costs, legal constraints, emissions inventories, and the relationship between emissions and air quality throughout the region. Los Angeles probably has the most sophisticated regulatory system for air pollution in the world, in part because local agencies have been collecting emissions and air quality information for three decades and in part because these data have been extensively used by research scholars to study the Los Angeles air pollution problem. This information, of course, is especially helpful for illustrating the way that issues of designing a permits market might be resolved and for designing a particular set of market institutions for this pollutant in this region. It is not necessary, however, to have all of this information in order to move towards a tradable permits system. In addition to the discussion of the Los Angeles sulfate problem we will also discuss methods of approaching the same design problems when the available information is less reliable.

The problem of sulfate particulates in Los Angeles is somewhat unusual in that the state, not the federal government, is primarily responsible for its regulation. Sulfate particulates are suspected of being a health hazard and having other damaging effects, but the principal justification for controlling them in Los Angeles is that they account for a very large part -- between one-third and one-half -- of the reduced visibility due to air pollution in Los Angeles. There is no federal ambient air quality standards for sulfate particulates; however, the state has adopted a standard of 25 micrograms per cubic meter, averaged over a 24-hour period.

Although sulfates are released directly into the atmosphere by some sources, by far the most important cause of sulfates is the release and subsequent atmospheric oxidation of SO_2, nearly all of which is associated with petroleum products that contain sulfur as an impurity. There is a federal ambient air quality standard for SO_2; however, Los Angeles is not in violation of it. Hence, the state standard for sulfates is the binding constraint on SO_2 releases.

To control sulfate particulates in Los Angeles requires controlling emissions from over thirty different categories of sources. The most important sources are electric utilities that burn oil to generate electricity, petroleum refiners, coke calciners, glass manufacturers, a steel mill, industries that are heavy fuel burners, and mobil sources burning gasoline or diesel fuel. A tradable emissions permit system must be designed to account for emissions from these major sources.

The tools with which to undertake an analysis of the design of a permits market in Los Angeles are a detailed model of the relationship between emissions and air quality, and estimates of the abatement cost functions for all major sources in the region. The abatement cost functions provide estimates of the costs to each source of various degrees of abatement of its sulfur oxides emissions. A firm seeking to minimize the sum of its expenditures on permits and its abatement costs would elect to abate up to the point at which the marginal cost of abatement equaled the market price of a permit; therefore, the abatement cost functions provide a means for predicting the quantity of permits that each source would seek to hold at any given permit price. When all of the abatement cost functions are combined, the relationship between abatement and permit prices for the entire region can be estimated. Thus, given a limit on total emissions for the entire region — e.g., the number of permits to be issued — the abatement cost data yield a prediction about the price of a permit, the distribution of remaining emissions in the airshed, and the expenditures on abatement (in total and by source). When combined with information about how permits were initially distributed, these data can be used to estimate the effects on the costs of each industry of implementing any given design of a permits system and the extent to which market failure problems threaten the efficient operation of a TEP market.

The remainder of this report deals with each of the major areas of implementation analysis. The approach to air quality modelling that we have used is described in Chapter 2. Chapter 3 deals with the problem of simulating the performance of the permits market, using information on abatement costs and the emissions/air quality relationship to investigate the potential problems discussed above. Chapter 4 examines the environmental and administrative law that is pertinent to the issue of the legality of tradable emissions permits. Chapter 5 deals with the problems associated with public utility regulation: how economic regulation of electric utilities might affect the participation of utilities in a permits market.

FOOTNOTES

1. For an analysis of how taxes and subsidies affect entry, see Page (1976).

2. For a more detailed discussion, see Noll (1981).

3. See, for example, Ackerman and Hassler (1981).

4. A formal proof of this result is contained in Montgomery (1972) for the case where licenses are defined in terms of the ultimate pollutant to be regulated. If licenses are defined in terms of emissions, then the solution may not be the cost-minimizing strategy for achieving a given air quality target. The reason is that the same amount of emissions may have a different effect on ambient air quality if emitted at different locations. If so, charging firms the same price for a "unit" of emissions will typically imply that the marginal cost of improving the level of air quality will differ across firms. This result holds because firms are being charged a uniform price for emissions and not for pollution. An estimate of the difference in costs between the two pricing approaches has been developed by Atkinson and Lewis (1974) for the case of particulates in the St. Louis Air Quality Control Region.

5. See Baumol and Oates (1975), pp. 140-144, for a rigorous proof of this assertion.

6. Recently, the U.S. Environmental Protection Agency has extended this concept to include "multi-plant" bubbles, which is conceptually similar to the offset method.

7. ICF (1980), p. 26.

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CHAPTER 2

TECHNICAL ASPECTS OF THE LOS ANGELES SULFUR OXIDES AIR QUALITY PROBLEM

Glen R. Cass

When the smog problem in the Los Angeles Basin was first investigated, attention was focused on sulfur oxides emissions from industrial sources. Most of these emissions to the atmosphere were in the form of sulfur dioxide gas. Additional atmospheric measurements also identified particulate sulfur compounds, often referred to in the early literature as sulfuric acid mist or its gaseous precursor, sulfur trioxide. These particulate sulfur compounds were initially believed to be responsible for "thirty to sixty percent of the total reduction in visibility" at Los Angeles (Los Angeles Air Pollution Control District, 1950). It was also soon recognized that there was something unusual about Los Angeles sulfate air quality. The Los Angeles atmosphere exhibited sulfate concentrations comparable to those of cities in the industrial northeastern United States despite the fact that both sulfur dioxide emissions and ambient SO_2 concentrations in Southern California were modest by comparison. At the conclusion of an extensive aerometric survey of the Los Angeles area (Renzetti, et al., 1955), the question was posed, "Why are the sulfate and nitrate concentrations in the particulate loading in smog higher in Los Angeles than in other cities?" Twenty years later that question is beginning to be answered.

As local sulfur dioxide emission control programs succeeded in reducing ambient SO_2 concentrations, and as the extremely complex chemical nature of photochemical smog became better understood, public attention was directed at the control of emissions from the automobile which dominated other aspects of local air quality. Recently, two things have happened which have caused control strategies for sulfur oxides in Los Angeles to be reviewed.

The first of these is a rekindling of scientific interest in the role of particulate sulfates in the Los Angeles atmosphere. Particulate sulfates accounting for a few percent of the sulfur content of fuel are emitted directly from most combustion processes. Additional sulfates form from atmospheric oxidation of SO_2 downwind from a sulfur oxides source. These water-soluble sulfur oxides particles accumulate in a size range around 0.5 microns in diameter in the Los Angeles atmosphere (Hidy et al., 1975). Particles of this size are extremely effective scatterers of light (Middleton, 1952), and also are capable of deep penetration into the lung (Task Group, 1966). Recent studies indicate that sulfates contribute to visibility deterioration (Eggleton, 1969; Charlson et al., 1974; Waggoner et al., 1976; Weiss et al., 1977; White and Roberts, 1977; Cass, 1979) and to the acidification of rain water (Cogbill and Likens, 1974; Likens, 1976) throughout the United States and Europe.

A second compelling reason for focusing on Los Angeles is the potential for increase in basin-wide combustion of fuel oils containing sulfur if curtailment of natural gas deliveries to Southern California should occur. Figure 1 shows the Pacific Lighting Corporation's (1974) estimated gas supplies from existing sources in contrast to projected requests for service as seen in 1974. It had been estimated by the Los Angeles Air Pollution Control District (1975a) that substitution of sulfur-bearing fuel oil for natural gas combustion over the following few years could have increased SO_2 emissions in Los Angeles County from a low of 257 tons per day in 1970 to a level of about 470 tons per day by 1979 in the absence of any further emission controls beyond those existing in 1974. On the same basis, the California Air Resources Board estimated that SO_2 emissions in the entire South Coast Air Basin (which contains Los Angeles County) could have increased from a 1973 level of 515 tons per day to a level of between 720 and 920 tons per day by 1983 (California Air Resources Board, 1975). Control of the impact of this potential increase in sulfur oxides emissions brought forth a heated public debate.

Prompted by the increase in fuel oil combustion, the local findings concerning visibility, and a concurrent national debate over the health consequences of sulfate air quality, the California Air Resources Board adopted an air quality goal for total suspended particulate sulfates. A 24-hour average sulfate concentration of 25 micrograms per cubic meter is not to be exceeded. Air pollution control strategy studies aimed at evaluating the least costly means for sulfate air quality improvement have recently been completed by Cass (1978) and by the South Coast Air Quality Management District (1978). To date, initial steps have been taken to blunt any expected SO_x emissions increase by decreasing the sulfur content of fuel burned in the Los Angeles Basin. Other industrial processes will be modified in the future. While studies indicate that further emission control is feasible, as yet no comprehensive emission control strategy has been adopted which would meet the state sulfate air quality goal in Los Angeles over the long term. If such actions are taken, they undoubtedly will be quite expensive. Substantial savings might be achieved by better understanding the options available for managing sulfate air quality in this particular air basin in an economically efficient manner.

CASE STUDY OF THE EMISSIONS AND AIR QUALITY PROBLEM

The technical description upon which our test markets will be built is based on the sulfate air quality control strategy study

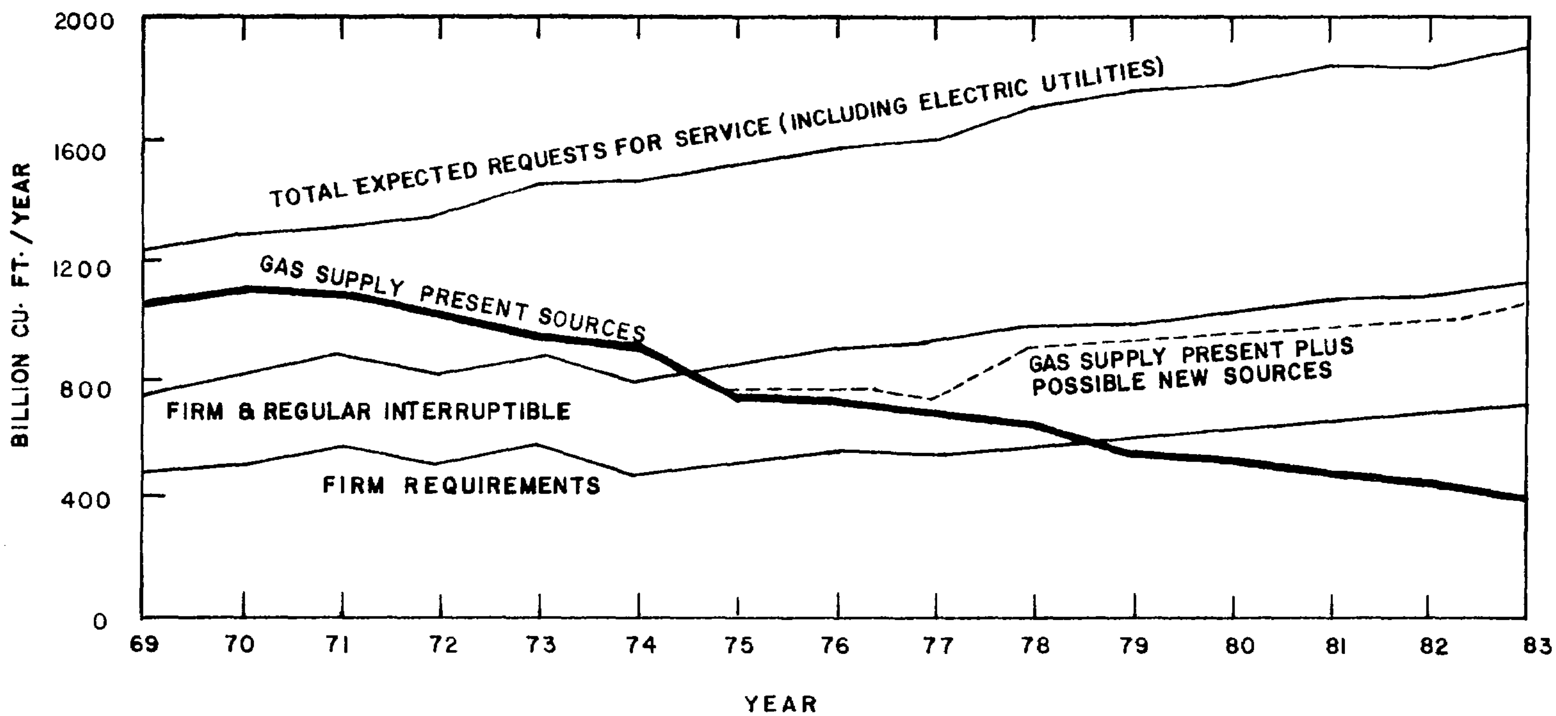


Fig. 1 Pacific Lighting Corporation

Natural Gas Supply vs. Requests for Service as Expected in 1974 completed for Los Angeles by Cass (1978). The research plan for that study is shown in Figure 2. Mathematical models were formulated and tested which relate sulfur oxides emissions to observed sulfate air quality and to air quality effects on visibility. That study was conducted in a way that emission control opportunities and costs can be compared in a rational manner to assess the least costly means of meeting an air quality objective. As a result of that work, a great deal is known about how this particular air pollution problem operates.

The geographic region of interest is the South Coast Air Basin which surrounds Los Angeles, as shown in Figure 3. Spatial gradients in sulfate air quality indicate that the atmosphere over metropolitan Los Angeles is enriched in sulfates due to local emissions sources. Annual mean sulfate concentrations above 14 $\mu g/m^3$ were measured over central Los Angeles at a time when background concentrations in incoming marine or desert air averaged 3 to 5 $\mu g/m^3$. This localized sulfate enrichment is illustrated in Figure 4. In contrast to the problems arising from long distance transport of sulfates in the Eastern United States, a sulfate air quality model can be validated in the South Coast Air Basin while employing only local emissions data plus a small increment from background sulfates.

Sulfate concentrations observed at the downtown Los Angeles station of the Los Angeles Air Pollution Control District during the decade 1965 through 1974 are shown in time series in Figure 5a. Concentration fluctuations from day to day are quite large, with high values occurring at least occasionally in all seasons of the year. However, the data can be filtered statistically to reveal seasonal trends, as shown in Figure 5b. It is seen that a broad summer seasonal peak in sulfate concentrations occurs in all years of record, with clusters of very high sulfate concentrations also observed in two of nine winters examined (winter 1970-71 and winter 1971-72). A successful air quality control strategy study must consider both high summer and high winter sulfate conditions in the Los Angeles area.

In order to assess the sources contributing to such an air quality problem, a source emissions inventory must be constructed. A 50 by 50 mile square grid was laid down over the metropolitan Los Angeles area as shown in Figure 6.

Emissions estimates for both sulfur dioxide and primary sulfates resolved over that grid system were obtained for the twenty-six classes of mobile and stationary sources listed in Table 1 for each month of the years 1972 through 1974. Major off-grid sources at locations shown in Figure 6 also were surveyed for inclusion in air quality model calculations. The spatial distribution of average daily total sulfur oxides emissions during 1973 illustrated in Figure 7 was obtained by overlaying similar maps developed for each source class of interest.

Research Plan

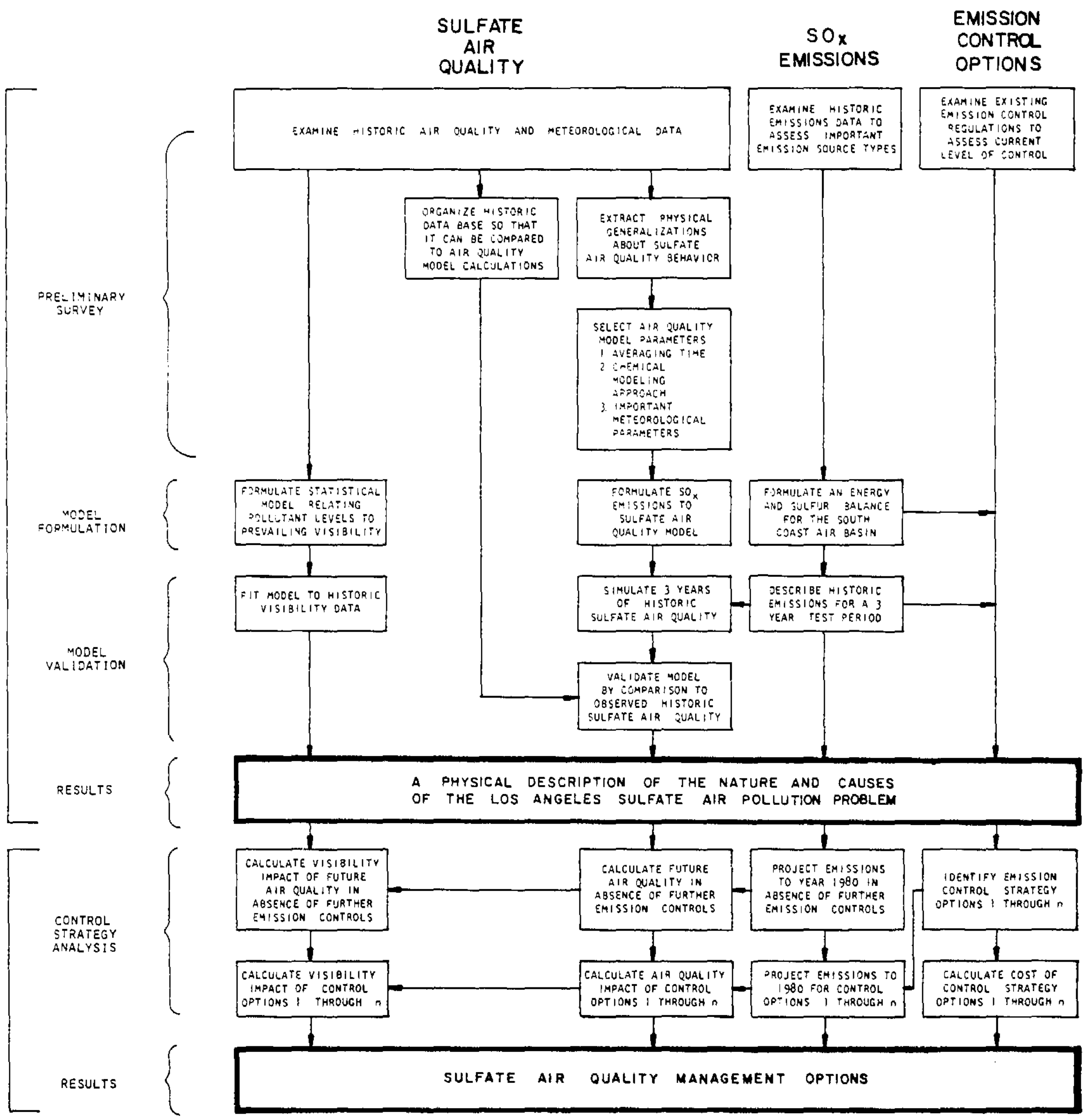


Fig. 2

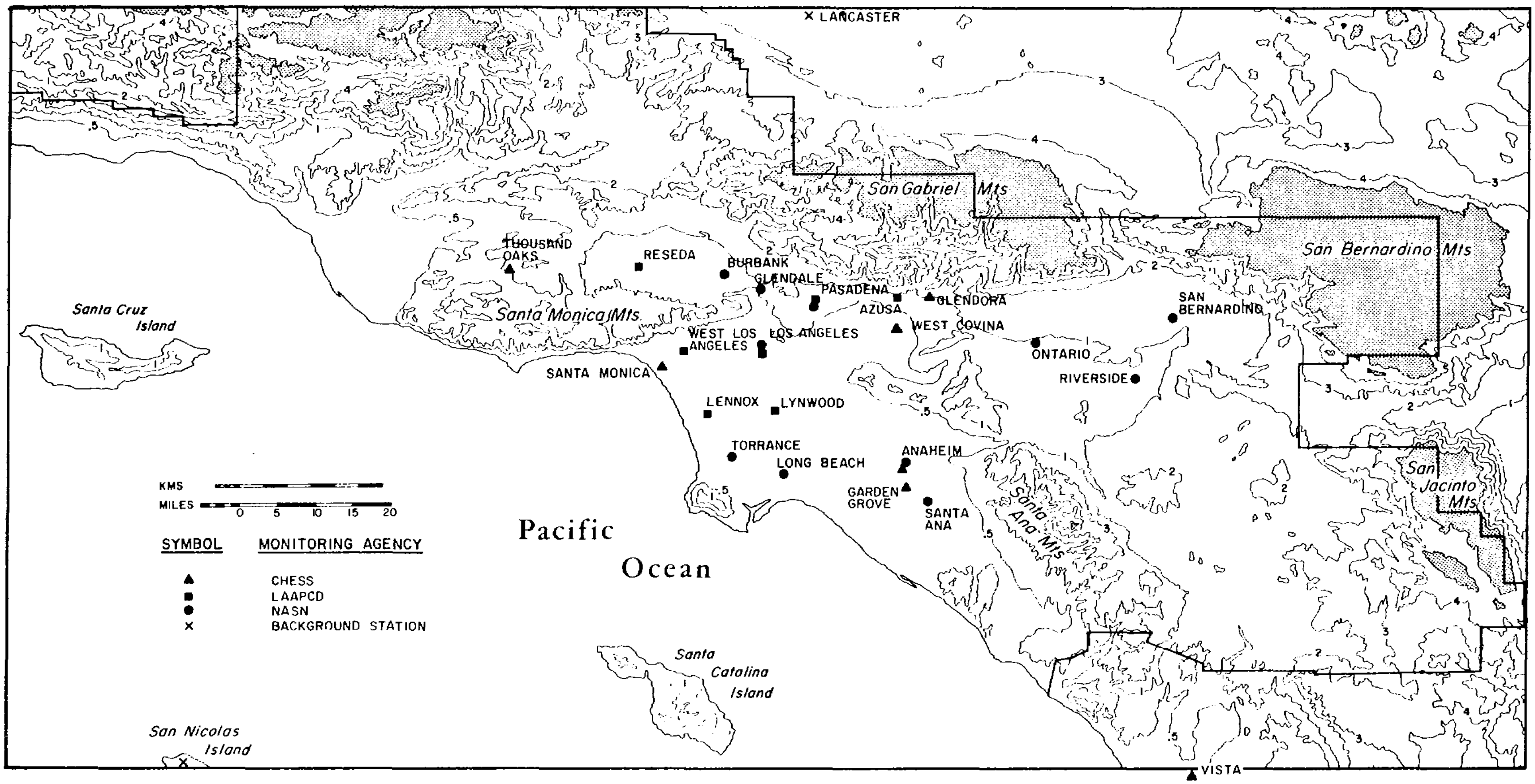


Fig. 3 Sulfate Air Quality Monitoring Sites in or near the South Coast Air Basin

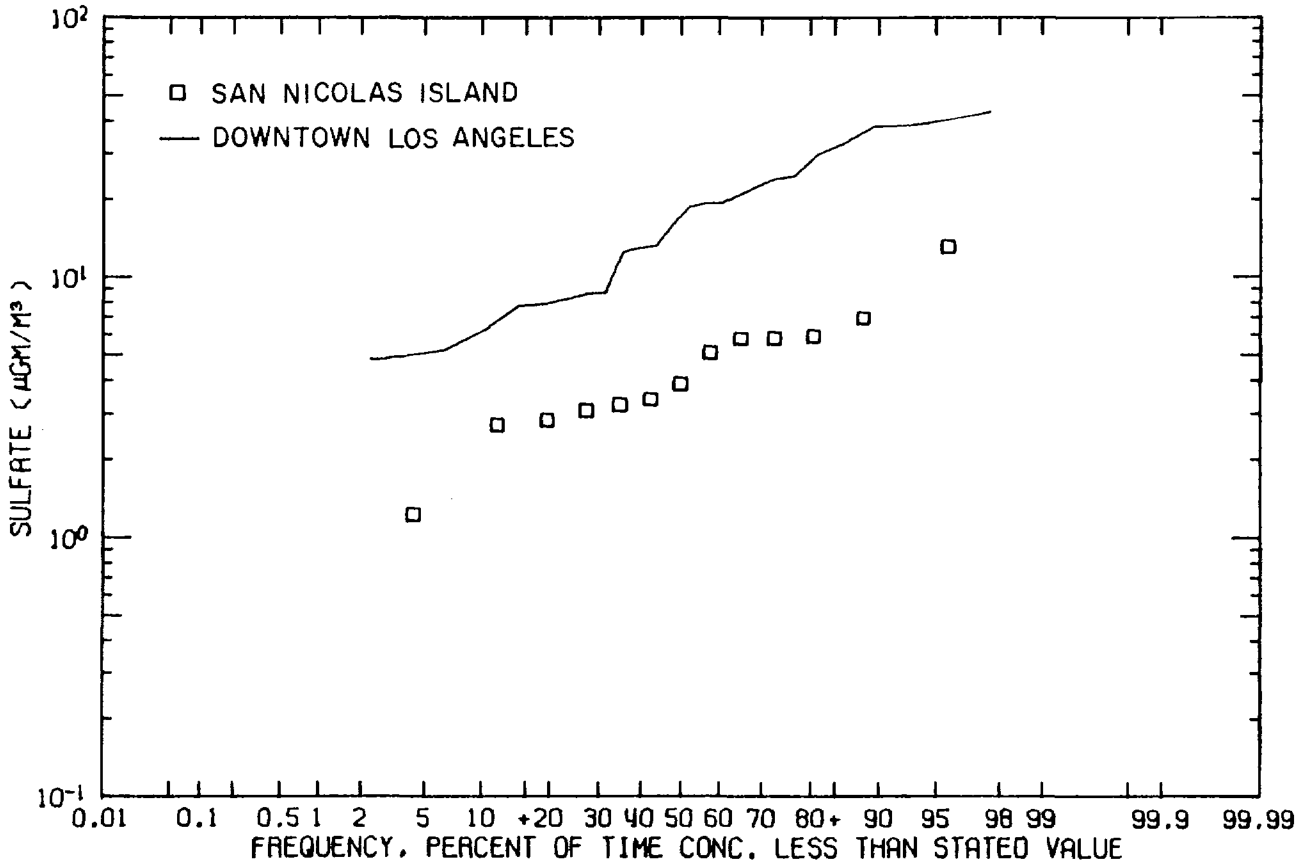


Fig. 4 Sulfate at San Nicolas Island vs. Downtown Los Angeles
July through October 1970

