INVESTIGATION OF LEAST COST APPROACH TO LONG TERM CONGESTION REDUCTION IN URBAN AREAS

by

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16. Abstract

This report presents results of a research effort that is concerned with developing certain tools that can generate information that may be used by policy makers in deciding the desirability and utility of employing certain high technology options in solving ground transportation and congestion problems. These options include (IVHS), roadway powered electric vehicle systems (RPEV), light rail transit (LRT) and pricing among others. In addition to the primary concern of traffic congestion in urban areas, this tool can be used to advantage in addressing the policy issues surrounding technologies that affect other important concerns such as air quality improvement, petroleum resource conservation and traffic accident prevention.

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EXECUTIVE SUMMARY

This research effort is concerned with developing certain policy guidance tools that can be used to generate information that may be used by policy makers in deciding the desirability and utility of employing certain high technology options in solving ground transportation congestion and other large scale problems. In addition to the primary concern of traffic congestion in urban areas, other important issues that are addressed include:

1. Improvement in the air quality in urban areas.
2. Conservation of petroleum resources.
3. A significant improvement in the national balance of payments because of the large reduction in the requirements for petroleum for internal combustion engines (ICE) for automotive use.
4. A reduction in the current trend towards global warming as the result of the smaller amount of carbon dioxide production by the automotive transportation system that use the advanced technologies.
5. A reduction in automotive operating costs as the result of replacing the ICE power and drive train with electrical systems that have both higher energy conversion efficiencies and more reliable longer life components thus freeing up large sums of money for other more productive uses.
6. An improvement in automotive safety that may reduce the national death toll by thousands of lives annually and reduce the accident rate resulting in property damage and personal injury.

The policy guidance provided by the results of investigations using the methodologies developed by this effort can be of significant value to policy makers in major urban areas

throughout the country. The approach used in this research utilizes very common and widely available tools and software packages. The models are run on new high speed, PC microcomputers with most of the logic generated utilizing spreadsheet and graphics programs. This approach to model development is taken deliberately so the policy guidance package may be readily transferred to commonly available computer systems in other urban areas. The output from these programs is presented in a form that can be quickly understood and compared by knowledgeable, nontechnical professional and lay persons. It is the objective of this research to provide a tool that can show, directly, the effects on important urban and national issues of implementing various types of transportation solutions such as those listed above. One of the difficulties with the way transportation policy decisions are made today is that many are made with less than enough information about the expected effects on the issues that are being addressed. The primary reason for this is that the normal process for generating the required information takes excessively long periods of time, sometimes extending into months or even years. This research effort addresses the end result issues directly in an interactive manner so that "what if" alternatives may be fully explored in a timely manner.[1]

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CHAPTER 1

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INTRODUCTION

The Center for Urban Transportation Studies (CUTS) is presently conducting transportation research under the University Centers Program in conjunction with the Mountain-Plains Consortium (MPC).

The particular research that CUTS is conducting is concerned with the development of certain transportation policy guidance tools that may be particularly useful to nontechnical policy decision makers who have the responsibility of investigating the advantages and effectiveness of certain new technologies that have been proposed for ground transportation. The new technologies that the research addresses offer certain claims that suggest a reduction and management of congestion on urban roadways, improvement in air quality, conservation of petroleum reserves and reduction in petroleum imports, improvement in auto related safety and a general improvement in the quality of ground transportation.

Certain other larger issues are also favorably addressed by these technologies such as the reduction of CO_2 as the result of hydrocarbon combustion in ground transportation vehicles. This can reduce the tendency towards global warming caused by the increased greenhouse effect produced by an increased concentration of CO_2 in the atmosphere. This is especially true if the required electrical energy is generated by nonhydrocarbon sources such as hydroelectric, geothermal, ocean thermal energy conversion (OTEC), wind, solar and nuclear facilities. The national balance of payments could be favorably affected by the reduced requirement for imported petroleum and subsequent effects of acid rain could be curtailed. The results of this research could offer aid in formulating policy in these areas.

The technologies of interest involve the implementation of certain automation and electrification features into the automobile/roadway system. It is obvious that a single research program cannot thoroughly investigate the broad scope of this subject. The research focuses on developing analytical and computer simulation tools that can provide the capability of evaluating various policy considerations and conducting direct comparative analyses of the new proposed transportation systems with the more traditional approaches of building more lanes of roadway, developing additional public transit capacity, and