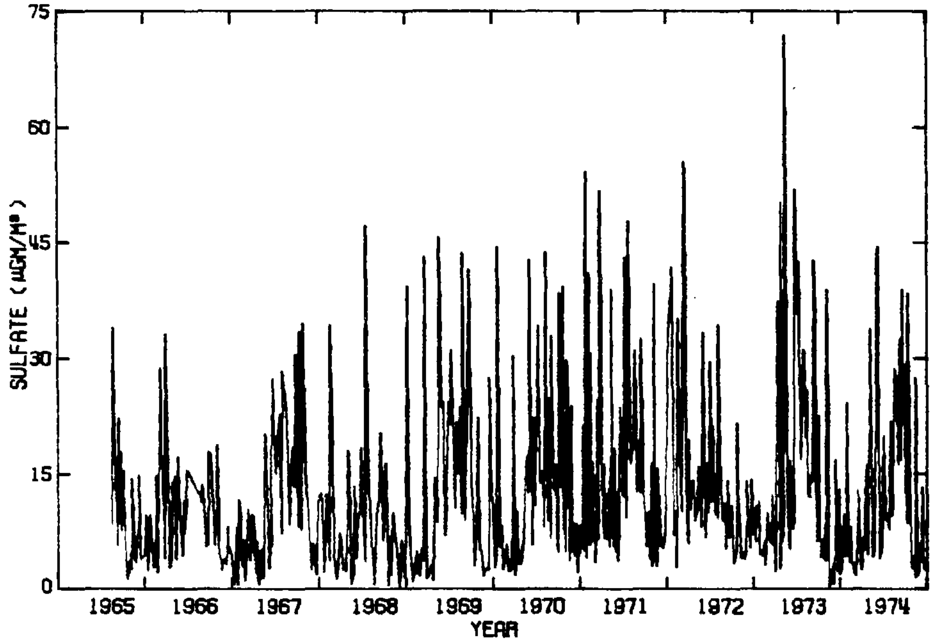


Fig. 5a LAAPCD Sulfate Data at Downtown Los Angeles

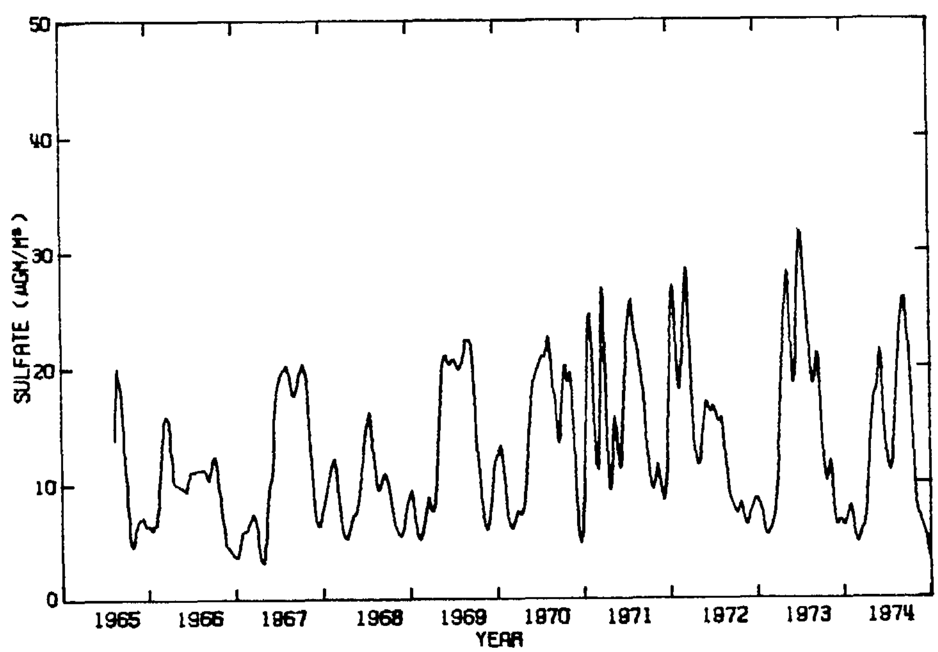


Fig. 5b Sulfate Seasonal Trend at Downtown Los Angeles

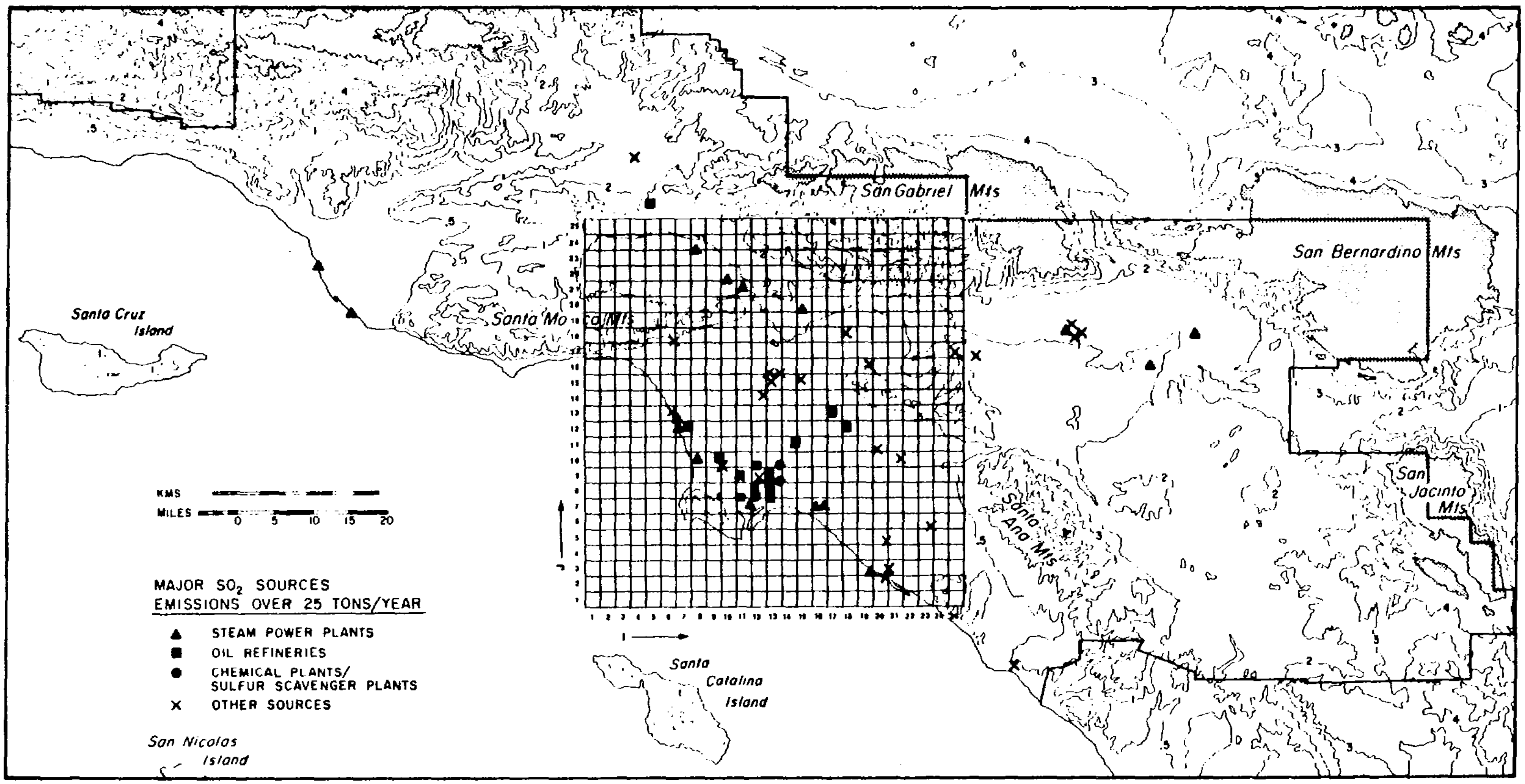


Fig. 6 The Central Portion of the South Coast Air Basin Showing the Grid System Used

TABLE 1a

1973 SULFUR OXIDES EMISSIONS WITHIN THE 50 by 50 MILE SQUARE GRID
(IN SHORT TONS PER DAY AS SO_2)

STATIONARY SOURCES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Fuel Combustion													
Electric Utilities	232.77	212.31	212.13	123.36	139.48	163.87	157.77	189.23	174.16	192.05	229.72	155.48	181.71
Refinery Fuel	25.07	13.50	10.61	4.26	3.99	3.73	2.91	2.14	2.37	4.01	21.69	18.96	9.42
Other Interruptible Gas Customers	12.78	2.24	2.07	0.98	0.81	0.39	0.39	0.40	0.43	0.76	3.58	2.57	2.29
Firm Gas Customers	0.46	0.46	0.37	0.33	0.26	0.21	0.17	0.16	0.19	0.20	0.26	0.36	0.29
Chemical Plants													
Sulfur Recovery	57.18	57.18	57.18	57.18	57.08	57.08	50.70	66.20	66.20	66.20	66.20	66.20	60.40
Sulfuric Acid	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Other Chemicals	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Petroleum Refining and Production													
Fluid Catalytic Crackers	52.07	52.07	52.07	52.07	52.07	52.07	52.07	52.07	52.07	52.07	52.07	52.07	52.07
Sour Water Strippers	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Delayed Cokers	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28
Misc. Refinery Process	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Oil Field Production	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
Misc. Stationary Sources													
Petroleum Coke Kilns	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.52
Glass Furnaces	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Metals Industries	8.78	8.78	8.78	8.78	8.78	8.78	8.78	8.78	8.78	8.78	8.78	8.78	8.78
Mineral Products	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sewage Treatment Digesters	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
Other Industrial Processes	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Permitted Incinerators	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
MOBILE SOURCES													
Autos and Lt. Trucks-Surface	17.17	17.75	18.56	18.76	14.27	14.15	14.05	14.36	13.51	13.51	16.95	15.70	15.71
Autos and Lt. Trucks-Freeway	10.98	11.35	11.87	12.01	9.13	9.05	8.99	9.19	8.64	8.64	10.85	10.05	10.05
Heavy Duty Vehicles-Surface	10.18	10.50	10.94	11.05	10.99	10.88	10.80	10.99	10.35	10.34	10.71	9.90	10.64
Heavy Duty Vehicles-Freeway	6.51	6.72	7.00	7.07	7.03	6.96	6.91	7.03	6.62	6.61	6.85	6.33	6.80
Airport Operations	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
Shipping Operations	10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13	10.13
Railroad Operations	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32
TOTAL	504.73	463.64	462.36	366.63	374.67	397.95	384.27	431.33	414.10	433.95	498.44	417.18	428.94

TABLE 1b

MAJOR OFF-GRID EMISSION SOURCES INCLUDED WITHIN THE 1973 SOUTH COAST AIR BASIN

SULFUR OXIDES MODELING INVENTORY

(IN SHORT TONS PER DAY AS SO_2)

STATIONARY SOURCES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Fuel Combustion													
Electric Utilities	60.19	45.46	57.94	39.18	53.62	64.68	54.07	58.97	45.38	59.69	91.75	66.46	58.20
Refinery Fuel	---	---	---	---	---	---	---	---	---	---	---	---	---
Other Interruptible Gas Customers	---	---	---	---	---	---	---	---	---	---	---	---	---
Firm Gas Customers	---	---	---	---	---	---	---	---	---	---	---	---	---
Chemical Plants													
Sulfur Recovery	---	---	---	---	---	---	---	---	---	---	---	---	---
Sulfuric Acid	---	---	---	---	---	---	---	---	---	---	---	---	---
Other Chemicals	---	---	---	---	---	---	---	---	---	---	---	---	---
Petroleum Refining and Production													
Fluid Catalytic Crackers	---	---	---	---	---	---	---	---	---	---	---	---	---
Sour Water Strippers	---	---	---	---	---	---	---	---	---	---	---	---	---
Delayed Cokers	---	---	---	---	---	---	---	---	---	---	---	---	---
Misc. Refinery Processes	---	---	---	---	---	---	---	---	---	---	---	---	---
Oil Field Production	---	---	---	---	---	---	---	---	---	---	---	---	---
Misc. Stationary Sources													
Petroleum Coke Kilns	---	---	---	---	---	---	---	---	---	---	---	---	---
Glass Furnaces	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Metals Industries	41.46	41.46	41.46	41.46	41.46	41.46	41.46	41.46	41.46	41.46	41.46	41.46	41.46
Mineral Products	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
Sewage Treatment Digesters	---	---	---	---	---	---	---	---	---	---	---	---	---
Other Industrial Processes	---	---	---	---	---	---	---	---	---	---	---	---	---
Permitted Incinerators	---	---	---	---	---	---	---	---	---	---	---	---	---
TOTAL	103.78	89.05	101.53	82.77	97.21	108.27	97.66	102.56	88.97	103.28	135.34	110.05	101.79

TOTAL SOX EMISSIONS FOR 1973 IN TONS/DAY AS SO2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
25	0.0	0.0	0.0	0.1	0.1	0.1	0.1	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	0.0	0.0	0.0	0.0	0.0
24	0.0	0.1	0.1	0.1	0.2	0.1	0.1	4.7	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	0.0	0.0	0.0	0.0
23	0.0	0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.1	0.0	0.0	0.1	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
22	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	3.9	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.2	0.2	3.4	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.2	0.0	0.2	0.1	0.1	0.1	2.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
19	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.2	0.3	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1
18	0.0	0.0	0.0	0.0	0.1	0.5	0.2	0.2	0.2	0.3	0.3	0.5	0.2	0.2	0.2	0.2	0.2	0.4	0.2	0.1	0.2	0.1	0.1	0.1	0.5
17	0.0	0.0	0.0	0.0	0.1	0.4	0.2	0.3	0.3	0.4	0.5	0.6	0.3	0.3	0.2	0.1	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.1
16	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.1	0.2	0.2	0.4	0.6	3.5	0.4	0.1	0.1	0.2	0.1	5.7	0.2	0.1	0.0	0.1	0.1	0.0
15	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.1	0.2	0.3	0.3	0.8	0.7	0.3	0.1	0.2	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.3	0.2	0.1	0.3	0.4	0.2	0.2	0.2	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.5	5.0	0.3	0.2	0.1	0.2	0.1	0.1	0.2	0.2	0.3	2.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	43.0	0.3	0.1	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.2	7.6	0.0	0.0	0.1	0.1	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.3	0.2	0.1	0.2	0.4	0.2	0.2	0.1	0.1	0.2	0.2	0.1	0.1	0.0	0.0	0.1
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	12.6	0.4	0.3	20.1	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.3	0.3	0.2	0.1	0.1	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	68.8	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	25.0	22.4	0.6	0.2	0.1	0.3	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.0
7	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.7	1.8	1.3	0.1	0.1	101.5	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.0
6	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.1	0.1	0.5	0.2	0.0
5	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.1	0.2	0.0	0.1
4	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
3	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.5	4.9	0.1	0.0	0.1	0.0	0.0
2	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	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
1	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	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0

SOX
TONS/DAY
428.945

Fig. 7

Figure 8 shows the time history of sulfur oxides emissions from sources located within the 50 by 50 mile square grid over three past years. An underlying increment to sulfur oxides emissions from mobile sources is observed which shows little seasonal variation. Added to that is a nearly constant contribution from miscellaneous stationary sources (principally from petroleum coke calcining kilns). Petroleum refinery process emissions are shown, mostly from refinery fluid catalytic cracking units. Emissions from chemical plants (which constituted the largest single emissions source class during 1972) decline sharply during our three year period of interest as local sulfur recovery and sulfuric acid plants added new emissions control equipment.

A strong seasonal variation in emissions from fuel burning sources is observed. Peak sulfur oxides emissions from electric utilities occur in the winter months as high priority home heating customers increase their consumption of natural gas forcing low priority gas customers, including electric utilities and some industries, to shift to combustion of sulfur-bearing fuel oil. A successful air quality model applied in Los Angeles will have to be able to track strong seasonal changes in emissions source strength which are usually six months out of phase with the summer peak sulfate concentrations observed.

The origin of Los Angeles sulfur oxide air pollutant emissions also can be examined on the basis of energy and sulfur balance calculations. Flows of energy resources which contain sulfur as they pass from crude oil suppliers to refiners to electric utilities, and to end users such as light industry or motorists can be reconciled. Table 2 shows the results of such an energy balance. Over 3.7 quadrillion BTU's per year of energy resources were tracked throughout the Los Angeles area, with less than a 1 percent net difference between documented resources and sinks. The key feature of such a survey is that a material balance on sulfur supplied within those fuels also can be performed, as shown in Table 3. That analysis identifies several very important features:

1. Virtually all of the sulfur entering the air basin in that year arrived in a barrel of crude oil. Refiners thus exercise choice over the potential sulfur oxides emissions in the basin at the time that they make an initial selection of crude oil quality.

2. Nearly 50 percent of the sulfur arriving was recovered at the refinery level as elemental sulfur or sulfuric acid. Refiners can and do recover enormous amounts of sulfur as a consequence of cracking and hydrotreating activities at their plants. The extent of this desulfurization operation could be increased (at some cost).

3. Approximately 25 percent of the sulfur was segregated into products like petroleum coke, asphalt and exported high sulfur fuel oil which would not be burned locally. Refiners can respond to concerns over product quality by shunting high sulfur refined products

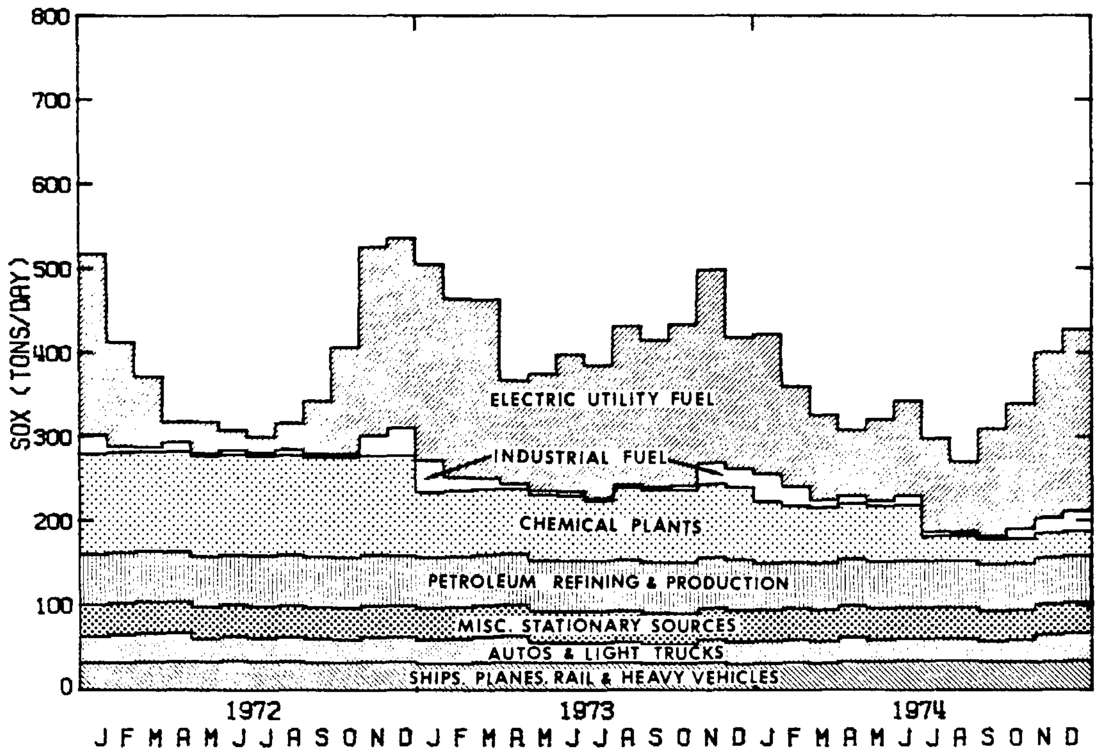


Fig. 8 Sulfur Oxides Emissions Within the 50 by 50 Mile Square

TABLE 2

SOUTH COAST AIR BASIN ENERGY BALANCE --1973
(10^{12} BTU's PER YEAR)

	Electricity	Natural Gas	Crude and Unfinished Oils	NGL	LPG	Still Gas for Fuel	Gasoline	Jet Fuel	Light and Middle Distillate Fuel Oil	Residual and Heavy Distillate Fuel Oil	Petroleum Coke	Lubricants	Asphalt and Road Oil	Other Hydrocarbons	Coal	Digester Gas	TOTAL
SOURCES																	
Resource base: imports plus local crude oil and natural gas production	97.3	1050.3	2182.3	20.9	14.4		69.6	4.4	83.6	127.6	5.5	12.3	0.1	4.6	57.4	2.6	3732.9
Adjustments: change in gas storage; out-of-basin electric use	-13.1	-25.2	—	—	—		—	—	—	—	—	—	—	—	—	—	-38.3
Subtotal	84.2	1025.1	2182.3	20.9	14.4		69.6	4.4	83.6	127.6	5.5	12.3	0.1	4.6	57.4	2.6	3694.6
TRANSFORMATION SECTOR																	
Refinery feedstock (-)			-2124.8[a]	-23.9	-8.7									-16.9[b]			-2174.3
Refinery fuels (-)	-9.8	-48.5				-149.8				-11.8							-219.9
Refinery production(+)					36.1	108.4	863.0	224.3	126.9	581.2	112.0	18.5	88.0	60.3			2218.7
Utility fuels (-)		-160.9							-2.7	-386.3						-0.3	-550.2
Utility production (+)	179.9	—	—	—	—	—	—	—	—	—	—	—	—	—		—	179.9
Subtotal	170.1	-209.4	-2124.8	-23.9		-14.0	863.0	224.3	124.2	183.1	112.0	18.5	88.0	43.4		-0.3	-545.8
CONSUMED IN BASIN AS ENERGY RESOURCE																	
System uses; losses	-28.8	-20.5															-49.3
Residential/commercial	-133.8	-431.4			-6.6				-8.1	-8.1					-0.2		-588.2
Industrial (other than refinery)	-71.2	-153.9			-1.0				-15.6	-19.5					-57.2	-2.3[a]	-320.7
Transportation (civilian)					-1.9		-650.3	-17.3	-59.9	-9.1							-738.5
Military							-2.2	-6.1	-6.5	-0.1							-14.9
Miscellaneous	-21.9	-8.7			-3.0		—	—	-14.5	-0.6					—	—	-48.7
Subtotal	-255.7	-614.5			-12.5		-652.5	-23.4	-104.6	-37.4					-57.4	-2.3	-1760.3
CONSUMED AS A RAW MATERIAL[c]		-18.6			-8.4						pass through	-10.8[a]	-71.6[a]	-42.9[a]			-152.3
EXPORTS																	
As a commodity (by ship)			-57.5		-0.2		-47.9	-17.4	-89.7	-155.1	-109.4	-20.0	-16.5	-5.1			-518.8
As a commodity (overland)		-186.8[d]					-194.7	-21.8	-52.9	-27.9							-484.1
In transport mode fuel tanks		—	—		—		-3.8	-111.5	-2.7	-86.0	—	—	—	—			-204.0
Subtotal		-186.8	-57.5		-0.2		-246.4	-150.7	-145.3	-269.0	-109.4	-20.0	-16.5	-5.1			-1206.9
SUMMARY																	
Total sources (+ flows)	277.2	1050.3	2182.3	20.9		158.9	932.6	228.7	210.5	708.8	117.5	30.8	88.1	64.9	57.4	2.6	
Total sinks (- flows)	-278.6	-1054.5	-2182.3	-23.9		-179.6	-898.9	-174.1	-252.6	-704.5	-109.4	-30.8	-88.1	-64.9	-57.4	-2.6	
Absolute difference	-1.4	-4.2	(a)	-3.0		-20.7	33.7	54.6	-42.1	4.3	8.1	(a)	(a)	(a)		(a)	29.3
Difference as % of sources	-0.51%	-0.40%	(a)	-14.35%		-13.03%	3.61%	23.87%	20.0%	0.61%	6.89%	(a)	(a)	(a)		(a)	
Difference as % of total energy resources	-0.04%	-0.11%		-0.08%		-0.56%	0.91%	1.48%	-1.14%	0.12%	0.22%						0.79%

Notes: (a) Obtained by difference
(b) May include some natural gas
(c) Or put to other non-energy resource use
(d) Includes exchange with out-of-basin utility

TABLE 3

SOUTH COAST AIR BASIN SULFUR BALANCE -- 1973
(1000s LBS. SULFUR PER DAY)

	Natural Gas	Crude Oil, Unfinished Oils & Other Refinery Feedstocks	LPG and Still Gas for Fuel	Gasoline	Light and Middle Distillates & Jet Fuel	Residual and Heavy Distillate Fuel Oil	Petroleum Coke	Misc. Petroleum Products	Coal	Digester Gas	Hydrogen Sulfide	Sulfur	Acid Sludge	Sulfuric Acid	Misc. Indus. Raw Materials Sufficient to Balance Process Losses	Solid or Liquid Waste	Atmospheric Emissions: Industrial Process	Atmospheric Emissions: Fuel Burning	TOTAL
SOURCES																			
Resource base: imports plus local crude oil and natural gas production	0.81	3942.5	0.01	6.40	39.76	33.70	16.11	small	91.73	0.63		0.06			17.69				
Adjustment: change in gas storage	-0.02																		
Subtotal	0.79	3942.5	0.01	6.40	39.76	33.70	16.11		91.73	0.63		0.06			17.69				4181.38
TRANSFORMATION SECTOR																			
Refinery																			
Feedstock sulfur		-3551.5																	
Fuel sulfur	-0.04		-2.45			-9.19													
Products and wastes			2.45	81.88	135.65	361.31	332.21	67.49			1980.4		363.4	-363.4		136.95	53.73	18.60	
Sulfur Recovery and Sulfuric Acid																			
Feedstock sulfur											-1980.4	-420.8	-363.4						
Products and wastes								5.80				1720.7		959.4			81.46		
Electric Utilities																			
Fuel sulfur	-0.12				-0.18	-235.73				-0.02								235.59	
Subtotal	-0.16	-3551.5	0.70	81.88	135.47	116.40	332.21	73.29		-0.02	0	1299.90	0	596.0		136.95	135.19	254.19	1.63
END USE CONSUMPTION SECTOR																			
(Fuel Combustion in Basin)																			
System usage losses	-0.03																	0.03	
Residential/commercial	-0.33		-0.003		-2.80	-4.66			-0.33									1.19	
Industrial (other than refinery)	-0.11		-0.001		-5.40	-11.18			-91.41	-0.58						30.03		58.43[a]	
Transportation (civilian)			-0.001	-41.15	-23.03	-21.64												85.82	
Military				-0.14	-1.88	-0.26												3.26	
Miscellaneous	-0.01		-0.002		-4.63	-0.36												6.88	
Subtotal	-0.48		-0.01	-41.29	-38.74	-38.06			-91.73	-0.58						30.03		160.80	0.00
ADJUSTMENT FOR EFFECT OF RAW MATERIALS PROCESSING INDUSTRIES	-0.01		-0.01				-25.92								-17.69		43.31[b]		-0.07
EXPORTS																			
As a commodity (by ship)	-0.07	-121.8	~0	-3.03	-32.81	-302.57	-310.46					-1.67							
As a commodity (overland)	-0.07			-12.32	-20.38	-16.99						unknown							
In transport mode fuel tanks				-0.24	-8.32	-206.26													
Subtotal	-0.14	-121.8	~0	-15.59	-61.51	-525.80	-310.46					-1.67							-1047.33
SINK FOR MISC. NON-FUEL RESOURCES WHOSE ULTIMATE CUSTOMER WILL NOT BE SOUGHT								-73.29				-1298.29		-596.0					-1967.58
SUMMARY																			
Total sources (+ flows)	0.81	3942.5	2.66	86.28	165.41	839.01	348.22	73.29	91.73	0.63	1980.4	1720.76	363.4	958.4	17.69	185.00	586.51		
Total sinks (- flows)	-0.81	-3673.3	-1.47	-56.88	-100.81	-808.25	-345.96	-73.29	-91.73	-0.63	-1980.4	-1720.76	-363.4	-958.4	-17.69				
Absolute difference	0	269.2	0.19	29.40	64.60	30.76	2.26	–					0						321.41
Difference as % of sources	0	6.8%	7.1%	34.1%	39.1%	3.7%	0.65%												
Difference as % of total sulfur input of 4181.38 thousand lbs/day	0	6.4%	~0%	0.70%	1.54%	0.74%	0.05%										14.0%		

Notes: (a) This fuel burning total includes 41.36 thousand pounds of sulfur per day from combined fuel burning and industrial processes activities at Kaiser Steel.

(b) These industrial process emissions include:

Misc. chemical industries	0.09
Oil field production	4.50
petroleum coke kilns	25.32
glass furnaces	2.23
metals industries	8.88
minerals industries	1.50
other industrial processes	0.01
incinerators	0.87

away from an air basin which presents serious emissions control problems.

4. Only about 14 percent of the sulfur which could have been emitted to the atmosphere from combustion and processing of fuels actually did escape from the system into the Los Angeles atmosphere.

The energy and sulfur balance results show that the Los Angeles sulfur oxides control problem possesses great inherent flexibility as well as an advanced stage of technical maturity. Emissions control is possible (and indeed is occurring) by means in addition to direct application of control technology to emissions points. Perhaps the most important choices affecting sulfur oxides emissions involve industrial process selection in the first place, and substitutions between alternate energy resources. These factors affecting emissions might respond to a continuously variable system of economic incentives like transferable emissions rights in a way that is not captured by a hardware-oriented emissions source performance standard or single go/no-go limits on the maximum sulfur content of a certain type of fuel.

EMISSIONS/AIR QUALITY RELATIONSHIPS

Assessment of the particular emissions sources contributing to sulfate air quality at a specific location is a difficult task. In Los Angeles, sulfur oxides emissions from over one hundred large sources and several thousand minor ones are co-mingled by the wind and transported wherever the wind blows. Within this dynamic system, chemical reactions act to oxidize SO_2 to form additional sulfates over time, and to remove pollutants by deposition at the ground.

The problem of tracking individual source contributions to observed air quality in such a situation is too complex to be handled by pencil and paper. Instead, a large computer simulation model can be built which will track individual air parcels and perform the necessary accounting.

The air quality model used in this study was formulated by Cass (1978) and has been described briefly as follows. Single mass points marked with the magnitude and initial chemical composition of sulfur oxides emissions from each source are inserted at measured time intervals into a mathematical representation of the atmospheric fluid flow above the location of their points of origin. Depending on the plume rise characteristics of each source and meteorological conditions at the time of release, a pollutant parcel may be inserted either above or below the base of the temperature inversion which separates a well mixed layer next to the ground from a stable air mass aloft. As these sulfur oxides laden air parcels are transported downwind, chemical reactions and surface removal processes act to alter the mass of SO_2 and sulfates represented by each particle. Sulfur oxides residing within the mixed layer next to the ground are affected both by ground level dry deposition and by atmospheric oxidation of SO_2 to form additional sulfates. Pollutant parcels stored within the stable layer aloft are isolated from surface removal processes but still are available for chemical reaction. Exchange of air parcels between the mixed layer next to the ground and the stable layer aloft occurs as inversion base height changes over time.

The trajectories of successive particles released from a source form streaklines downwind from that source. Streaklines present at each hour of the month are computed and superimposed. The horizontal displacement of each particle located below the inversion base is paired with the particle's probable chemical status and divided by the depth of the mixed layer at the time that the streakline of interest was computed. The resulting magnitudes are assigned to a matrix of receptor cells by summing the contribution for all particles falling within the same receptor cell. Totals are accumulated separately for SO_2 and for sulfates. The accumulated totals are divided by the dimensions of a receptor cell and the number of time steps being superimposed in order to directly obtain the spatial distribution of long-term average SO_2 and sulfate concentrations appearing throughout the airshed.

By repeating that process for each source in the airshed and superimposing the results onto an estimate of sulfate background air quality, a multiple source urban air quality model for sulfates is obtained. Superposition is permitted because all chemical processes are modeled in a form that is linear in emissions.

The gridded emissions inventory previously described was matched to the air quality model. The model's ability to track sulfate concentrations was tested over each month of the years 1972 through 1974. Source class contributions to observed air quality were computed and compared in time series to observations at monitoring sites such as those shown in Figures 9 and 10. The spatial distribution of sulfate concentrations was computed both for the air basin as a whole and for the partial contribution of each major source type, as shown in Figures 11, 12 and 13. Comparison between observations and predictions at all monitoring sites shown in Figure 11 for which monthly average data could be computed typically appear as shown in Figure 14.

ECONOMICALLY EFFICIENT STRATEGIES FOR SULFATE AIR QUALITY IMPROVEMENT

Analysis of the source class contributions to observed sulfate air quality shown in Figures 9 and 10 yields an important conclusion. No single source type contributes more than a relatively small fraction to the total sulfate pollutant burden in the air basin. An emissions control strategy which requires significant air quality changes must be diversified over a large number of dissimilar types of sources. Even relatively small source classes, like heavy duty diesel vehicles, should not be overlooked.

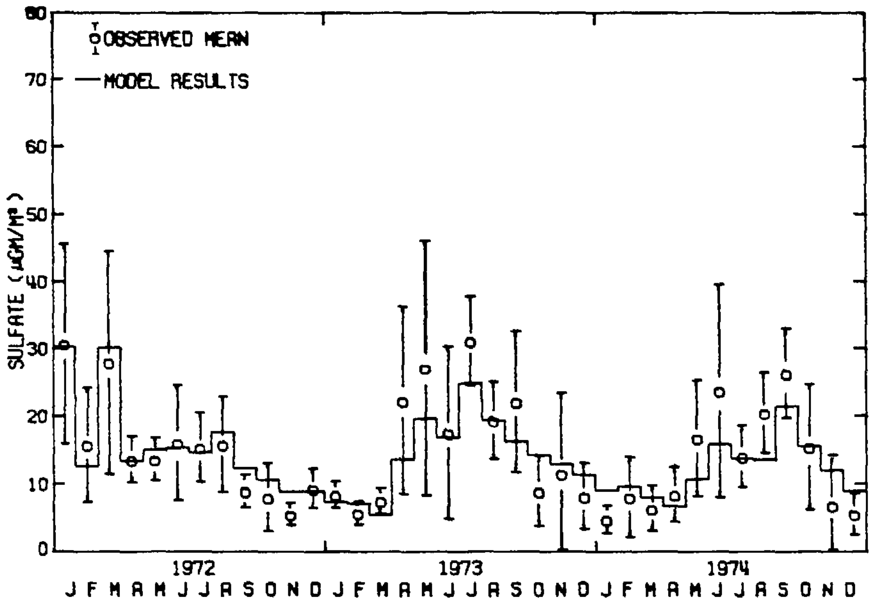


Fig. 9a Monthly Arithmetic Mean Sulfate Concentrations at Downtown Los Angeles (APCD)
Air Quality Model Results vs. Observed Rules

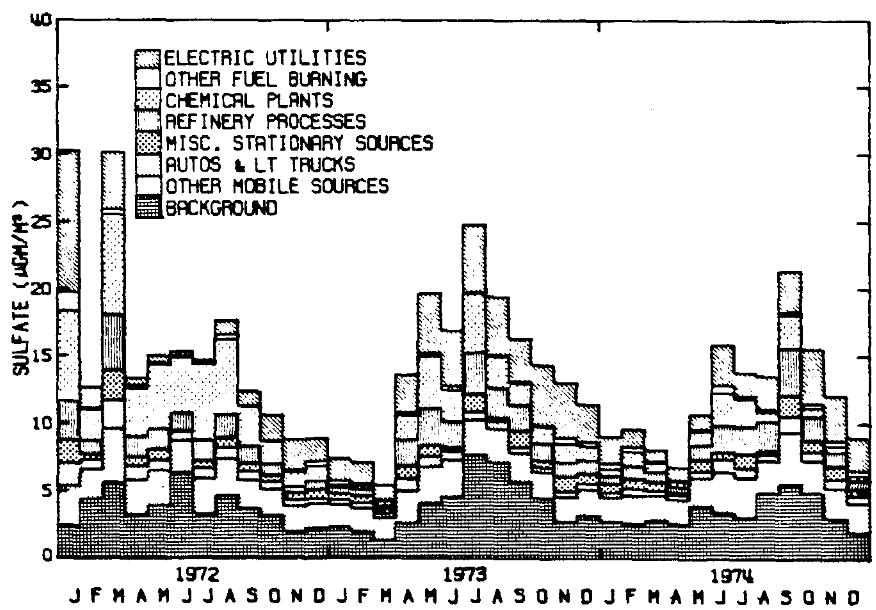


Fig. 9b Source Class Contribution to Sulfate Concentrations Observed at Downtown Los Angeles (APCD)

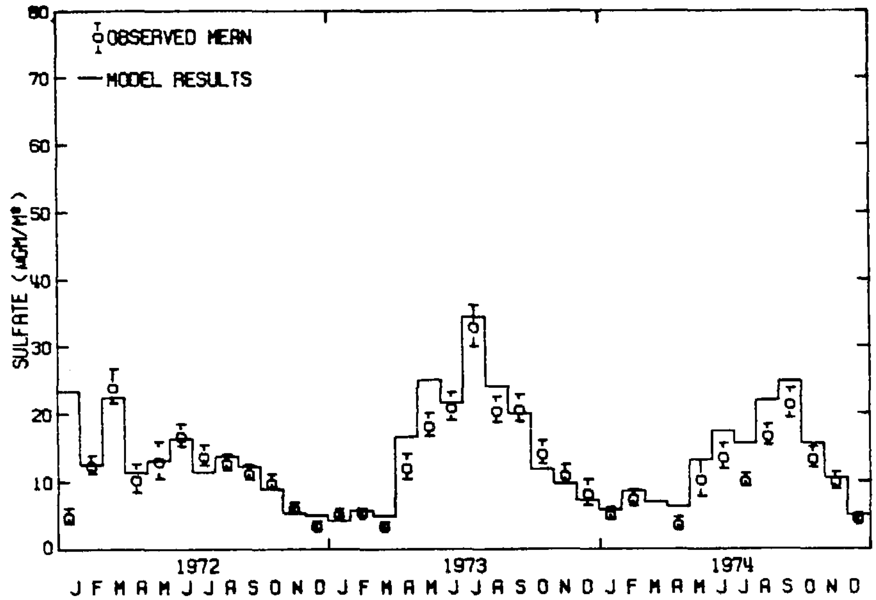


Fig. 10a Monthly Arithmetic Mean Sulfate Concentrations at Glendora (Chess)
Air Quality Model Results vs. Observed Values

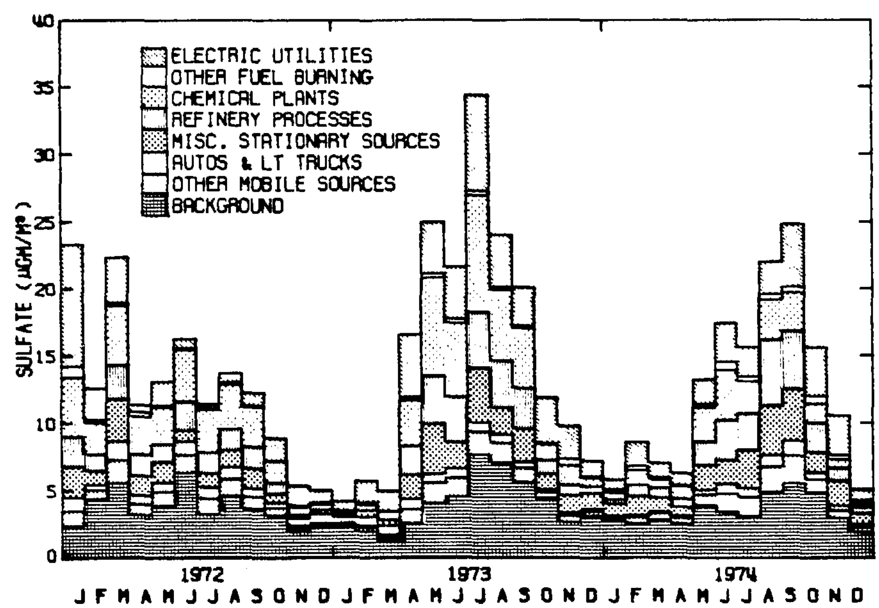


Fig. 10b Source Class Contribution to Sulfate Concentrations Observed at Glendora (Chess)

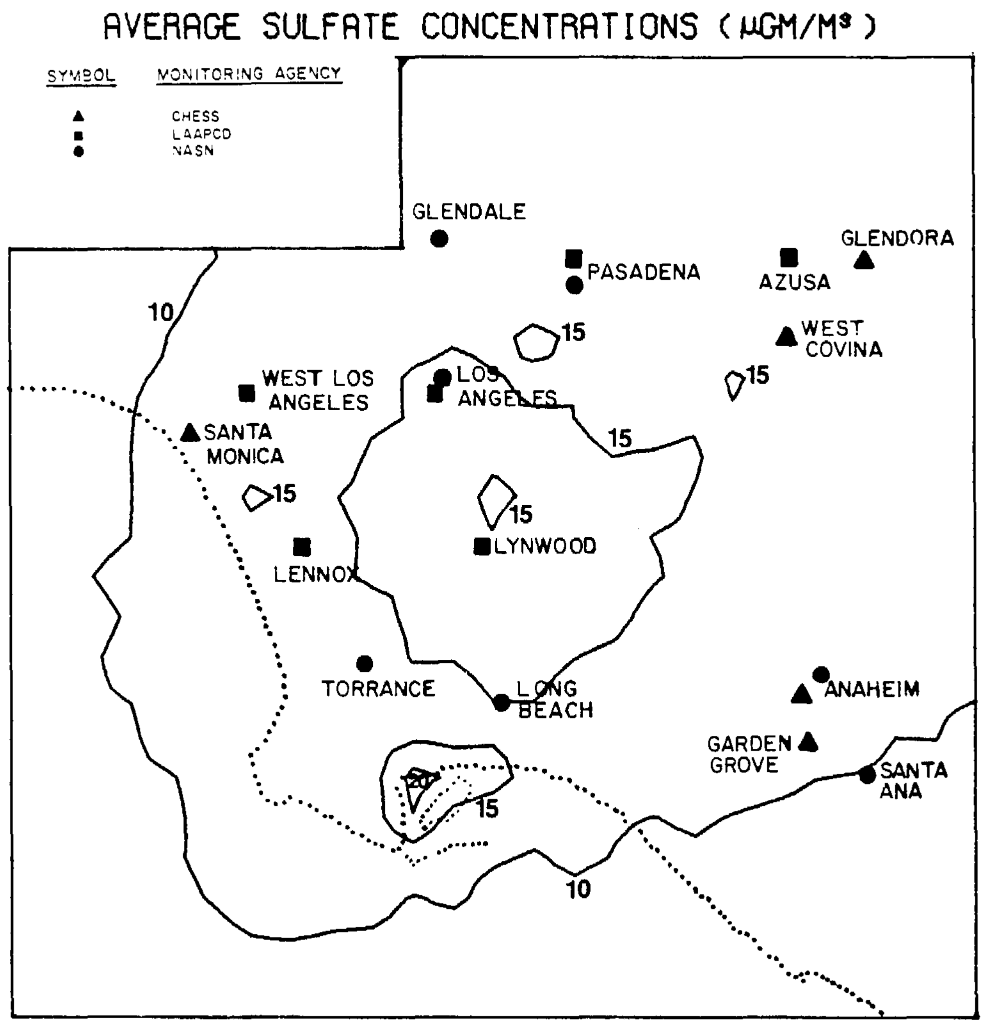


Fig. 11 Calendar Year 1972

AVERAGE SULFATE CONCENTRATIONS ($\mu GM/M^3$)

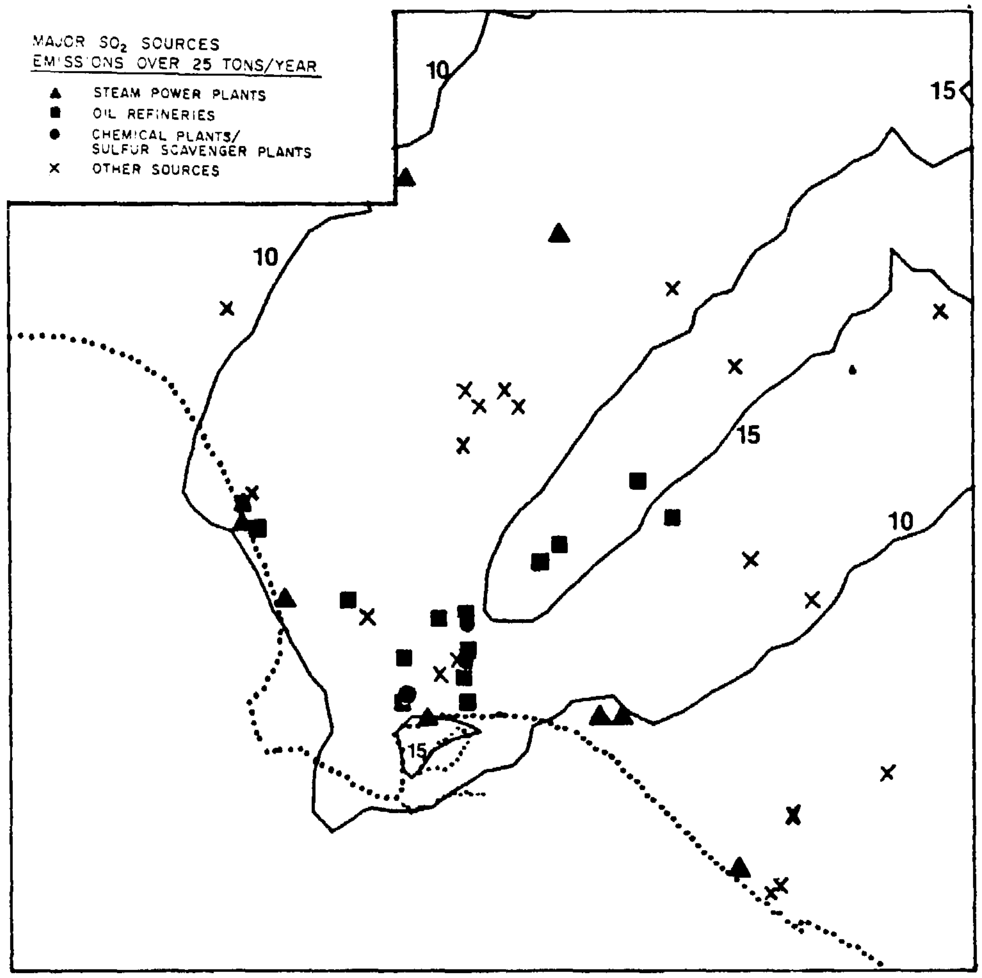


Fig. 12 Calendar Year 1973

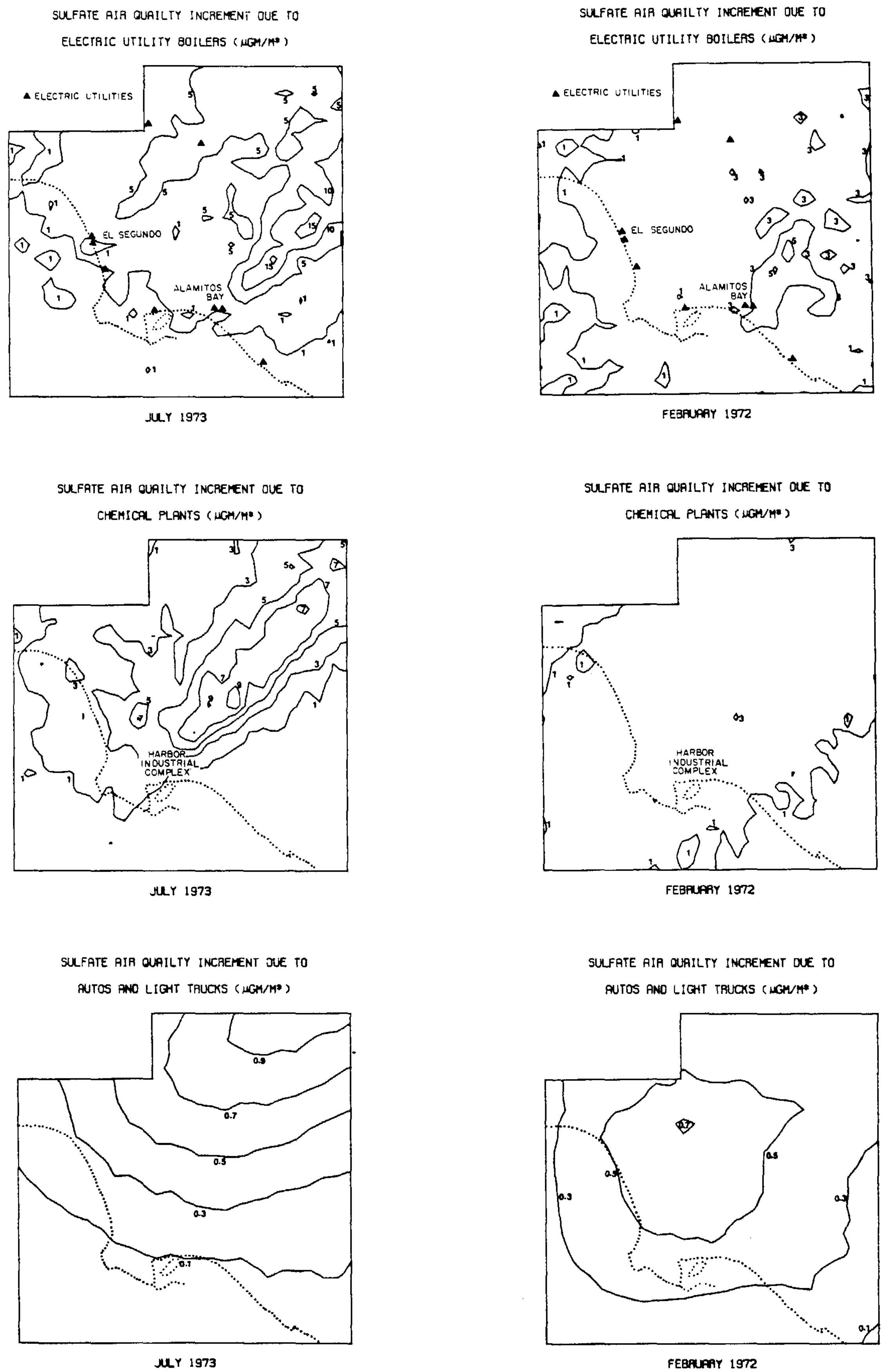

SULFATE AIR QUAILTY INCREMENT DUE TO
ELECTRIC UTILITY BOILERS (µGM/M³)
▲ ELECTRIC UTILITIES
EL SEGUNDO
ALAMITOS BAY
JULY 1973
SULFATE AIR QUAILTY INCREMENT DUE TO
ELECTRIC UTILITY BOILERS (µGM/M³)
▲ ELECTRIC UTILITIES
EL SEGUNDO
ALAMITOS BAY
FEBRUARY 1972
SULFATE AIR QUAILTY INCREMENT DUE TO
CHEMICAL PLANTS (µGM/M³)
HARBOR INDUSTRIAL COMPLEX
JULY 1973
SULFATE AIR QUAILTY INCREMENT DUE TO
CHEMICAL PLANTS (µGM/M³)
HARBOR INDUSTRIAL COMPLEX
FEBRUARY 1972
SULFATE AIR QUAILTY INCREMENT DUE TO
AUTOS AND LIGHT TRUCKS (µGM/M³)
0.9
0.7
0.5
0.3
0.1
JULY 1973
SULFATE AIR QUAILTY INCREMENT DUE TO
AUTOS AND LIGHT TRUCKS (µGM/M³)
0.5
0.3
0.1
FEBRUARY 1972

Fig. 13

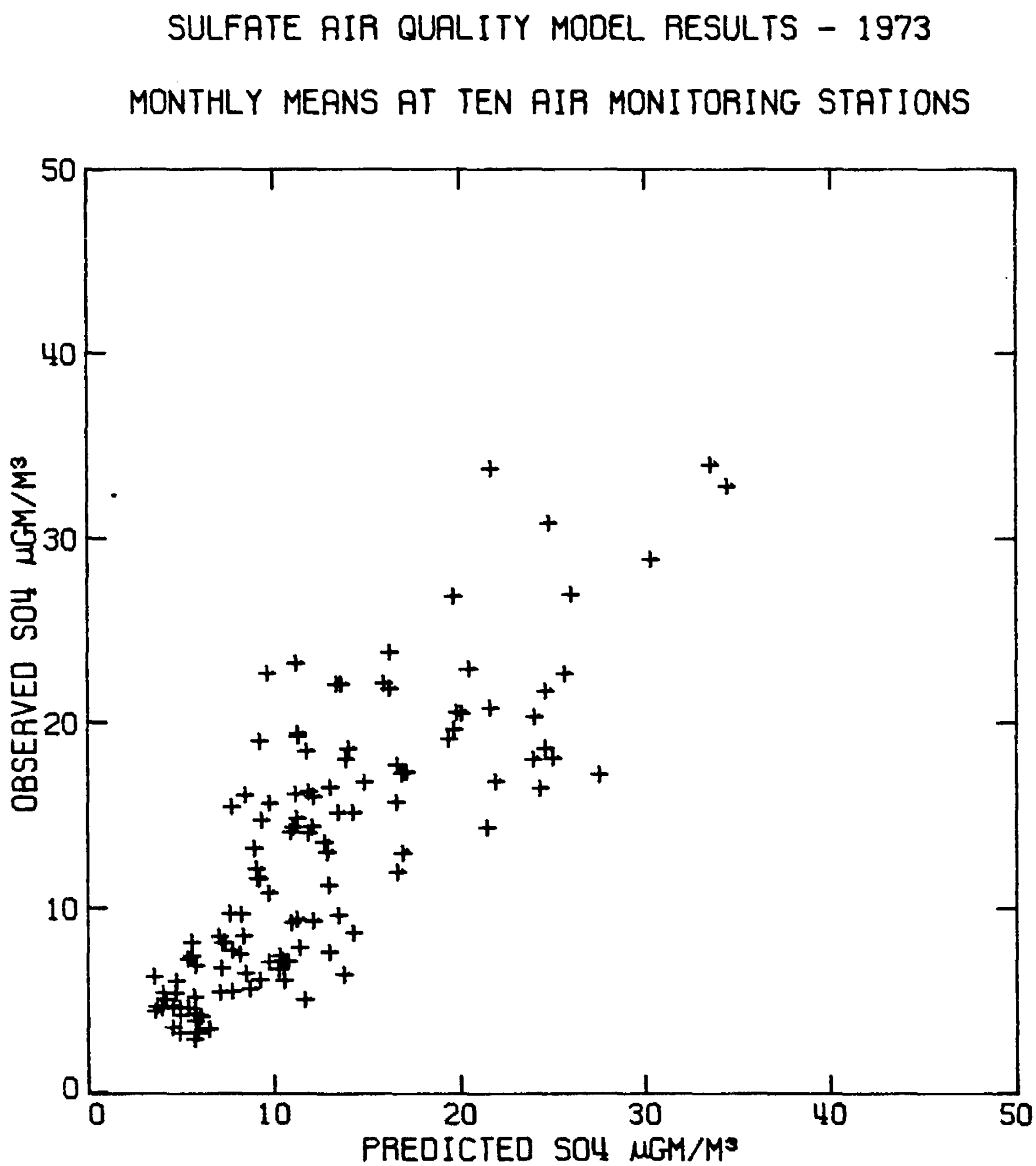

SULFATE AIR QUALITY MODEL RESULTS - 1973
MONTHLY MEANS AT TEN AIR MONITORING STATIONS
OBSERVED SO4 µGM/M³
PREDICTED SO4 µGM/M³
0
10
20
30
40
50

Fig. 14

Because the emissions to air quality model is linear in most types of SO_x emissions changes, the results of the air quality modeling studies can be used to evaluate sulfate air quality control strategy options. The first step in a procedure for design of emission control strategies by engineering methods is indicated in Table 4. Technological control measures identified by Hunter and Helgeson (1976) are listed in that table along with the annual average SO_x emissions for the year 1973 to which each control measure would apply. The incremental sulfate air quality improvement at downtown Los Angeles shown in Table 4 is that which would have been realized in 1973 if each candidate control strategy option had been installed and in operation in that year. That air quality impact estimate for each source class was obtained from the 1973 air quality model validation effort. The air quality model generates a set of <u>transfer coefficients</u> that give the effect on sulfate air quality at each monitoring site of a spatially homogeneous unit increase or decrease in SO_x emissions across <u>all</u> members of a <u>single</u> source class. These transfer coefficients, in $\mu g\ m^{-3}$ per ton SO_x emitted per day, when multiplied by the number of tons per day of emission control contemplated for a source class yield an estimate of the resulting improvement in sulfate air quality. In general, the magnitudes of these transfer coefficients differ between monitoring sites and source types due to the geographical distribution of the sources, and due to differences in source stack height and fraction sulfates initially present in each source's exhaust.

The last column of Table 4 shows that a measure of source emission control option effectiveness can be computed from the above data, in terms of sulfate concentration reduction at Los Angeles per dollar spent on SO_x control. If the limited set of control measures defined by Hunter and Helgeson (1976) were used to control 1973 sulfate concentrations, the least costly progression of air quality improvement versus cumulative control cost would have been as shown in the upper curve of Figure 15.

The South Coast Air Quality Management District (1978) also has used these air quality modeling results combined with a forecast emissions inventory to evaluate another set of available control technologies under conditions expected to prevail in the mid-1980s as shown in Figure 16. On the basis of rollback calculations, they determined the basinwide emission levels likely to be associated with attainment of various state and federal standards for SO_2 and for particulate sulfates, as shown in Table 5. Annual mean sulfate concentrations predicted by rollback for each of their candidate control strategies were tested against the predictions of the full scale sulfate simulation model of Cass (1978). It was found that the rollback model results did not differ greatly from the simulation model outcome for the cases tested.

TABLE 4

ANNUAL COST AND SULFATE AIR QUALITY IMPACT OF STATIONARY SOURCE SO_x EMISSIONS CONTROL TECHNOLOGIES IF APPLIED TO SO_x EMISSIONS IN THE SOUTH COAST AIR BASIN AS THEY EXISTED IN 1973

Emission Control Strategy Option	SO_x Emissions Control Effectiveness When Applied to 1973 Emissions Inventory				Incremental Cost of Emission Control Option (1975-76 Cost Basis)		Annual Mean Sulfate Air Quality Improvement at Downtown Los Angeles		Cost Effectiveness Index
	Degree of Control	Emissions from Source Class to Which Control Measure Would Apply (tons/day)	Emissions from Source Class After Application of that Control Measure (tons/day)	Total Reduction in Annual Average Emissions (tons/day)	Dollars Per Ton SO_x Removed	Total Annual Cost (10^6 Dollars)	$\mu gm/m^3$ $SO_4^=$ Reduced per ton/day Emission Reduction	Total Incremental Sulfate Reduction ($\mu gm/m^3$)	$\mu gm/m^3$ $SO_4^=$ Reduced per 10^9 Dollars Annual Cost
Electric Utility Residual Fuel Oil Desulfurization (a)									
(a) Reduction in fuel sulfur limit from 0.5% to 0.4%	-20%	239.9	191.9	48.0	377 (b)	6.60	0.0138 (e)	0.662	100.3
(b) Further reduction from 0.4% S to 0.3% S	-25%	191.9	143.9	48.0	471 (b)	8.25	0.0138 (e)	0.662	80.2
(c) Further reduction from 0.3% S to 0.2% S	-33%	143.9	95.9	48.0	942 (b)	16.50	0.0138 (e)	0.662	40.1
(d) Further Reduction from 0.2% S to 0.1% S	-50%	95.9	47.9	48.0	1695 (b)	29.70	0.0138 (e)	0.662	22.3
Industrial Residual Fuel Oil Desulfurization (a)									
(a) Reduction in fuel sulfur limit from 0.5% S to 0.4% S	-20%	8.3	6.6	1.7	377 (b)	0.23	0.0158	0.027	117.4
(b) Further reduction from 0.4% S to 0.3% S	-25%	6.6	5.0	1.6	471 (b)	0.28	0.0158	0.025	89.3
(c) Further reduction from 0.3% S to 0.2% S	-33%	5.0	3.3	1.7	942 (b)	0.58	0.0158	0.027	46.6
(d) Further reduction from 0.2% S to 0.1% S	-50%	3.3	1.7	1.6	1695 (b)	0.99	0.0158	0.025	25.2
Chemical Plant Emission Limit Met at 500 ppm SO_x (or less) in exhaust (Rule 53.3)	-93%	80.0	5.5	74.5	235 (c)	6.39	0.0217	1.617	253.0
(a) Claus tail gas clean-up units applied to sulfur plants									
(b) Additional absorption units, demisters, or plant derating applied to H_2SO_4 plants									
Petroleum Refining and Production									
(a) Caustic scrubber applied to refinery fluid catalytic crackers (FCC)	-95%	52.1	2.6	49.5	1144	20.67	0.0257	1.272	61.5
(b) Claus plant applied to oil field fire flooding operation exhaust	-90%	4.5	0.5	4.0	312	0.46	0.0257 (d)	0.103	223.9
Petroleum Coke Calcining Kiln Emissions Reduction Obtained From Scrubbing Coke Dust Prior to Combustion	-80%	25.5	5.1	20.4	600	4.47	0.0165	0.337	75.4
Steel Mill									
(a) Desulfurization of coke oven gas	-90%	21.2	2.1	19.1	122	0.85	0.0024	0.046	54.1
(b) Scrubber applied to mill sinter plants	-80%	4.8	1.0	3.8	470	0.65	0.0024	0.009	13.8

Notes

(a) Middle distillate fuel oil desulfurization was not addressed by Hunter and Helgeson (1976) and thus will be excluded from this example.

(b) The additional cost *beyond 0.5% sulfur fuel* was estimated by Hunter and Helgeson (1976) as \$0.12, \$0.27, \$0.57, and \$1.11 per barrel for fuel meeting 0.4% sulfur, 0.3% sulfur, 0.2% sulfur, and 0.1% sulfur rules respectively. Thus 0.3% sulfur fuel would cost (\$0.27 - \$0.12) = \$0.15 more per barrel than 0.4% sulfur fuel. See Chapter 7 footnotes 2 and 3 for additional information and assumptions.

(c) No specific cost data for sulfuric acid plant control were given, but rules affecting both sulfur recovery and acid plants were adopted simultaneously and are assumed to be equally cost-effective.

(d) The air quality impact shown is proportional to the petroleum processing source class as a whole. This source is physically distant from downtown Los Angeles and this may not have an impact at downtown Los Angeles which is proportionately as large as from the FCC units which dominate that source class. However, the cost effectiveness of controlling that source is so high that control strategy conclusions would be distorted little even if the air quality impact estimate were reduced several fold.

(e) Based on emissions from both on-grid plus off-grid power plants located within the 1973 boundaries of the South Coast Air Basin. If only a subset of those power plants were to be considered for control, the impact per ton of SO_x emissions reduced would be expected to vary depending on the group of generating stations chosen.

STATIONARY SOURCE EMISSION CONTROLS
IDENTIFIED BY HUNTER AND HELGESON (1976)
APPLIED TO SOx EMISSIONS SOURCES LOCATED
IN THE SOUTH COAST AIR BASIN
AS THEY EXISTED IN 1973

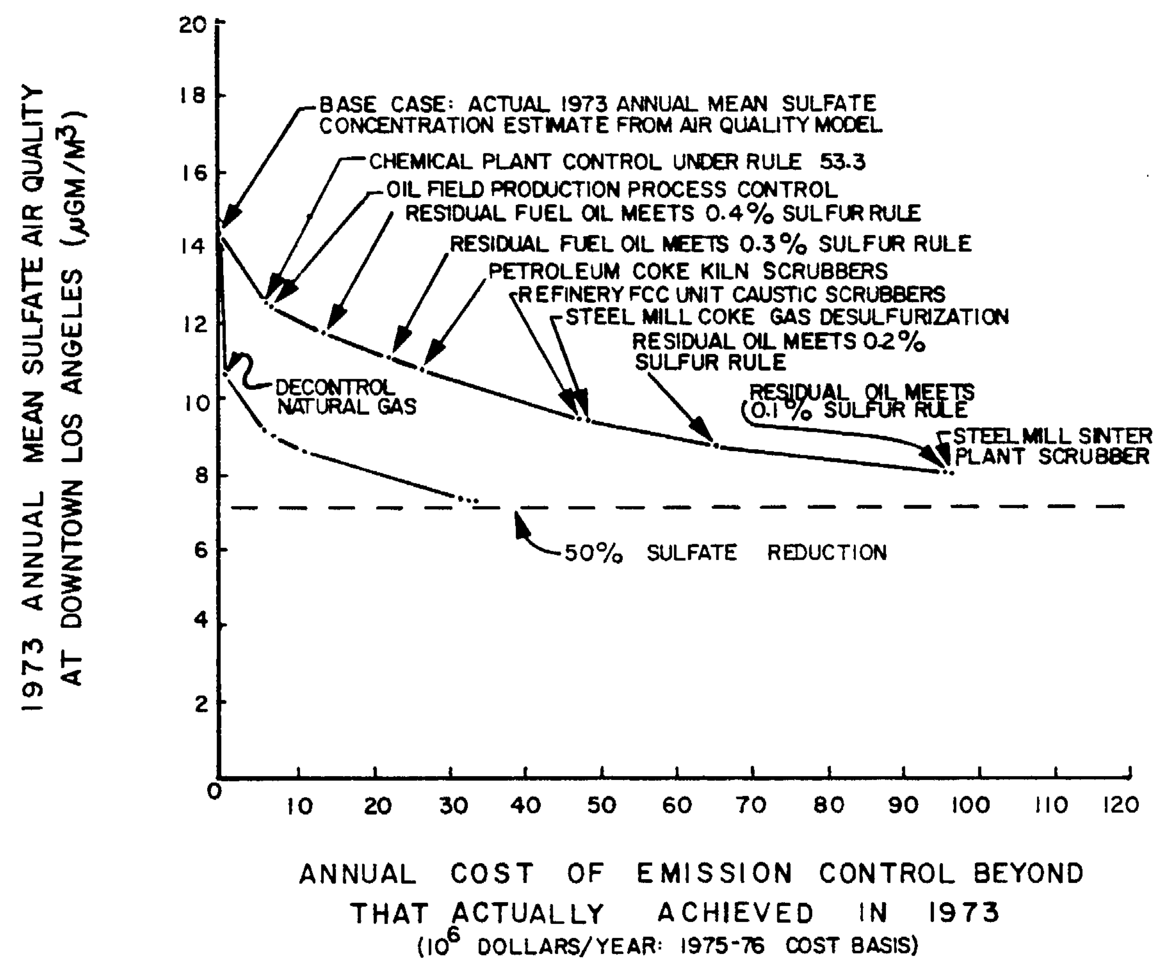


Fig. 15

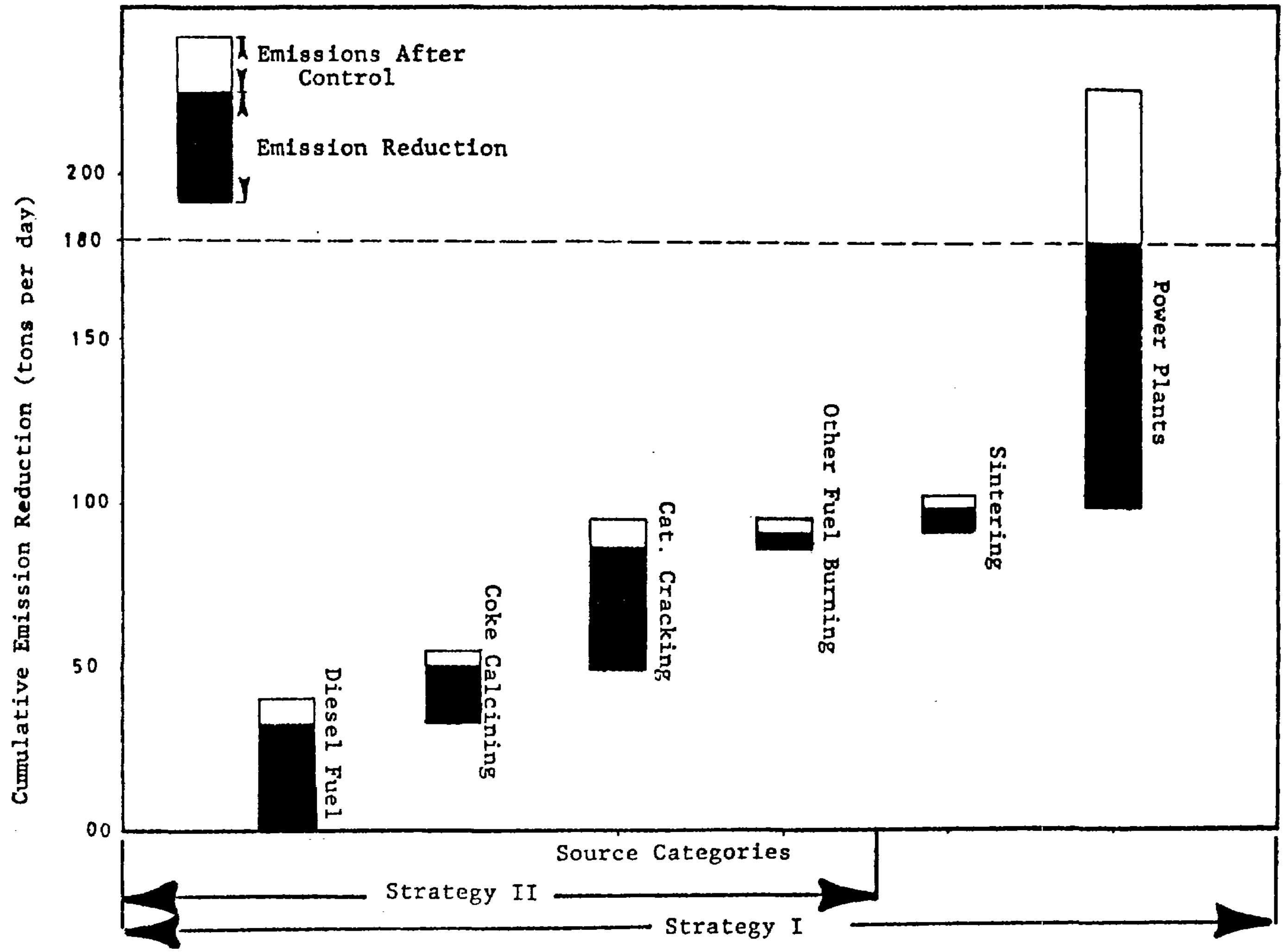


Fig. 16 Control Strategy I Cumulative SO_2 Reductions from Affected Source Categories

TABLE 5

ALLOWABLE SO_x EMISSIONS IN THE SOUTH COAST AIR BASIN
(based on the 1978 South Coast
Air Quality Management District Study)

Air Quality Objective	Allowable SO_x Emissions in the South Coast Air Basin (a) (tons/day)	Equivalent allowable SO_x Emissions within the On-Grid Plus Off-Grid Inventory Region used in this Study (b) (tons/day)
1. Attain all state and Federal SO_2 standards plus the California Sulfate Air Quality Standard.	142	149
2. Attain all state and Federal SO_2 standards but violate California Sulfate Standard 3 percent to 5 percent of the time.	227	238
3. Attain all state and Federal SO_2 standards but violate California Sulfate Standard regularly.	297	312

(a) South Coast Air Quality Management District (1978); based on a four county emission inventory region.

(b) Increased by a factor of 1.05 above SCAQMD values in order to account for Ventura County power plants that are included in the present survey.

TECHNICAL PROBLEMS POSED BY A SYSTEM OF TRANSFERABLE LICENSES TO EMIT AIR POLLUTANTS

The air quality model and control strategy optimization procedure just described raises several serious questions about the technical advisability of a market for transferable licenses to emit air pollutants. First, if the least costly combination of control equipment needed to reach an air quality target can be computed from engineering calculations, what do we gain from a market system? Secondly, Table 4 shows that different sources have different effects on air quality per ton of SO_x emitted. The minimum cost solution to this air quality problem in principle involves capitalizing on these air quality differences so as to control the high impact sources to a greater degree than low impact sources. If source owners are allowed to trade emissions on the basis of permits denominated in tons per day, we loose the ability to systematically handicap the high leverage sources. Does this matter? Finally, is it not possible that a market system would redistribute permitted emissions spatially in a way that would create local "hot spots," or neighborhoods with extremely bad air quality?

The first of these questions is readily answered using results from the 1973 sulfate control strategy study (Cass, 1978). Engineering optimization of a solution to the Los Angeles sulfate problem is extremely sensitive to assumptions about the level of natural gas availability. If fuel oil burning sources could be switched to natural gas, better air quality could be achieved at a much lower cost, as shown in Figure 15. However, the level of natural gas supply is not under state or local control, and is not readily forecast. Thus fixed emission control regulations designed by engineering means to minimize control cost at one level of gas supply would quickly become obsolete when the natural gas supply changes. Regulatory lags are inevitable, thus one would likely be operating with a sub-optimal set of control regulations in place at all times. A transferable license system, by specifying a total level of SO_x emissions but not a specific set of control hardware or fuel sulfur content, preserves the flexibility of source owners to respond quickly to a rising or falling level of natural gas supply.

The remaining questions about the degree of inefficiency implied when one ignores the spatial distribution of emission sources and allows all source owners in Los Angeles to freely trade SO_x emissions licenses can only be answered empirically. In this particular air basin, would an open market in licenses result in redistribution of emissions so that high impact sources were left uncontrolled or so that new air quality hot spots were created where none existed previously?

The air quality model developed by Cass (1978) can be used to answer those questions. The procedure is as follows. The SO_x emissions potential of the South Coast Air Basin during the early 1980s first will be assessed. This emissions projection must be made in a manner that is very flexible with respect to altered natural gas supply. That is because these emission data must be used later to test the emission license market's ability to respond to large changes in gas supply. Next the air quality model will be combined with the new emissions data and used to determine the transfer coefficients that relate emissions strength to air quality given the spatial distribution of sources that could prevail in the early 1980s. These transfer coefficients giving the air quality impact of each source type on each monitoring site can then be combined with new data on emission control costs. The least costly way to attain any level of air quality can be computed in an engineering sense and compared to the distribution of emissions and air quality that would result from a simulation of the effect of a transferable license market. In this way one can see whether great cost savings might result from imposition of the engineering optimization scheme. If not, the flexibility of the transferable license approach is well worth a small loss in static cost minimization.

Finally, the spatial distribution of air quality under projected 1980s emission patterns will be examined. It will be determined whether future "hot spots" (neighborhoods with much poorer than average air quality) will result, or whether sulfate air quality in the Los Angeles area will remain fairly uniformly distributed geographically in the future as it has been in the past.

THE SULFUR OXIDES EMISSION POTENTIAL OF THE SOUTH COAST AIR BASIN

A projection of the potential for sulfur oxides emissions from sources located in the central portion of the South Coast Air Basin was assembled. Emission data were sought that would be appropriate to evaluation of pollution control problems during the early part of the 1980s. That inventory will serve as the base case against which emission control strategies for improving sulfate air quality will be tested.

A complete description of all assumptions built into the emission inventory is presented in Appendix E to this report. The approach taken was not to try to predict the actual SO_x emission rate for a particular future year. The actual level of sulfur oxides emissions in the Los Angeles area in any given year is a strong function of the level of natural gas supply. When natural gas is plentiful, most stationary combustion sources burn gas rather than sulfur-bearing fuel oil, and SO_x emissions are relatively low. Conversely, in years with a poor natural gas supply, several hundred additional tons per day of SO_2 are emitted from residual and distillate oil combustion. Natural gas supplies have been observed to fluctuate widely in response to Federal regulations that are beyond the control of state and local pollution abatement authorities. Hence the actual level of SO_x emissions in any particular year is not readily forecast, and any abatement plan that is inflexible to the point of requiring a firm emissions forecast is liable to fail dramatically.

Instead, the approach taken here was to develop a spatially and temporally resolved inventory of the potential for sulfur oxides emissions as they would occur under conditions of low natural gas supply. This inventory forms a realistic estimate of the upper limit on SO_x emissions in Los Angeles in the early 1980s. From this base case, emissions rates that would prevail in the presence of any arbitrary level of natural gas supply can be quickly constructed by attenuating the SO_x emissions from fuel burning sources in proportion to the additional gas supply contemplated.

A basic starting point will be taken that is similar to that assumed by the South Coast Air Quality Management District (1978) emissions forecast. New emission control measures agreed upon or adopted prior to January 1978 will be assumed to be implemented in future years. Emissions from all other sources not affected by recent changes in regulations will be projected into the early 1980s assuming that trends apparent in 1977 remain unchanged into the near future. As a practical matter, this means that base case emissions from electric utilities were computed in the presence of a 0.25 percent limit on the sulfur content of fuel oil, while other fuel burning sources were allowed to burn up to 0.50 percent sulfur fuel oil. Rules adopted prior to January 1978 governing emission reductions at chemical plants, steel mills, and secondary lead smelters were assumed to be implemented during the early 1980s. The effect of reductions in emissions from nonutility fuel burning sources, refinery fluid catalytic crackers, petroleum coke calcining kilns proposed prior to January 1978 but not adopted by that time were excluded from the base case emission inventory. The decision to include or exclude any particular emission control proposal when making these emission projections will not bias the outcome of this study. That is because removal or addition of all candidate emission control systems will be considered as a possible perturbation from the base case when evaluating likely actions by source owners under a transferable license system. It is merely necessary at this point that the base case be precisely defined.

Appendix A2 of the study by Cass (1978) presented a spatially and temporally resolved SO_x emissions inventory for the central portion of the South Coast Air Basin during each month of the years 1972, 1973, and 1974. That emissions inventory was projected into early 1980s while maintaining nearly the same organization of sources into groups of like equipment. Major point sources and dispersed area-wide sources of sulfur oxides were assigned to appropriate locations within the 50-by-50 mile square grid shown in Figure 6. Major equipment items located beyond that grid system were itemized separately, while small off-grid area sources were neglected as before. The most important parameter of that emission projection is the chosen level of natural gas supply. The approach taken to setting a base case level of natural gas supply thus bears detailed attention.

THE LEVEL OF NATURAL GAS SUPPLY

The principal source of sulfur oxides emissions in the United States is from the combustion of sulfur bearing fossil fuels (U.S. Environmental Protection Agency, 1974). Historically, the cornerstone of the South Coast Air Basin sulfur oxides emission control strategy has rested on desulfurization of refinery gas, plus provision of a high level of natural gas supply to industry and electric utilities. Low sulfur oil was to be used only in the event that cleaner burning gaseous fuels became unavailable. This policy of promoting gaseous fuel use was so successful that in 1970, only about 21 percent of Los Angeles County SO_x emissions were derived from stationary source fuel combustion (Southern California Air Pollution Control District, 1976).

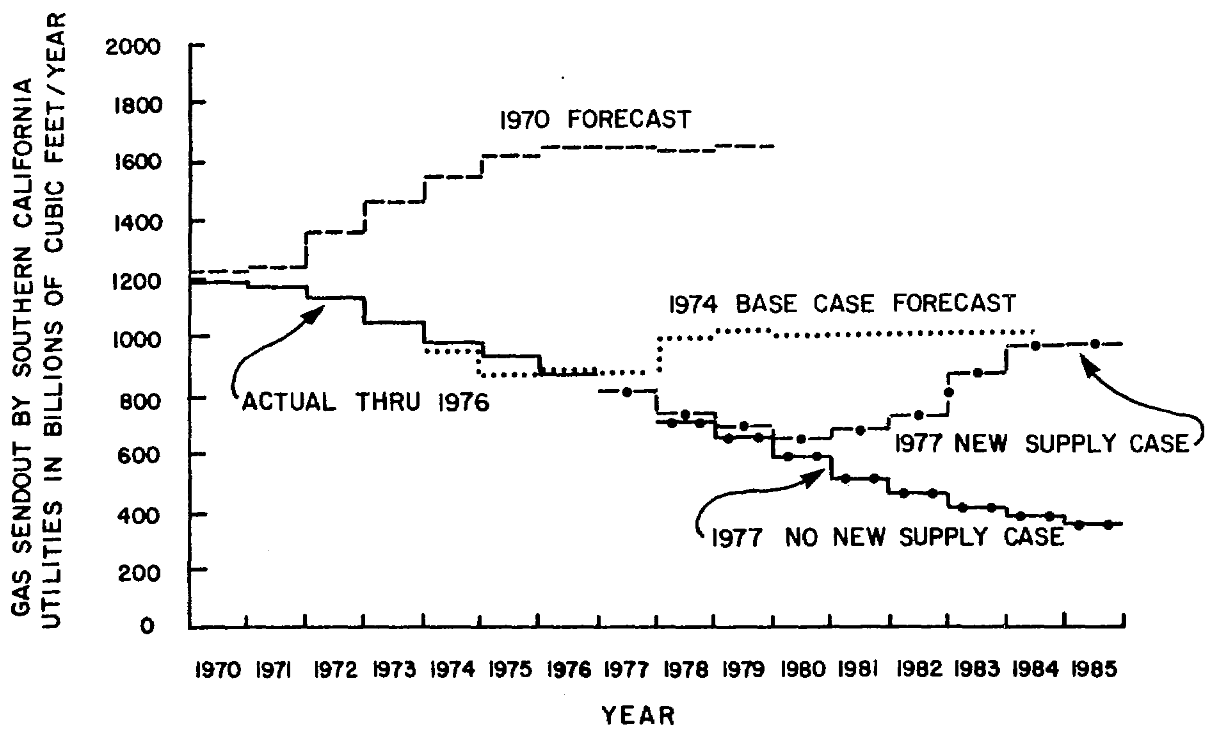
Since about the year 1970, natural gas deliveries to Southern California have steadily declined under the combined effects of interstate natural gas price regulations imposed by the Federal government, plus regulation-aggravated declines in both gas exploration and new gas reserve accumulation. While the amount of energy needed to run the economy of the South Coast Air Basin might be projected from historical data given in the energy and sulfur balance portion of the study by Cass (1978; Appendix A3), emissions of sulfur oxides cannot be forecast without knowing the combination of gas and oil that will be available to meet that energy requirement. In order to address that issue with reasonable accuracy, reliable information must exist on whether the natural gas supply will continue to deteriorate or will improve.

Forecasts of future natural gas deliveries to southern California customers are prepared annually by the utility systems serving California (for example, see the 1977 California Gas Report). The Pacific Lighting Companies act as the largest purchasing agent for natural gas sold in southern California, and as such should be in the best position to know their distribution capabilities, customers' requests for service, and the supply of gas available to them from producer's around the world (including LNG). If they cannot forecast their own level of natural gas purchase more than a year or so in advance, then it would be unwise for us to place much faith in our ability to second guess their behavior more than a few years hence under the assumption that trends apparent in 1977 continued into the future.[1]

Figure 17 provides a comparison of forecast natural gas deliveries to southern California[2] prepared by California utilities at three different times during the 1970s (<u>California Gas Report</u>, <u>1970</u>, <u>1974</u>, and <u>1977</u> editions). The 1970 forecast contained a prediction for steady growth in natural gas deliveries, reaching a level of greater than 1.6 trillion cubic feet per year in 1979. Instead, actual gas deliveries began an almost immediate decline. The 1974 forecast tended to show a short-term decline followed by a subsequent recovery of gas supply to 1974 levels. By 1977, however, the forecast

SOUTHERN CALIFORNIA NATURAL GAS SUPPLY FORECASTS

COMPARISON OF UTILITY INDUSTRY NATURAL GAS
DELIVERY FORECASTS MADE DURING THE 1970's



SOURCE: CALIFORNIA GAS REPORT 1970, 1974, and 1977 Editions

Fig. 17

for a quick recovery was abandoned in favor of continued decline in gas deliveries until at least 1980. From 1980 forward, two forecasts diverge. The "new supply" case which anticipates completion of several international supply projects shows recovery to 1974 levels by 1985, while the "no new supply" case projects a continued decline into the future. About the only trend common to more than one of these forecasts is that a lower bound to gas supply is provided by the extension of the 1970 through 1976 actual delivery line through to the 1977 "no new supply" case. A crosssection taken through all forecasts at the year 1979 indicates a divergence between forecasts made at seven-year intervals which is larger than the amount of gas then expected actually to be delivered in 1979.[3] The inference must be that any seven-year forecast prepared in this manner should be treated as a possibility to be encouraged or discouraged as one sees fit, but should not be relied upon as a given. On the other hand, the utility forecaster's track record over a two-to-three year time period following the date of a particular forecast is not too bad.

With the above discussion in mind, natural gas supply conditions in Southern California during the early 1980s will be represented not by a forecast that one expects will actually happen but rather by a case which falls within the range of the forecasts shown in Figure 17 and which has public policy implications so important that that case should be examined closely. The level of gas service chosen for study corresponds to a gas delivery rate of 0.655 Tcf per year to Southern California. At that level of service in the early 1980s, all high priority gas customers with no capability to use alternate fuels (California Public Utilities Commission priority groups 1 and 2A, plus underground injection) would receive service equal to 100 percent of their natural gas requirements. All other industries and electric utilities with alternate fuel capability would have their service almost completely curtailed (<u>1977 California Gas Report</u>, Table 1b-sc).

That level of natural gas service is chosen as the base case for our study for several important reasons. First, it corresponds to utility estimates for natural gas supply in the early 1980s at a time when the "new supply" and "no new supply" cases are nearly identical. Secondly, it represents an approximate average between the "new supply" and "no new supply" forecasts during the remainder of the first half of the 1980s. Most importantly, it represents the maximum amount of natural gas curtailment possible before small customers and thus the local economy would become seriously damaged financially. As such, it represents the point at which the California Public Utilities Commission would probably intervene to protect small customers by transferring gas from Northern to Southern California. In that case, the supply forecast is reinforced on its lower bound.

After the base case level of natural gas supply to Southern California was selected, then electricity generation plans were obtained on a unit-by-unit basis from major electric utilities in the air basin. Fuel use needed to generate those quantities of electricity were computed. From that fuel use estimate, electric utility SO_x emissions estimates were derived. A forecast of total thermal energy consumption by refinery and industrial fuel burners next was made on a spatially resolved basis for the early 1980s. Then the natural gas supply forecast was used to estimate the level of fuel oil and refinery gas consumption required to meet that industrial energy demand under conditions of low natural gas supply. SO_x emissions were then computed from fuel use as before.

Industrial process SO_x emissions estimates for the early 1980s were obtained by personal interview with South Coast Air Quality Management District engineers. An equipment list compiled from the historical emissions inventory of Appendix A2 of the study by Cass (1978) was used as a check list for this interview procedure. Each item of equipment emitting over 25 tons of SO_x annually was reviewed to determine if it was still in operation, if its emissions were expected to be impacted by regulations or consent agreements adopted prior to January 1978, or if an improved estimate of future emissions could be made.

Finally, mobile source emissions data were updated. A freeway and surface street traffic growth survey was used to forecast 1980 traffic volumes on a spatially resolved basis. Then highway traffic was subdivided into catalyst-equipped and non catalyst-equipped gasoline-fueled vehicles, plus diesel trucks and buses. Fuel combustion estimates for railroads, ships, and aircraft were projected to the early 1980s based upon conversations with transportation industry personnel.

EMISSIONS PROJECTION SUMMARY AND DISCUSSION

Figure 18 summarizes the sulfur oxides emissions projection for the central portion of the South Coast Air Basin under conditions of low natural gas supply. In the event of the loss of the industrial natural gas supply, emissions within the 50-by-50 mile grid would total about 355 tons per average day. Major off-grid sources would amount to another 64.3 tons per day of SO_x emissions. Those figures correspond quite closely to the 343 tons per day on-grid, plus 91 tons per day off-grid during the year 1974. In spite of the introduction of several new emissions control regulations during the late 1970s future air quality might look much like past air quality if large amounts of fuel oil were burned by local industries.

Comparison of Figure 18 to Figure 8 shows that annual average data hide some remarkable changes which would have occurred between 1974 and any future year in which natural gas supplies run low. The strong seasonal variation in electric utility fuel SO_x emissions present in the early 1970s would be absent under conditions of low natural gas supply. The annual average value of those utility fuel SO_x emissions would remain about the same in spite of a great increase in oil combustion because the sulfur content of fuel was cut from a

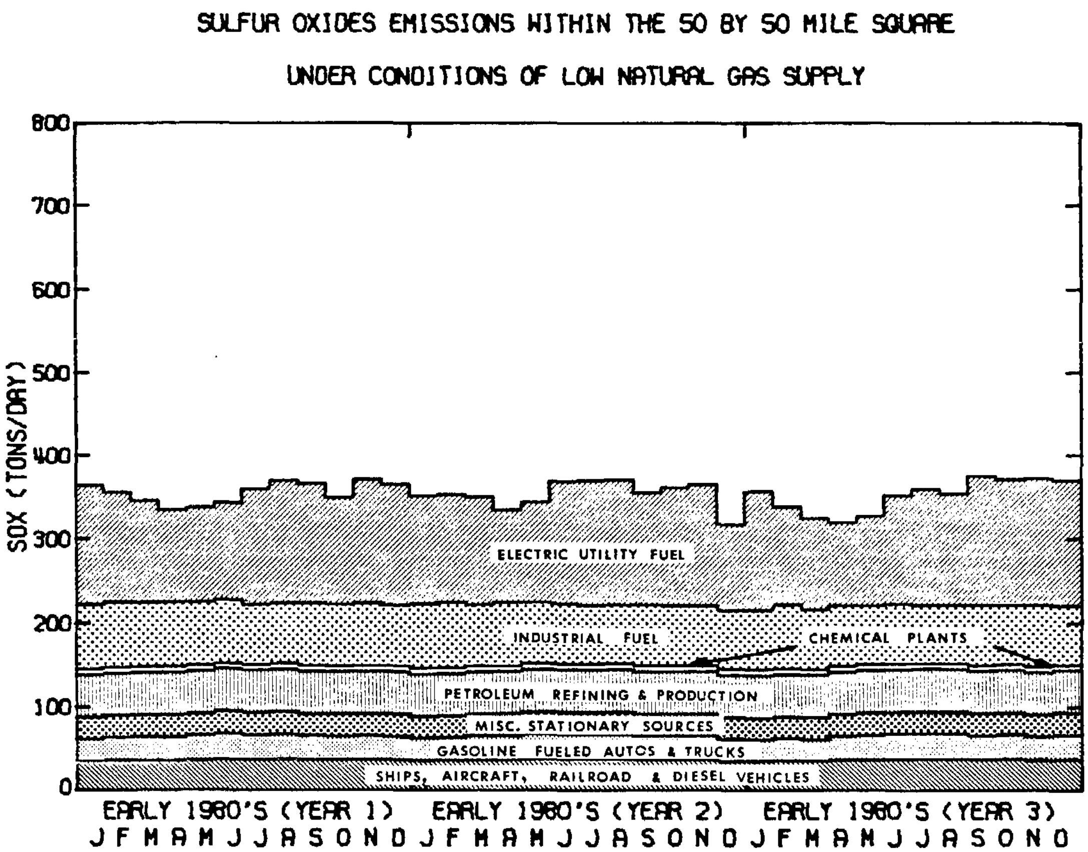

SULFUR OXIDES EMISSIONS WITHIN THE 50 BY 50 MILE SQUARE
UNDER CONDITIONS OF LOW NATURAL GAS SUPPLY
SOX (TONS/DAY)
800
700
600
500
400
300
200
100
0
ELECTRIC UTILITY FUEL
INDUSTRIAL FUEL
CHEMICAL PLANTS
PETROLEUM REFINING & PRODUCTION
MISC. STATIONARY SOURCES
GASOLINE FUELED AUTOS & TRUCKS
SHIPS, AIRCRAFT, RAILROAD & DIESEL VEHICLES
EARLY 1980'S (YEAR 1)
EARLY 1980'S (YEAR 2)
EARLY 1980'S (YEAR 3)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Fig. 18

maximum of 0.50 percent by weight in 1974 down to a maximum of 0.25 percent sulfur by weight at present.

A second major change in emissions between the early 1970s and the early 1980s involves the nearly complete elimination of SO_x emissions from chemical plants. However, in place of the chemical plant emissions, more than 70 tons per day of SO_x emissions could occur from nonutility industrial fuel burning under conditions of low natural gas supply. Bringing fuel burning emissions under control through maintenance of the natural gas supply or installation of desulfurization or emissions control equipment thus is seen to be critical during the decade of the 1980s if sulfate air quality is to be improved beyond 1974 levels.

Tables 6 through 8 show the monthly emissions history for individual source and equipment types within the general source categories of Figure 18. The emissions inventory created for air quality model use contains spatially resolved source strength data defined on the 50-by-50 mile grid for each of the 28 source types shown in Tables 6 through 8 for each month of three test years. An itemization of large off-grid sources also is included.

One principal reason for compiling emissions on a source-by-source basis is to be able to display the spatial distribution of SO_x emission strength. Figures 19 through 21 summarize annual average SO_x emissions density for those test years. It is seen that the largest SO_x emission source densities are still located in a narrow strip along the coastline stretching from Los Angeles International Airport (near Lennox) on the north to Huntington Beach (opposite Santa Ana) on the south. However, sulfur oxides emissions in the downtown Los Angeles area would grow beyond levels observed in the early 1970s if increased industrial fuel oil use were to occur in the presence of a low natural gas supply.

THE RELATIONSHIP BETWEEN EMISSIONS AND AIR QUALITY UNDER BASE CASE CONDITIONS

The emissions to air quality model described by Cass (1978) was employed to explore the air quality consequences of the emissions projection just described. The objective of this exercise was two-fold. First, a reestimation of the transfer coefficients that map emissions strength from each source class into observed air quality at each monitoring site was desired given a geographic distribution of emissions characteristic of the 1980s. Secondly, we wish to examine the spatial distribution of air quality that would result from a major change in emissions (in this case a change to all-oil combustion by industry) in order to see if any major "hot spot" neighborhoods are generated that would experience very poor air quality.

Tables 6 through 8 provide 36 consecutive monthly emissions estimates for each source type of interest. These three years of

TABLE 6a

Sulfur Oxides Emissions Within the 50 by 50 Mile Square Grid
Early 1980's Test Year 1
(in short tons per day as SO_2)

STATIONARY SOURCES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
FUEL COMBUSTION													
ELECTRIC UTILITIES													
RESIDUAL OIL	139.80	127.93	119.15	107.61	110.18	113.12	136.13	143.48	139.07	124.44	144.54	141.57	128.95
DISTILLATE OIL	2.28	2.09	1.94	1.76	1.80	1.85	2.22	2.34	2.27	2.03	2.36	2.31	2.10
REFINERY FUEL	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00
LOW PRIORITY NATURAL GAS CUSTOMERS	49.41	50.28	48.75	49.98	47.89	48.44	44.64	45.67	47.99	46.76	48.29	45.39	47.77
HIGH PRIORITY NATURAL GAS CUSTOMERS	0.46	0.43	0.29	0.27	0.24	0.20	0.17	0.15	0.16	0.18	0.30	0.40	0.27
CHEMICAL PLANTS													
SULFUR RECOVERY	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51
SULFURIC ACID	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08
OTHER CHEMICALS	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
PETROLEUM REFINING AND PRODUCTION													
FLUID CATALYTIC CRACKERS	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95
SOUR WATER STRIPPERS	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
DELAYED COKERS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MISC. REFINERY PROCESS	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
OIL FIELD PRODUCTION	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30
MISC. STATIONARY SOURCES													
PETROLEUM COKE KILNS	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82
GLASS FURNACES	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
NON-FERROUS METALS	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
FERROUS METALS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MINERAL PRODUCTS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SEWAGE TREATMENT DIGESTERS	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
OTHER INDUSTRIAL PROCESSES	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
PERMITTED INCINERATORS	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
MOBILE SOURCES													
CATALYST-EQUIPPED LT. DUTY VEHICLES - SURFACE	7.06	7.38	7.57	7.50	7.84	8.26	7.92	8.13	7.74	7.61	7.71	7.67	7.70
CATALYST-EQUIPPED LT. DUTY VEHICLES - FREEWAY	4.92	5.14	5.27	5.23	5.46	5.76	5.52	5.66	5.39	5.30	5.37	5.34	5.36
NON-CATALYST LT. DUTY VEHICLES	14.55	15.20	15.59	15.45	16.16	17.02	16.32	16.75	15.95	15.67	15.88	15.80	15.86
HEAVY HIGHWAY DIESEL VEHICLES	17.15	17.91	18.38	18.21	19.04	20.06	19.23	19.74	18.80	18.47	18.71	18.62	18.69
AIRPORT OPERATIONS	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
SHIPPING OPERATIONS	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21
RAILROAD OPERATIONS	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33
TOTAL	365.35	356.08	346.66	335.73	338.33	344.43	361.87	371.64	367.09	350.18	372.88	366.82	356.4

TABLE 6b

Major Off-Grid Emission Sources Included within the
South Coast Air Basin Sulfur Oxides Modeling Inventory
Early 1980's Test Year 1
(in short tons per day as SO_2)

STATIONARY SOURCES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
FUEL COMBUSTION													
ELECTRIC UTILITIES													
RESIDUAL OIL	51.38	47.02	43.79	39.55	40.50	41.58	50.03	52.74	51.11	45.74	53.13	52.03	47.40
DISTILLATE OIL	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.03	0.02
REFINERY FUEL	---	---	---	---	---	---	---	---	---	---	---	---	---
LOW PRIORITY NATURAL GAS CUSTOMERS	---	---	---	---	---	---	---	---	---	---	---	---	---
HIGH PRIORITY NATURAL GAS CUSTOMERS	---	---	---	---	---	---	---	---	---	---	---	---	---
CHEMICAL PLANTS													
SULFUR RECOVERY	---	---	---	---	---	---	---	---	---	---	---	---	---
SULFURIC ACID	---	---	---	---	---	---	---	---	---	---	---	---	---
OTHER CHEMICALS	---	---	---	---	---	---	---	---	---	---	---	---	---
PETROLEUM REFINING AND PRODUCTION													
FLUID CATALYTIC CRACKERS	---	---	---	---	---	---	---	---	---	---	---	---	---
SOUR WATER STRIPPERS	---	---	---	---	---	---	---	---	---	---	---	---	---
DELAYED COKERS	---	---	---	---	---	---	---	---	---	---	---	---	---
MISC. REFINERY UNITS	---	---	---	---	---	---	---	---	---	---	---	---	---
OIL FIELD PRODUCTION	---	---	---	---	---	---	---	---	---	---	---	---	---
MISC. STATIONARY SOURCES													
PETROLEUM COKE KILNS	---	---	---	---	---	---	---	---	---	---	---	---	---
GLASS FURNACES	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
NON-FERROUS METALS	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
FERROUS METALS	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55
MINERAL PRODUCTS	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
SEWAGE TREATMENT DIGESTERS	---	---	---	---	---	---	---	---	---	---	---	---	---
OTHER INDUSTRIAL PROCESSES	---	---	---	---	---	---	---	---	---	---	---	---	---
PERMITTED INCINERATORS	---	---	---	---	---	---	---	---	---	---	---	---	---
TOTAL OFF-GRID STATIONARY SOURCES	68.12	63.74	60.53	56.29	57.24	58.32	66.77	69.49	67.85	62.48	69.88	68.78	64.14

TABLE 7a

Sulfur Oxides Emissions Within the 50 by 50 Mile Square Grid
Early 1980's Test Year 2
(in short tons per day as SO_2)

STATIONARY SOURCES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
FUEL COMBUSTION													
ELECTRIC UTILITIES													
RESIDUAL OIL	126.10	126.41	126.70	107.76	117.74	143.06	145.77	146.63	131.75	138.79	141.45	99.46	129.31
DISTIALLATE OIL	2.06	2.06	2.07	1.76	1.92	2.33	2.38	2.39	2.15	2.26	2.31	1.62	2.11
REFINERY FUEL	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00
LOW PRIORITY NATURAL GAS CUSTOMERS	49.69	50.23	45.16	48.16	45.85	44.77	43.41	42.88	45.17	44.38	45.19	42.73	45.60
HIGH PRIORITY NATURAL GAS CUSTOMERS	0.46	0.46	0.37	0.33	0.26	0.21	0.17	0.16	0.19	0.20	0.26	0.36	0.28
CHEMICAL PLANTS													
SULFUR RECOVERY	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51
SULFURIC ACID	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08
OTHER CHEMICALS	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
PETROLEUM REFINING AND PRODUCTION													
FLUID CATALYTIC CRACKERS	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95
SOUR WATER STRIPPERS	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
DELAYED COKERS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MISC. REFINERY PROCESS	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
OIL FIELD PRODUCTION	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30
MISC. STATIONARY SOURCES													
PETROLEUM COKE KILNS	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82
GLASS FURNACES	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
NON-FERROUS METALS	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
FERROUS METALS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MINERAL PRODUCTS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SEWAGE TREATMENT DIGESTERS	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
OTHER INDUSTRIAL PROCESSES	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
PERMITTED INCINERATORS	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
MOBILE SOURCES													
CATALYST-EQUIPPED LT. DUTY VEHICLES - SURFACE	7.19	7.41	7.72	7.79	8.16	8.08	8.02	8.15	7.68	7.67	7.67	7.09	7.72
CATALYST-EQUIPPED LT. DUTY VEHICLES - FREEWAY	5.01	5.16	5.38	5.43	5.68	5.63	5.58	5.68	5.35	5.34	5.34	4.94	5.38
NON-CATALYST LT. DUTY VEHICLES	14.82	15.27	15.90	16.06	16.81	16.65	16.52	16.80	15.82	15.80	15.80	14.60	15.91
HEAVY HIGHWAY DIESEL VEHICLES	17.46	17.99	18.74	18.92	19.81	19.62	19.46	19.80	18.65	18.62	18.62	17.20	18.75
AIRPORT OPERATIONS	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
SHIPPING OPERATIONS	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21
RAILROAD OPERATIONS	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33
TOTAL	352.51	354.71	351.76	335.93	345.95	370.07	371.03	372.21	356.48	362.78	366.36	317.72	354.79

TABLE 7b

Major Off-Grid Emission Sources Included within the South Coast Air Basin Sulfur Oxides Modeling Inventory
Early 1980's Test Year 2
(in short tons per day as SO_2)

STATIONARY SOURCES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
FUEL COMBUSTION													
ELECTRIC UTILITIES													
RESIDUAL OIL	46.35	46.46	46.57	39.61	43.28	52.58	53.58	53.90	48.42	51.01	51.99	36.56	47.53
DISTILLATE OIL	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.02
REFINERY FUEL	---	---	---	---	---	---	---	---	---	---	---	---	---
LOW PRIORITY NATURAL GAS CUSTOMERS	---	---	---	---	---	---	---	---	---	---	---	---	---
HIGH PRIORITY NATURAL GAS CUSTOMERS	---	---	---	---	---	---	---	---	---	---	---	---	---
CHEMICAL PLANTS													
SULFUR RECOVERY	---	---	---	---	---	---	---	---	---	---	---	---	---
SULFURIC ACID	---	---	---	---	---	---	---	---	---	---	---	---	---
OTHER CHEMICALS	---	---	---	---	---	---	---	---	---	---	---	---	---
PETROLEUM REFINING AND PRODUCTION													
FLUID CATALYTIC CRACKERS	---	---	---	---	---	---	---	---	---	---	---	---	---
SOUR WATER STRIPPERS	---	---	---	---	---	---	---	---	---	---	---	---	---
DELAYED COKERS	---	---	---	---	---	---	---	---	---	---	---	---	---
MISC. REFINERY UTNIS	---	---	---	---	---	---	---	---	---	---	---	---	---
OIL FIELD PRODUCTION	---	---	---	---	---	---	---	---	---	---	---	---	---
MISC. STATIONARY SOURCES													
PETROLEUM COKE KILNS	---	---	---	---	---	---	---	---	---	---	---	---	---
GLASS FURNACES	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
NON-FERROUS METALS	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
FERROUS METALS	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55
MINERAL PRODUCTS	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
SEWAGE TREATMENT DIGESTERS	---	---	---	---	---	---	---	---	---	---	---	---	---
OTHER INDUSTRIAL PROCESSES	---	---	---	---	---	---	---	---	---	---	---	---	---
PERMITTED INCINERATORS	---	---	---	---	---	---	---	---	---	---	---	---	---
TOTAL OFF-GRID STATIONARY SOURCES	63.09	63.20	63.31	56.35	60.02	69.33	70.33	70.65	65.16	67.75	68.74	53.30	64.27

TABLE 8a

Sulfur Oxides Emissions Within the 50 by 50 Mile Square Grid
Early 1980's Test Year 3
(in short tons per day as SO_2)

STATIONARY SOURCES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
FUEL COMBUSTION													
ELECTRIC UTILITIES													
RESIDUAL OIL	139.95	114.63	106.43	95.91	104.17	126.70	137.08	130.43	151.04	147.32	149.40	147.41	129.31
DISTILLATE OIL	2.28	1.87	1.74	1.57	1.70	2.07	2.24	2.13	2.46	2.40	2.44	2.41	2.11
REFINERY FUEL	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00
LOW PRIORITY NATURAL GAS CUSTOMERS	43.34	48.64	44.06	44.94	43.13	44.22	41.44	41.98	44.85	43.53	46.16	42.39	44.01
HIGH PRIORITY NATURAL GAS CUSTOMERS	0.41	0.41	0.35	0.27	0.23	0.21	0.17	0.15	0.16	0.17	0.25	0.35	0.26
CHEMICAL PLANTS													
SULFUR RECOVERY	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51
SULFURIC ACID	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08
OTHER CHEMICALS	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
PETROLEUM REFINING AND PRODUCTION													
FLUID CATALYTIC CRACKERS	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95	44.95
SOUR WATER STRIPPERS	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
DELAYED COKERS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MISC. REFINERY PROCESSES	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
OIL FIELD PROCESSES	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30
MISC. STATIONARY SOURCES													
PETROLEUM COKE KILNS	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82
GLASS FURNACES	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
NON-FERROUS METALS	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
FERROUS METALS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MINERAL PRODUCTS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SEWAGE TREATMENT DIGESTERS	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
OTHER INDUSTRIAL PROCESSES	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
PERMITTED INCINERATORS	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
MOBILE SOURCES													
CATALYST-EQUIPPED LT. DUTY VEHICLES - SURFACE	6.91	7.19	6.95	7.70	7.98	8.18	8.23	8.19	7.76	8.01	7.58	7.94	7.72
CATALYST-EQUIPPED LT. DUTY VEHICLES - FREEWAY	4.82	5.01	4.84	5.37	5.56	5.70	5.73	5.70	5.40	5.58	5.28	5.53	5.38
NON-CATALYST LT. DUTY VEHICLES	14.24	14.81	14.31	15.87	16.45	16.85	16.96	16.86	15.98	16.50	15.61	16.35	15.91
HEAVY HIGHWAY DIESEL VEHICLES	16.78	17.46	16.87	18.70	19.38	19.85	19.99	19.88	18.83	19.44	18.40	19.27	18.75
AIRPORT OPERATIONS	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
SHIPPING OPERATIONS	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21	13.21
RAILROAD OPERATIONS	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33
TOTAL	358.45	339.74	325.27	320.05	328.32	353.50	361.56	355.04	376.25	372.67	374.84	371.37	353.18

TABLE 8b

Major Off-Grid Emission Sources Included within the
South Coast Air Basin Sulfur Oxides Modeling Inventory
Early 1980's Test Year 3
(in short tons per day as SO_2)

STATIONARY SOURCES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
FUEL COMBUSTION													
ELECTRIC UTILITIES													
RESIDUAL OIL	51.44	42.13	39.12	35.25	38.29	46.57	50.38	47.94	55.51	54.15	54.19	54.18	47.53
DISTILLATE OIL	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02
REFINERY FUEL	---	---	---	---	---	---	---	---	---	---	---	---	---
LOW PRIORITY NATURAL GAS CUSTOMERS	---	---	---	---	---	---	---	---	---	---	---	---	---
HIGH PRIORITY NATURAL GAS CUSTOMERS	---	---	---	---	---	---	---	---	---	---	---	---	---
CHEMICAL PLANTS													
SULFUR RECOVERY	---	---	---	---	---	---	---	---	---	---	---	---	---
SULFURIC ACID	---	---	---	---	---	---	---	---	---	---	---	---	---
OTHER CHEMICALS	---	---	---	---	---	---	---	---	---	---	---	---	---
PETROLEUM REFINING AND PRODUCTION													
FLUID CATALYTIC CRACKERS	---	---	---	---	---	---	---	---	---	---	---	---	---
SOUR WATER STRIPPERS	---	---	---	---	---	---	---	---	---	---	---	---	---
DELAYED COKERS	---	---	---	---	---	---	---	---	---	---	---	---	---
MISC. REFINERY UNITS	---	---	---	---	---	---	---	---	---	---	---	---	---
OIL FIELD PRODUCTION	---	---	---	---	---	---	---	---	---	---	---	---	---
MISC. STATIONARY SOURCES													
PETROLEUM COKE KILNS	---	---	---	---	---	---	---	---	---	---	---	---	---
GLASS FURNACES	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
NON-FERROUS METALS	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
FERROUS METALS	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55	14.55
MINERAL PRODUCTS	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
SEWAGE TREATMENT DIGESTERS	---	---	---	---	---	---	---	---	---	---	---	---	---
OTHER INDUSTRIAL PROCESSES	---	---	---	---	---	---	---	---	---	---	---	---	---
PERMITTED INCINERATORS	---	---	---	---	---	---	---	---	---	---	---	---	---
TOTAL OFF-GRID STATIONARY SOURCES	68.16	58.87	55.86	51.99	55.03	63.31	67.12	64.68	72.26	70.90	71.66	70.93	64.27

TOTAL SOX EMISSIONS IN THE EARLY 1980'S: TEST YEAR 1 UNDER CONDITIONS OF LOW NATURAL GAS SUPPLY, IN TONS/DAY AS SO2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
25	0.0	0.0	0.0	0.1	0.1	0.2	0.1	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	0.0	0.0	0.0	0.0	0.0
24	0.0	0.1	0.1	0.3	0.2	0.1	0.1	2.3	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	0.0	0.0	0.0	0.0
23	0.1	0.1	0.1	0.1	0.5	0.2	0.4	0.3	0.1	0.0	0.0	0.1	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
22	0.1	0.2	0.1	0.1	0.2	0.3	0.2	0.2	0.4	2.4	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.1	0.1	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.3	2.2	0.2	0.0	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.2	0.0	0.4	0.1	0.1	0.2	3.0	0.1	0.1	0.1	0.1	0.1	0.4	0.1	0.1	0.0	0.0
19	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.5	0.5	0.2	0.5	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
18	0.0	0.0	0.0	0.0	0.1	1.6	0.2	0.4	0.4	0.4	0.5	0.8	0.8	0.3	0.3	0.2	0.3	0.6	0.2	0.2	0.1	0.1	0.1	0.1	1.9
17	0.0	0.0	0.0	0.1	0.1	0.7	0.6	0.3	0.4	0.5	1.0	2.4	0.4	0.3	0.2	0.1	0.1	0.2	0.4	0.1	0.0	0.0	0.0	0.2	0.1
16	0.0	0.0	0.0	0.1	0.3	0.4	0.4	0.2	0.2	0.2	0.7	1.9	2.5	1.0	0.4	0.1	0.3	0.1	0.7	0.2	0.1	0.2	0.2	0.1	0.0
15	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.2	0.1	0.3	0.7	2.8	2.8	1.5	1.4	0.1	0.2	0.0	0.0	0.0	0.2	0.1	0.1	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.3	0.2	0.1	0.3	1.4	1.4	0.8	0.2	0.3	0.7	0.2	0.1	0.0	0.0	0.0	0.1	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.7	9.8	0.4	0.4	0.1	0.2	0.5	0.3	0.4	0.3	0.4	3.6	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	23.6	0.5	0.2	0.2	0.3	0.2	0.4	0.4	1.1	0.3	0.4	3.0	0.1	0.0	0.1	0.1	1.5	1.5	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.5	0.3	0.1	0.3	1.5	0.2	0.3	0.2	0.3	0.3	0.7	0.2	0.6	0.2	0.1	0.1
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.5	12.0	2.2	0.5	11.7	0.3	0.1	0.1	0.2	0.1	0.1	0.3	0.4	0.5	0.3	0.2	0.2	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.4	0.3	25.5	0.3	0.2	0.3	0.2	0.2	0.1	0.1	0.1	0.4	0.3	0.2	0.1	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	18.2	21.0	1.2	0.5	0.1	60.8	0.2	0.2	0.2	0.1	0.1	0.4	0.2	0.2	0.0
7	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.1	4.8	1.8	0.1	0.0	0.1	0.2	0.4	0.3	0.2	0.2	0.1	0.5	0.2	0.0
6	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	3.2	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.8	0.2	0.1
5	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.2	0.6	0.0	0.1
4	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.2	0.1	0.1	0.1
3	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.9	4.9	0.2	0.1	0.1	0.0	0.0
2	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	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
1	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	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0

RESEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA

SOX
TONS/DAY
356.460

Fig. 19

TOTAL SOX EMISSIONS IN THE EARLY 1980'S: TEST YEAR 2 UNDER CONDITIONS OF LOW NATURAL GAS SUPPLY, IN TONS/DAY AS SO2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
25	0.0	0.0	0.0	0.1	0.1	0.2	0.1	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	0.0	0.0	0.0	0.0	0.0
24	0.0	0.1	0.1	0.3	0.2	0.1	0.1	2.3	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	0.0	0.0	0.0	0.0
23	0.1	0.1	0.1	0.1	0.5	0.2	0.2	0.2	0.1	0.0	0.0	0.1	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
22	0.1	0.2	0.1	0.1	0.2	0.3	0.2	0.2	0.3	2.3	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	2.2	0.2	0.0	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.2	0.0	0.4	0.1	0.1	0.2	3.0	0.1	0.1	0.1	0.1	0.1	0.4	0.1	0.1	0.0	0.0
19	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.4	0.5	0.2	0.4	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
18	0.0	0.0	0.0	0.0	0.1	1.5	0.2	0.3	0.4	0.4	0.5	0.8	0.8	0.3	0.3	0.2	0.3	0.6	0.2	0.2	0.1	0.1	0.1	0.1	1.8
17	0.0	0.0	0.0	0.1	0.1	0.7	0.7	0.3	0.4	0.5	1.0	2.3	0.4	0.3	0.2	0.1	0.1	0.2	0.4	0.1	0.0	0.0	0.0	0.2	0.1
16	0.0	0.0	0.0	0.1	0.3	0.4	0.4	0.2	0.2	0.2	0.6	1.6	2.3	0.8	0.4	0.1	0.3	0.1	0.7	0.2	0.1	0.2	0.2	0.1	0.0
15	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.2	0.1	0.2	0.8	2.9	3.1	1.6	1.4	0.1	0.2	0.0	0.0	0.0	0.2	0.1	0.1	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.3	0.2	0.1	0.3	1.5	0.9	0.8	0.2	0.3	0.6	0.2	0.1	0.0	0.0	0.0	0.1	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.7	9.8	0.4	0.4	0.1	0.2	0.5	0.2	0.3	0.3	0.4	3.5	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	23.6	0.4	0.2	0.2	0.3	0.2	0.4	0.4	1.1	0.3	0.4	3.0	0.1	0.0	0.1	0.1	1.5	1.5	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.5	0.3	0.1	0.3	1.6	0.2	0.3	0.2	0.3	0.3	0.7	0.2	0.6	0.2	0.1	0.1
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.5	12.0	2.2	0.5	11.8	0.3	0.1	0.1	0.2	0.1	0.1	0.3	0.4	0.5	0.3	0.2	0.2	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.4	0.3	25.5	0.3	0.2	0.3	0.2	0.2	0.1	0.1	0.1	0.4	0.3	0.1	0.2	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	18.2	21.0	1.3	0.5	0.1	61.0	0.2	0.2	0.2	0.1	0.1	0.4	0.2	0.2	0.0
7	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.1	4.7	1.8	0.1	0.0	0.1	0.2	0.4	0.3	0.2	0.2	0.1	0.5	0.2	0.0
6	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	3.4	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.8	0.2	0.1
5	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.2	0.6	0.0	0.1
4	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.2	0.1	0.1	0.1
3	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.9	4.9	0.2	0.1	0.1	0.0	0.0
2	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	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
1	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	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0

SOX
TONS/DAY
354.791

Fig. 20

TCTAL SOX EMISSICNS IN THE EARLY 1980'S: TEST YEAR 3 UNDER CONDITICNS OF LOW NATURAL GAS SUPPLY, IN TONS/DAY AS SO2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
25	0.0	0.0	0.0	0.1	0.1	0.2	0.1	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	0.0	0.0	0.0	0.0	0.0
24	0.0	0.1	0.1	0.3	0.2	0.1	0.1	2.3	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	0.0	0.0	0.0	0.0
23	0.1	0.1	0.1	0.1	0.5	0.2	0.3	0.2	0.1	0.0	0.0	0.1	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
22	0.1	0.1	0.1	0.1	0.2	0.3	0.2	0.2	0.3	2.3	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.2	0.3	2.2	0.2	0.0	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.2	0.0	0.4	0.1	0.1	0.2	3.0	0.1	0.1	0.1	0.1	0.1	0.4	0.1	0.1	0.0	0.0
19	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.4	0.5	0.2	0.4	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
18	0.0	0.0	0.0	0.0	0.1	1.3	0.2	0.3	0.3	0.4	0.4	0.8	0.7	0.3	0.3	0.2	0.3	0.6	0.2	0.2	0.1	0.1	0.1	0.1	1.6
17	0.0	0.0	0.0	0.2	0.1	0.5	0.6	0.3	0.4	0.5	0.9	1.6	0.4	0.3	0.2	0.1	0.1	0.2	0.3	0.1	0.0	0.0	0.0	0.2	0.1
16	0.0	0.0	0.0	0.1	0.3	0.3	0.4	0.2	0.2	0.2	0.6	1.6	2.2	0.8	0.3	0.1	0.3	0.1	0.7	0.2	0.1	0.2	0.2	0.1	0.0
15	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.2	0.1	0.2	0.7	3.0	3.5	1.5	1.5	0.1	0.2	0.0	0.0	0.0	0.2	0.1	0.1	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.3	0.2	0.1	0.3	1.5	1.3	0.7	0.2	0.3	0.7	0.2	0.1	0.0	0.0	0.0	0.1	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.7	9.8	0.4	0.4	0.1	0.2	0.5	0.2	0.3	0.3	0.4	3.5	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	23.6	0.4	0.2	0.2	0.3	0.2	0.3	0.4	1.1	0.3	0.4	3.0	0.1	0.0	0.1	0.1	1.5	1.5	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.5	0.3	0.1	0.3	1.5	0.2	0.3	0.2	0.2	0.3	0.7	0.2	0.6	0.2	0.0	0.1
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.5	12.0	2.4	0.5	11.8	0.3	0.1	0.1	0.2	0.1	0.1	0.3	0.4	0.4	0.3	0.2	0.2	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.3	25.7	0.3	0.2	0.3	0.2	0.2	0.1	0.1	0.1	0.4	0.3	0.1	0.2	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	18.2	21.1	1.2	0.5	0.1	61.0	0.2	0.2	0.2	0.1	0.1	0.4	0.2	0.2	0.0
7	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.0	4.7	1.8	0.1	0.0	0.1	0.2	0.4	0.3	0.2	0.2	0.1	0.5	0.2	0.0
6	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	3.3	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.8	0.2	0.1
5	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.2	0.6	0.0	0.1
4	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.2	0.1	0.1	0.1
3	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.9	4.9	0.2	0.1	0.1	0.0	0.0
2	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	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
1	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	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0

RESEDA, BURBANK, GLENDALE, PASADENA, AZUSA, GLENDORA, WEST COVINA, WEST LA, LOS ANGELES, SANTA MONICA, LENNOX, LYNWOOD, TORRANCE, LONG BEACH, ANAHEIM, GARDEN GROVE, SANTA ANA

SOX
TONS/DAY
353.179

Fig. 21

example emissions data were matched with three different years of historically observed meteorological data so that a range of air quality possibilities could be examined using the air quality simulation model. Meteorological data taken from years 1972 through 1974 form an attractive set of test conditions. Those years contain two instances of typical weather conditions leading to high summer sulfates and low winter sulfates (as in 1973 and 1974), plus one counter example yielding high winter sulfates with low summer sulfates (as in 1972). In order to capture the interplay between weather conditions and fuel use, the seasonal variation in energy consumption observed in those years was factored into the emissions projections at the time that those projections were made.

Remaining data needed to complete the air quality simulation are as described in Chapter 5 of Cass (1978). Estimates of the seasonal variation in sulfate background air quality and in SO_2 oxidation rate can be matched to appropriate meteorological conditions by basing those values within this simulation on historical observations during the years 1972-1974.

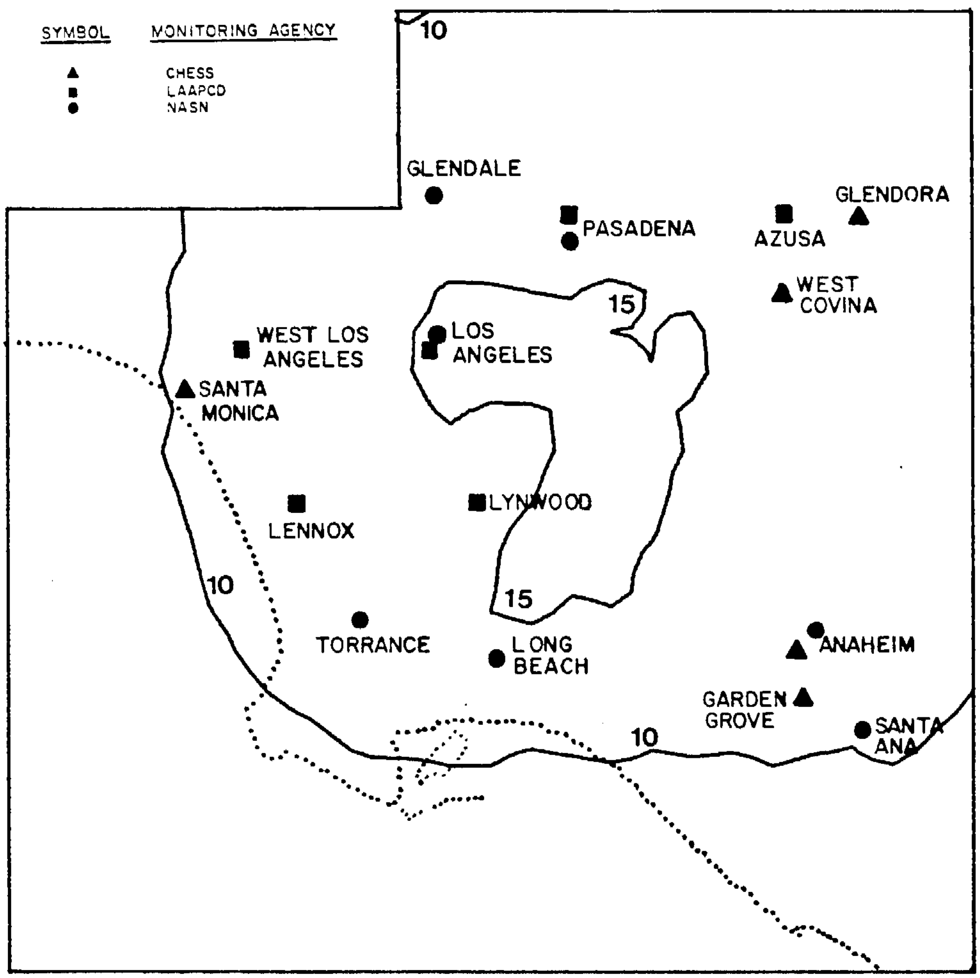
Annual mean sulfate concentrations that would result from the base case emissions pattern under three alternative years of meteorological events are shown in Figures 22 through 24. A composite average of these three test cases is given in Figure 25. By comparison with Figure 11, it is seen that sulfate concentration patterns in the 1980s under low natural gas supply conditions would not differ greatly from air quality observations in the early 1970s. The spatial distribution of sulfate air quality on the average in Figure 25 is fairly uniform over the most populous areas of the air basin, with most neighborhoods having sulfate concentrations averaging from 10 to 15 $\mu g\ m^{-3}$ over the long run.

The sources contributing to sulfate concentrations at a number of monitoring sites are presented in Figures 26-45. As was the case in the early 1970s, air quality at each monitoring site is due to the combined effects of small contributions from a large number of diverse source types. Sulfate concentrations attributed to automobiles have increased due to small additions of primary sulfates from catalyst equipped cars introduced to the vehicle fleet since 1975. Chemical plant emissions and air quality impacts have been nearly eliminated when compared with the early 1970s (see Figures 8,9,10). A substantial air quality increment due to stationary fuel burning sources would occur at each monitoring site if the low natural gas supply case were actually to occur in the 1980s. One can quickly visualize air quality in the presence of a <u>high</u> natural gas supply by eliminating the top two subdivisions on the bar graphs of Figures 26-45.

When each source class' contribution to air quality at a monitoring site is divided by basin-wide emissions from that source type, transfer coefficients are generated that show the effect on resulting air quality of a unit change in emissions from the source.

ANNUAL AVERAGE SULFATE CONCENTRATIONS ($\mu GM/M^3$)

UNDER LOW NATURAL GAS SUPPLY CONDITIONS

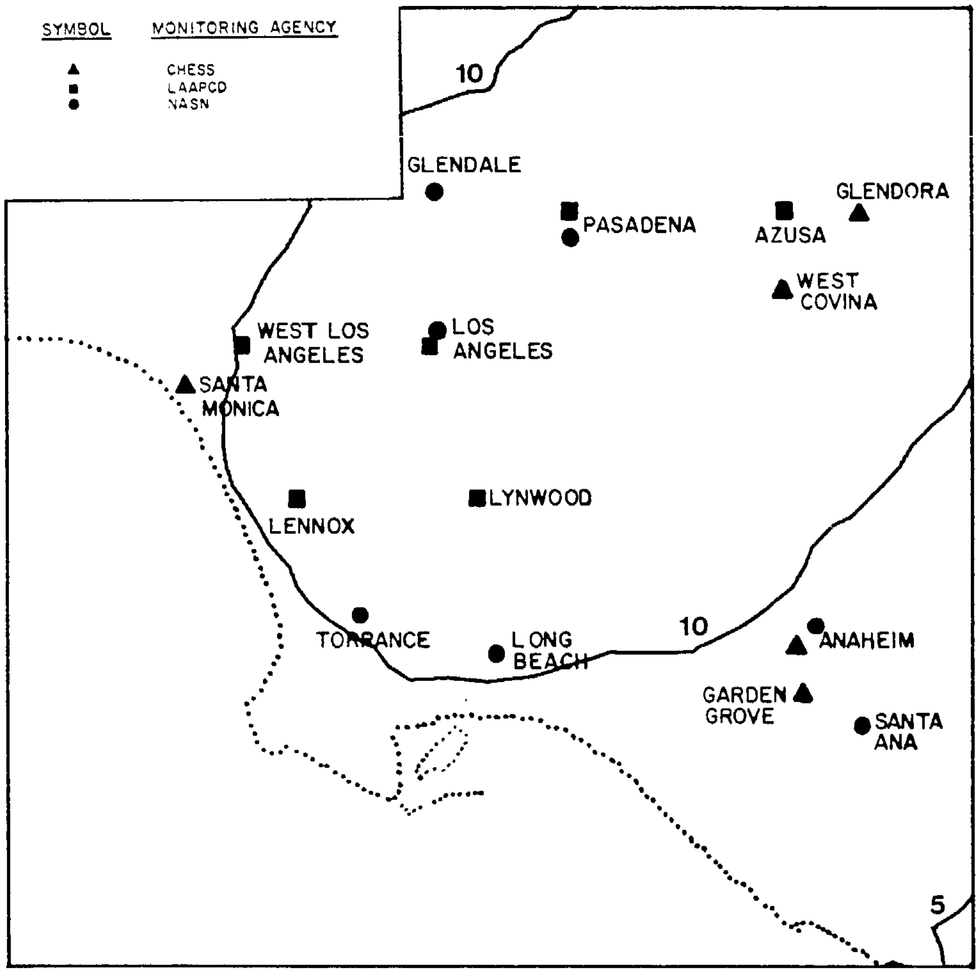


EARLY 1980'S - TEST YEAR 1

Fig. 22

ANNUAL AVERAGE SULFATE CONCENTRATIONS ($\mu GM/M^3$)

UNDER LOW NATURAL GAS SUPPLY CONDITIONS

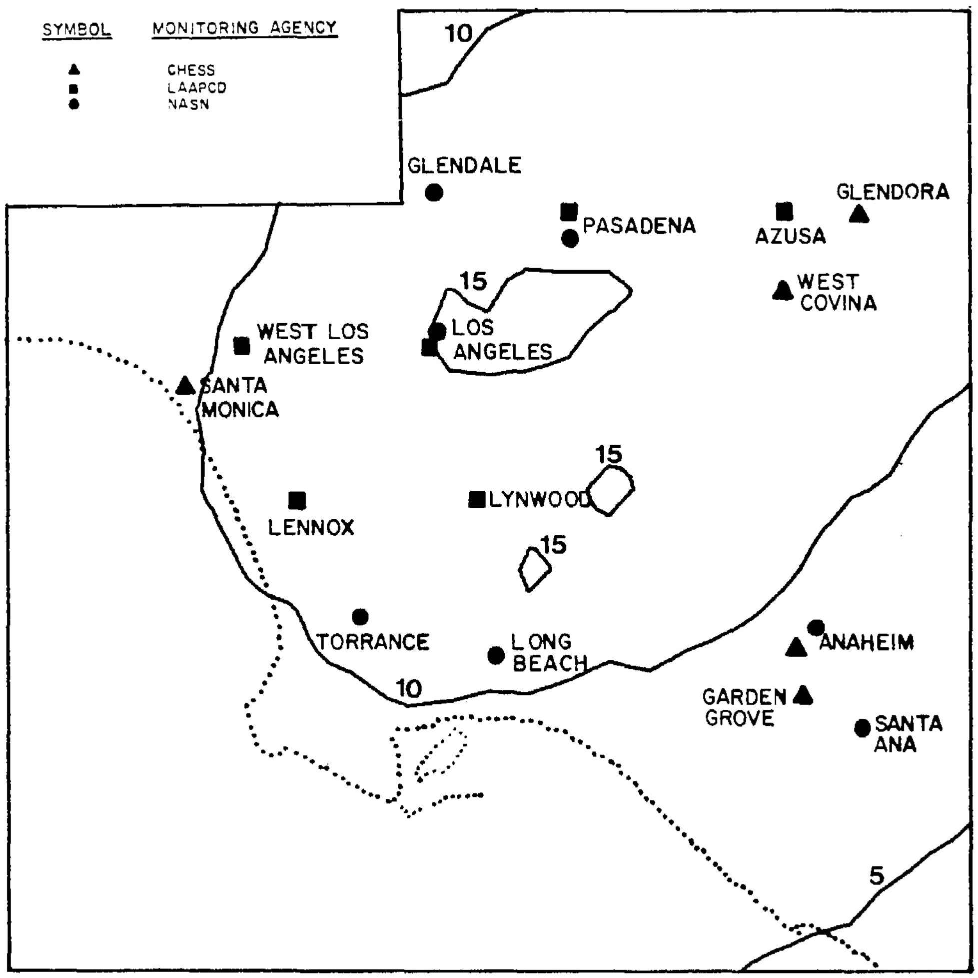


EARLY 1980'S - TEST YEAR 2

Fig. 23

ANNUAL AVERAGE SULFATE CONCENTRATIONS (μGM/M^3)

UNDER LOW NATURAL GAS SUPPLY CONDITIONS

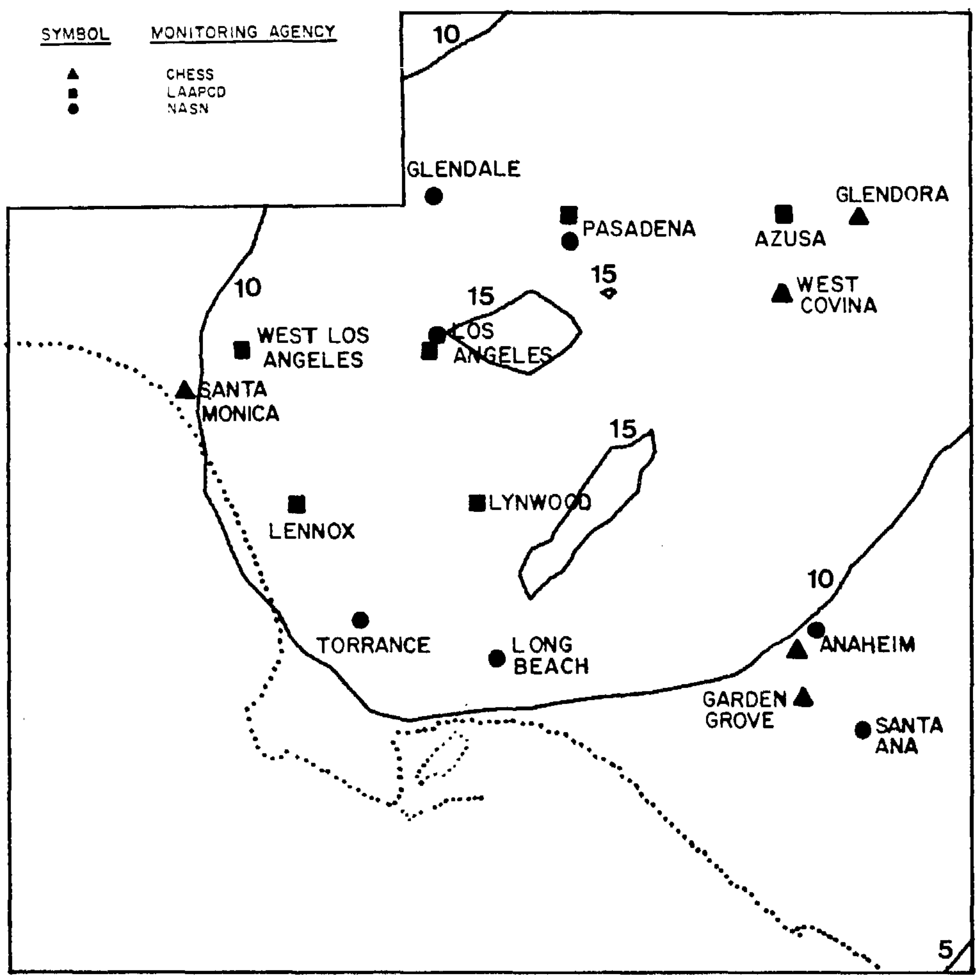


EARLY 1980'S - TEST YEAR 3

Fig. 24

LONG TERM AVERAGE SULFATE CONCENTRATIONS ($\mu GM/M^3$)

UNDER LOW NATURAL GAS SUPPLY CONDITIONS



EARLY 1980'S - COMPOSITE OF THREE TEST YEARS

Fig. 25

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT DOWNTOWN LOS ANGELES (APCD) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS

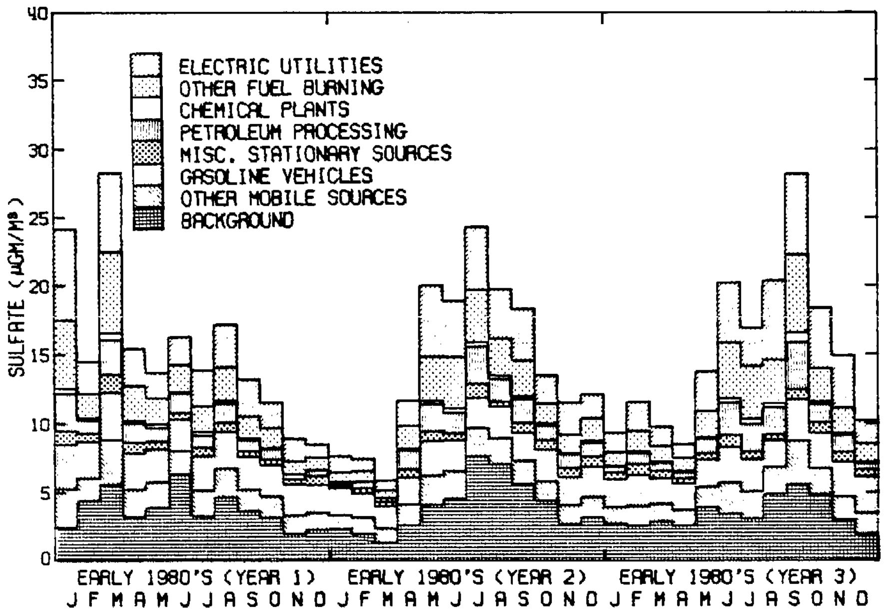


Fig. 26

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT LENNOX (APCD) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS

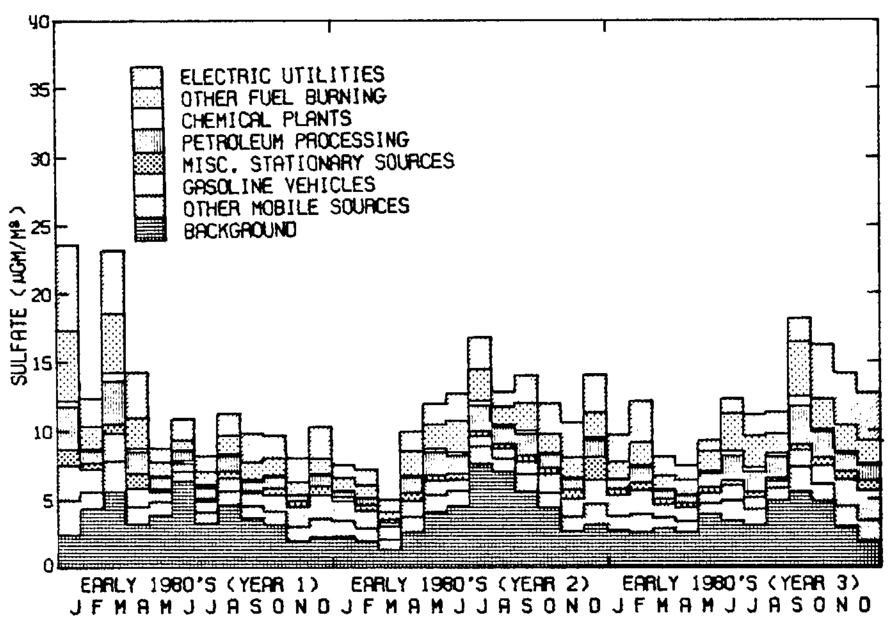


Fig. 27

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT WEST LOS ANGELES (APCD) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS

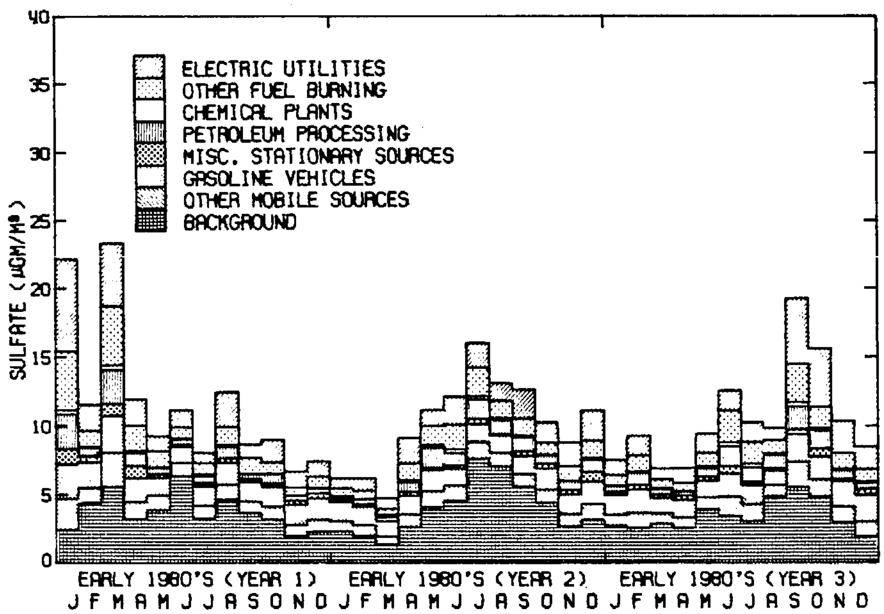


Fig. 28

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT SANTA MONICA (CHESS) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS

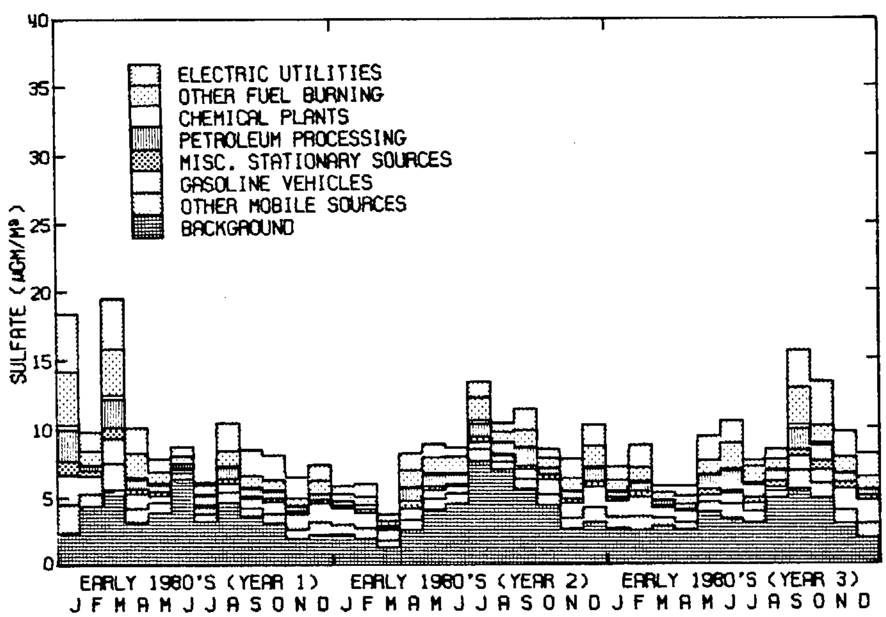


Fig. 29

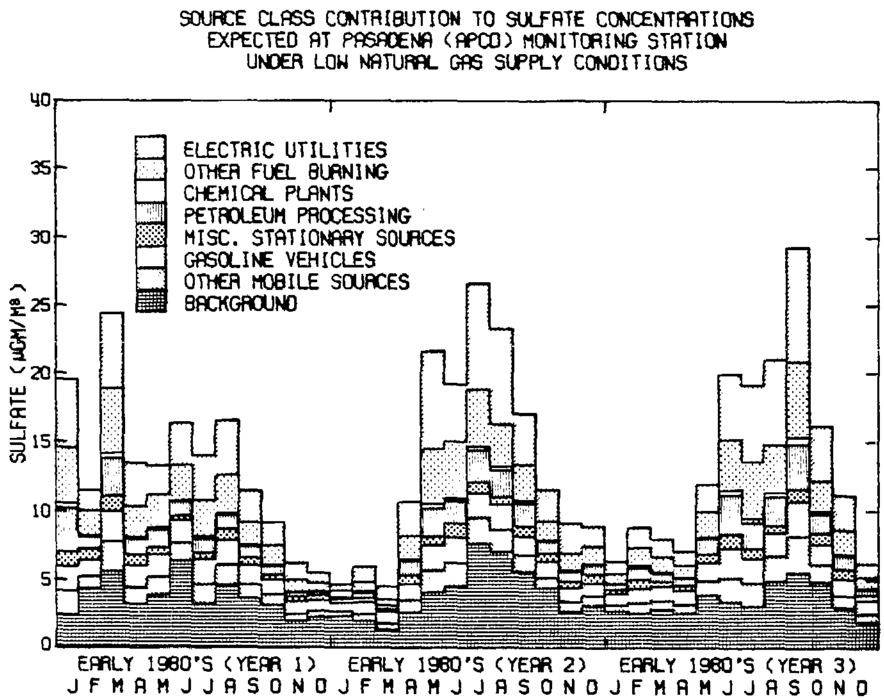

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT PASADENA (APCD) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS
ELECTRIC UTILITIES
OTHER FUEL BURNING
CHEMICAL PLANTS
PETROLEUM PROCESSING
MISC. STATIONARY SOURCES
GASOLINE VEHICLES
OTHER MOBILE SOURCES
BACKGROUND
SULFATE (µGM/M³)
0
5
10
15
20
25
30
35
40
EARLY 1980'S (YEAR 1)
EARLY 1980'S (YEAR 2)
EARLY 1980'S (YEAR 3)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Fig. 30

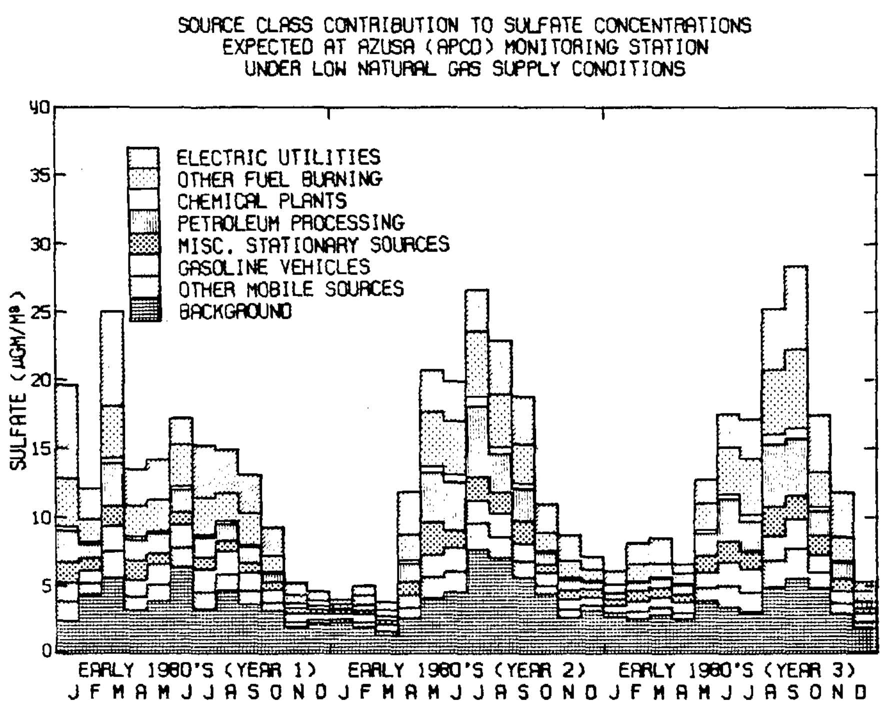

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT AZUSA (APCD) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS
ELECTRIC UTILITIES
OTHER FUEL BURNING
CHEMICAL PLANTS
PETROLEUM PROCESSING
MISC. STATIONARY SOURCES
GASOLINE VEHICLES
OTHER MOBILE SOURCES
BACKGROUND
SULFATE (µGM/M³)
0
5
10
15
20
25
30
35
40
EARLY 1980'S (YEAR 1)
EARLY 1980'S (YEAR 2)
EARLY 1980'S (YEAR 3)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Fig. 31

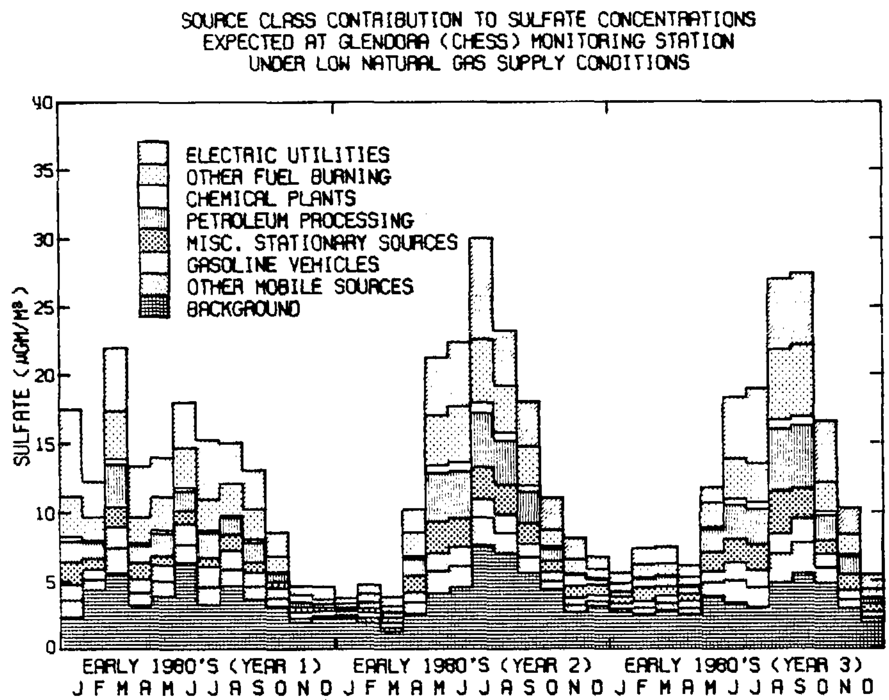

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT GLENDORA (CHESS) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS
ELECTRIC UTILITIES
OTHER FUEL BURNING
CHEMICAL PLANTS
PETROLEUM PROCESSING
MISC. STATIONARY SOURCES
GASOLINE VEHICLES
OTHER MOBILE SOURCES
BACKGROUND
SULFATE (μGM/M³)
0
5
10
15
20
25
30
35
40
EARLY 1980'S (YEAR 1)
EARLY 1980'S (YEAR 2)
EARLY 1980'S (YEAR 3)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Fig. 32

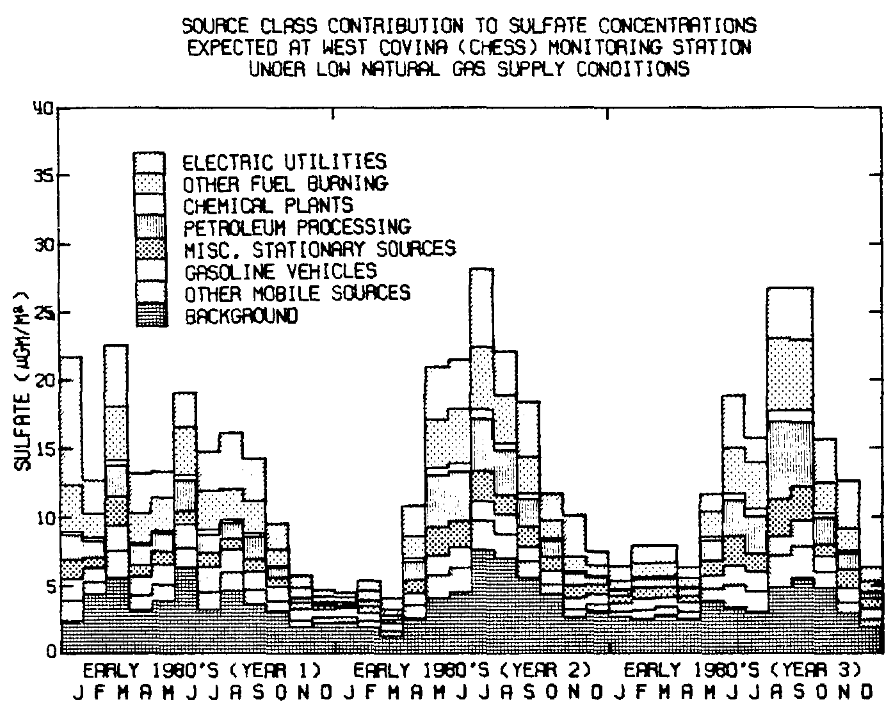

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT WEST COVINA (CHESS) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS
ELECTRIC UTILITIES
OTHER FUEL BURNING
CHEMICAL PLANTS
PETROLEUM PROCESSING
MISC. STATIONARY SOURCES
GASOLINE VEHICLES
OTHER MOBILE SOURCES
BACKGROUND
SULFATE (μGM/M³)
0
5
10
15
20
25
30
35
40
EARLY 1980'S (YEAR 1)
EARLY 1980'S (YEAR 2)
EARLY 1980'S (YEAR 3)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Fig. 33

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT ANAHEIM (CHESS) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS

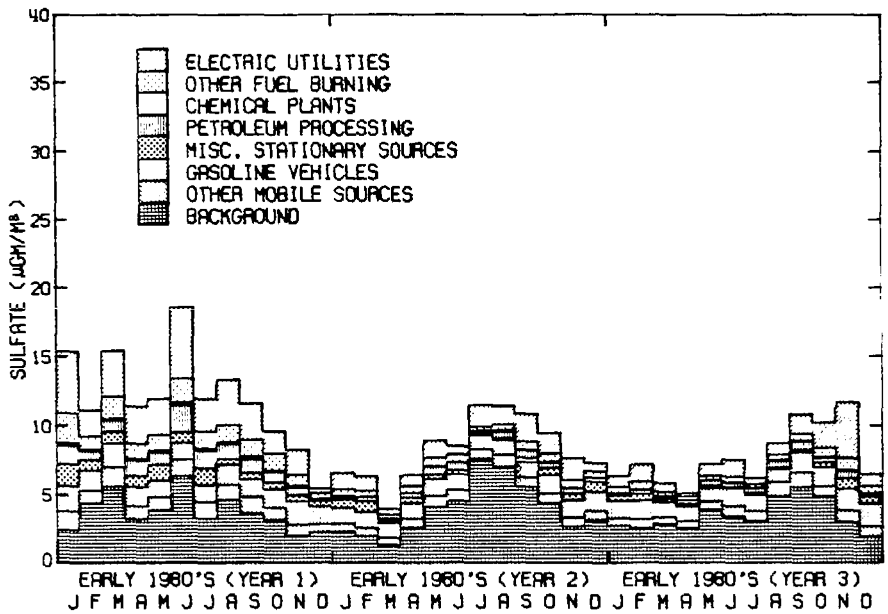


Fig. 34

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT GARDEN GROVE (CHESS) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS

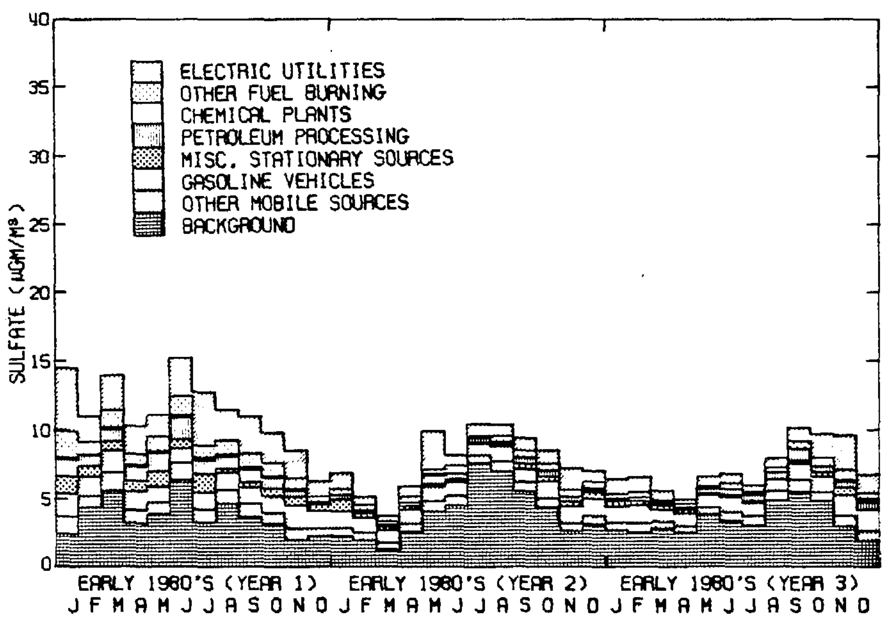


Fig. 35

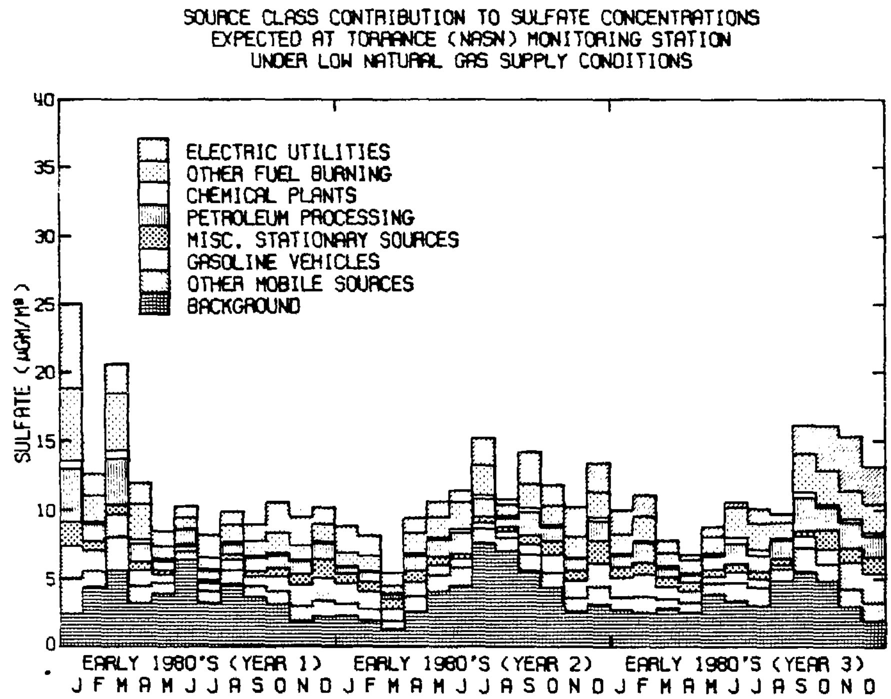

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT TORRANCE (NASN) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS
ELECTRIC UTILITIES
OTHER FUEL BURNING
CHEMICAL PLANTS
PETROLEUM PROCESSING
MISC. STATIONARY SOURCES
GASOLINE VEHICLES
OTHER MOBILE SOURCES
BACKGROUND
SULFATE (μGM/M³)
0
5
10
15
20
25
30
35
40
EARLY 1980'S (YEAR 1) EARLY 1980'S (YEAR 2) EARLY 1980'S (YEAR 3)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Fig. 36

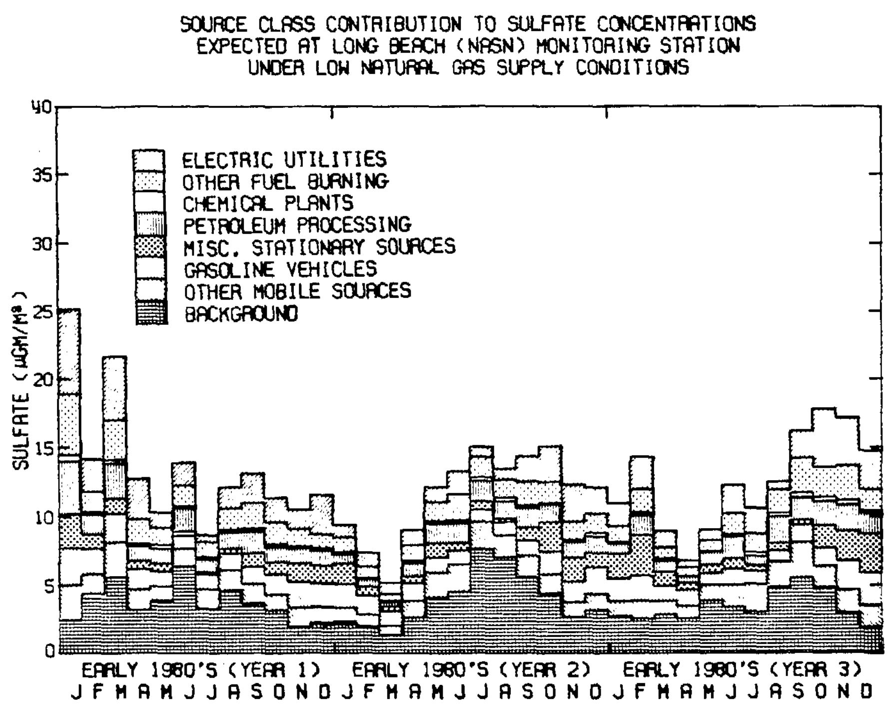

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT LONG BEACH (NASN) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS
ELECTRIC UTILITIES
OTHER FUEL BURNING
CHEMICAL PLANTS
PETROLEUM PROCESSING
MISC. STATIONARY SOURCES
GASOLINE VEHICLES
OTHER MOBILE SOURCES
BACKGROUND
SULFATE (μGM/M³)
0
5
10
15
20
25
30
35
40
EARLY 1980'S (YEAR 1) EARLY 1980'S (YEAR 2) EARLY 1980'S (YEAR 3)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Fig. 37

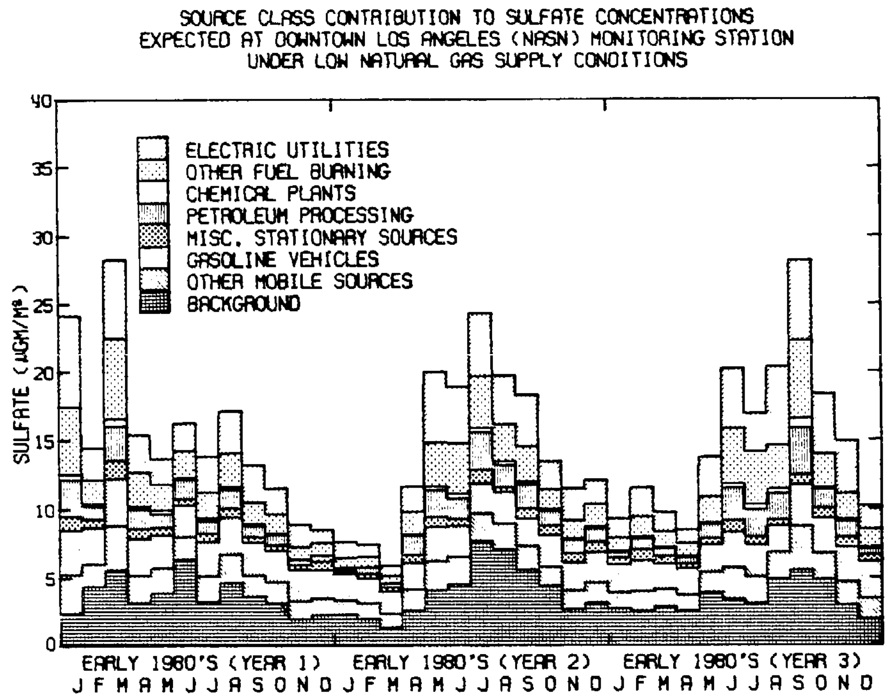

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT DOWNTOWN LOS ANGELES (NASN) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS
ELECTRIC UTILITIES
OTHER FUEL BURNING
CHEMICAL PLANTS
PETROLEUM PROCESSING
MISC. STATIONARY SOURCES
GASOLINE VEHICLES
OTHER MOBILE SOURCES
BACKGROUND
SULFATE (µGM/M³)
0
5
10
15
20
25
30
35
40
EARLY 1980'S (YEAR 1)
EARLY 1980'S (YEAR 2)
EARLY 1980'S (YEAR 3)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Fig. 38

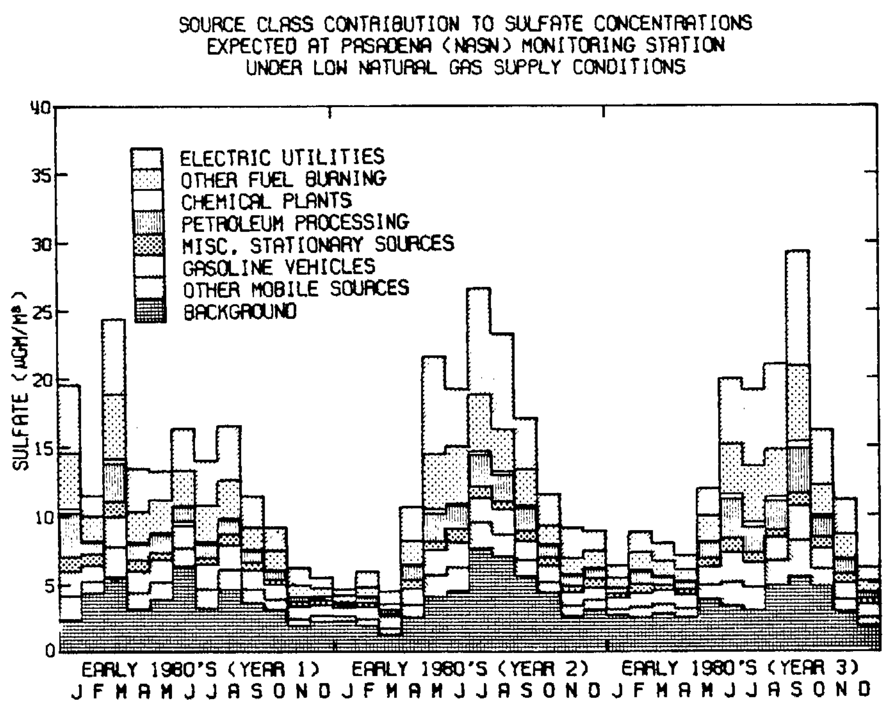

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT PASADENA (NASN) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS
ELECTRIC UTILITIES
OTHER FUEL BURNING
CHEMICAL PLANTS
PETROLEUM PROCESSING
MISC. STATIONARY SOURCES
GASOLINE VEHICLES
OTHER MOBILE SOURCES
BACKGROUND
SULFATE (µGM/M³)
0
5
10
15
20
25
30
35
40
EARLY 1980'S (YEAR 1)
EARLY 1980'S (YEAR 2)
EARLY 1980'S (YEAR 3)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Fig. 39

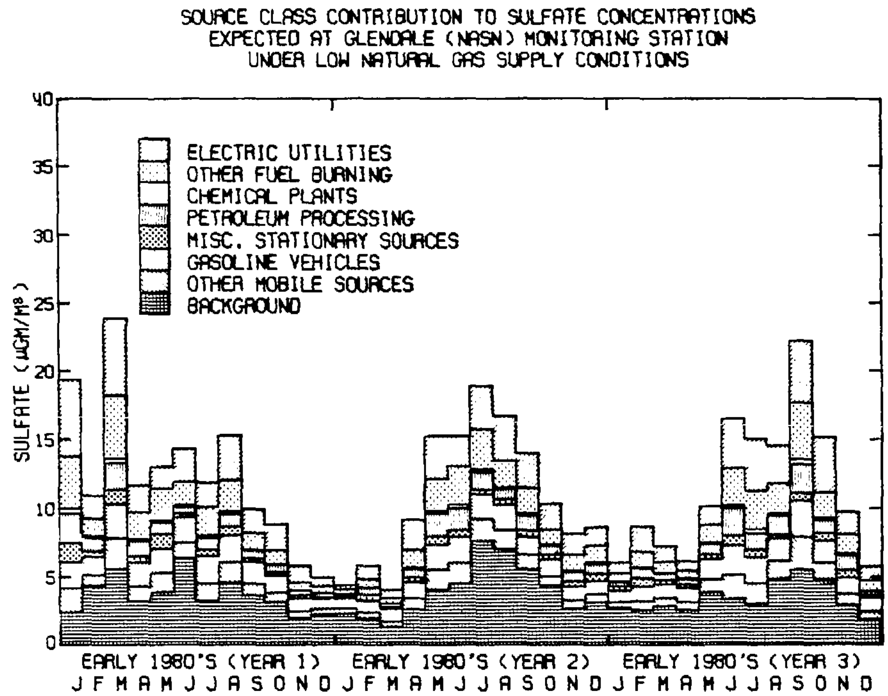

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT GLENDALE (NASN) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS
ELECTRIC UTILITIES
OTHER FUEL BURNING
CHEMICAL PLANTS
PETROLEUM PROCESSING
MISC. STATIONARY SOURCES
GASOLINE VEHICLES
OTHER MOBILE SOURCES
BACKGROUND
SULFATE (µGM/M³)
0
5
10
15
20
25
30
35
40
EARLY 1980'S (YEAR 1)
EARLY 1980'S (YEAR 2)
EARLY 1980'S (YEAR 3)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Fig. 40

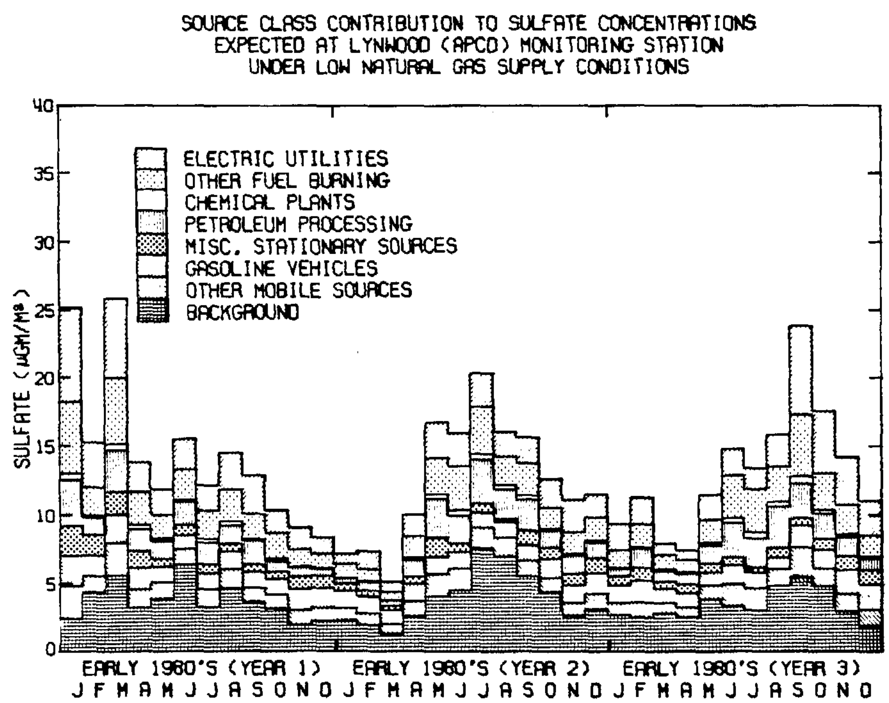

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT LYNWOOD (APCD) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS
ELECTRIC UTILITIES
OTHER FUEL BURNING
CHEMICAL PLANTS
PETROLEUM PROCESSING
MISC. STATIONARY SOURCES
GASOLINE VEHICLES
OTHER MOBILE SOURCES
BACKGROUND
SULFATE (µGM/M³)
0
5
10
15
20
25
30
35
40
EARLY 1980'S (YEAR 1)
EARLY 1980'S (YEAR 2)
EARLY 1980'S (YEAR 3)
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Fig. 41

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT ANAHEIM (NASN) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS

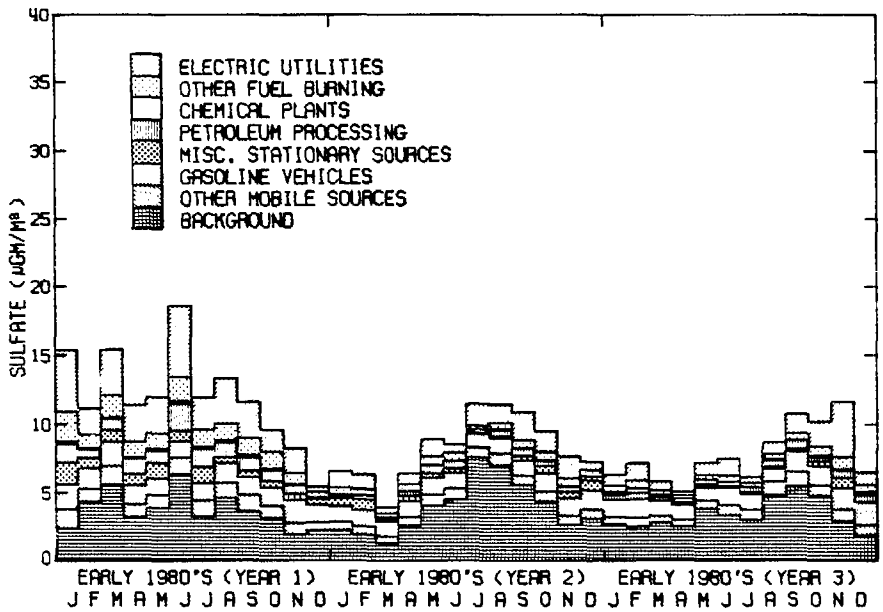


Fig. 42

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT SANTA ANA (NASN) MONITORING STATION
UNDER LOW NATURAL GAS SUPPLY CONDITIONS

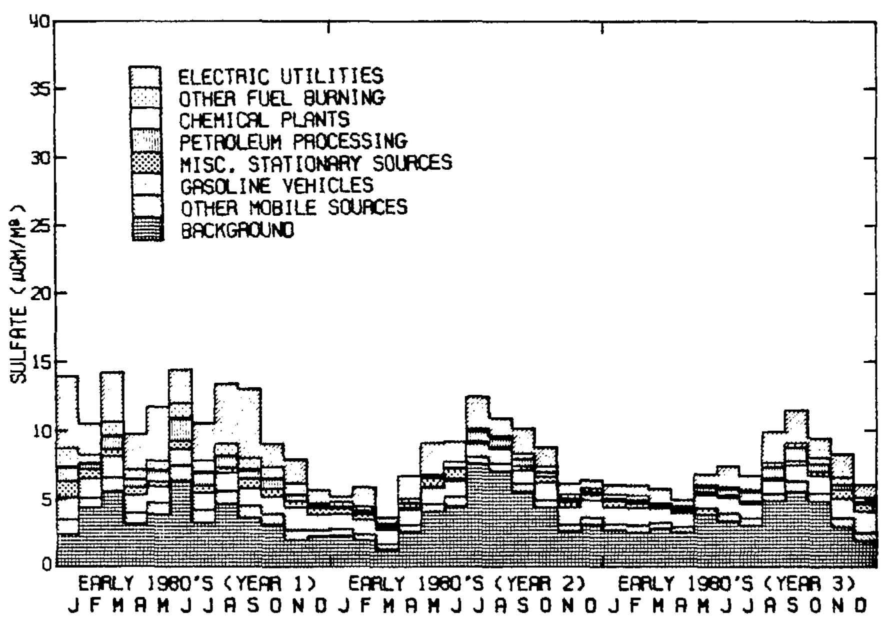


Fig. 43

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT PEAK LOCATED IN EAST LOS ANGELES
UNDER LOW NATURAL GAS SUPPLY CONDITIONS

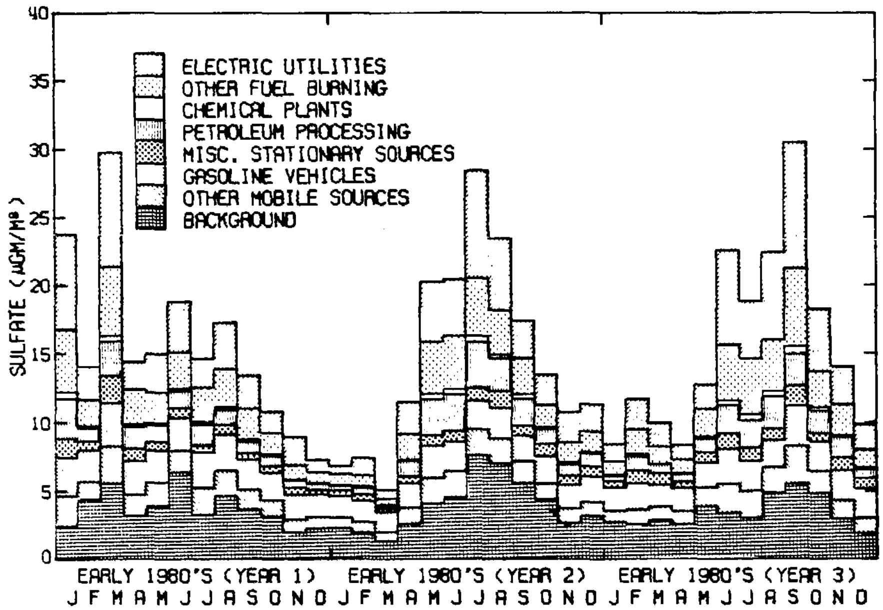


Fig. 44

SOURCE CLASS CONTRIBUTION TO SULFATE CONCENTRATIONS
EXPECTED AT PEAK LOCATED IN SANTA FE SPRINGS
UNDER LOW NATURAL GAS SUPPLY CONDITIONS

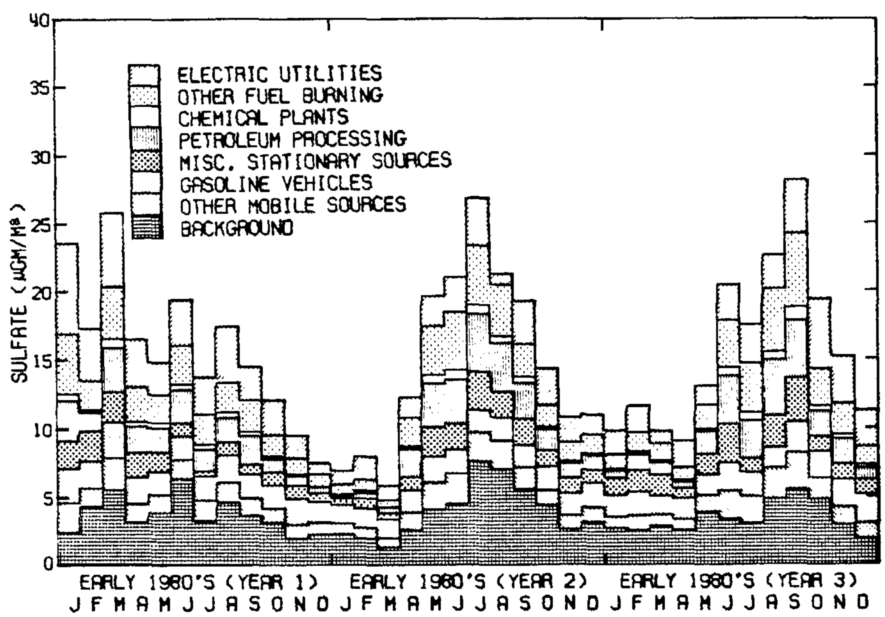


Fig. 45

An example set of these transfer coefficients, computed from the base case air quality projection, is shown in Table 9. A complete set of these normalized air quality impact values is given in Appendix H for 15 air monitoring sites and for the two peak concentration neighborhoods appearing in Figure 25.

A procedure for testing the air quality impact of any particular redistribution of emissions that would occur under a transferable license system is now available. A basin wide limit an emissions can be set at any desired level, in tons of SO_x per day. From the economic analysis of emission control alternatives to be described in subsequent chapters of this report, an estimate of the equilibrium combination of emissions control hardware and licenses to emit pollutants that would be purchased under a marketable permits system can be obtained for each source type. The magnitude of the remaining emissions from each source class when multiplied by the influence coefficients for that source class given in Table 9 and Appendix H yields an estimate of the air quality impact of each source type. Adding all incremental sulfate contributions from all sources to our prior estimate of sulfate background concentrations permits reconstruction of total sulfate concentrations at all monitoring sites for the license distribution under study.

CONCLUSION

The Los Angeles sulfur oxides air pollution problem is interesting for a host of scientific and public policy reasons. The traditional measure of pollution by sulfur oxides is in terms of SO_2 concentrations, which do not exceed Federal standards in this air basin. Meanwhile, the well known Los Angeles visibility problem is being aggravated through light scattering by the decay products of SO_2: sulfate aerosols. These sulfate air pollutant concentrations are unregulated at the Federal level but exceed a state-imposed standard that requires a major reduction in sulfur oxides emissions from existing sources. Attainment of good air quality and a strong economy over time will require that problems which surround the siting of new sources, like the abandoned SOHIO pipeline project, be resolved. Federal energy policies will also affect the attainment of air quality goals, because natural gas curtailments could cause increases in fuel oil combustion that would work against the intended improvements from existing and proposed emission controls.

In addition to the public policy importance of the Los Angeles sulfate problem, there are purely technical considerations which make it an ideal choice for a case study of transferable licenses to emit air pollutants. The emissions potential for sulfur oxides in the South Coast Air Basin has been documented in a way that permits examination of emission control problems under widely varying degrees of natural gas supply. Emissions to air quality relationships for sulfur oxides pollutants have been defined through an air quality simulation model and are relatively easy to manipulate. The major SO_x

TABLE 9

TRANSFER COEFFICIENTS RELATING SO_x EMISSIONS
TO ANNUAL MEAN SULFATE AIR QUALITY AT PASADENA
($\mu g\ m^{-3}$ sulfate/ton per day SO_x emitted)

TEST YEAR	UTILITY RESID.	UTILITY DIST OIL	REFINERY FUEL	OTHER FUEL	SULFUR PLANTS
1	0.01564	0.02345	0.02751	0.03244	0.02633
2	0.01915	0.01648	0.02733	0.02927	0.02458
3	0.01833	0.01597	0.02958	0.03306	0.03249
	SULFURIC ACID	REFINERY FCC UNIT	OTHER REFINERY	OIL FIELDS	COKE KILNS
1	0.02090	0.02501	0.02274	0.01028	0.01725
2	0.02296	0.02417	0.02093	0.00655	0.01544
3	0.02658	0.02932	0.02216	0.00688	0.01588
	GLASS FURNACES	FERROUS METALS	MISC. UNITS	CAT AUTO STREET	CAT AUTO FREEWAY
1	0.05357	0.00314	0.01514	0.04803	0.13577
2	0.04964	0.00288	0.01493	0.03906	0.12949
3	0.06041	0.00247	0.01630	0.04410	0.13992
	NON-CAT VEHICLES	DIESEL VEHICLES	AIRPORT	SHIPPING	RAILROAD
1	0.02576	0.03625	0.02926	0.02054	0.04686
2	0.01860	0.02926	0.02977	0.01999	0.04445
3	0.02212	0.03312	0.03742	0.02292	0.05061

sources in the air basin are few enough to make the problem tractible, but numerous enough to perhaps support a competitive market in emissions licenses. As will be seen in the next chapter, control measures necessary to limit SO_x emissions are available. Thus the remaining question is to choose between control alternatives -- which is exactly the problem that a market in licenses to emit air pollutants will be designed to solve.

FOOTNOTES

1. This problem is distinct from our ability to assess the <u>opportunities</u> for natural gas supply. While we might be able to make rather strong statements about what gas supplies could be made available in future years, we might not be able to forecast what will happen if events are left to unfold along their present course.

2. Not the South Coast Air Basin, but rather all of California south of the Pacific Gas and Electric service area.

3. That is, a 1970 forecast of greater than 1.6 trillion cubic feet delivered in 1979, a 1974 forecast for about 1.0 trillion cubic feet in 1979, and a 1977 forecast for less than 0.7 trillion cubic feet in 1979.

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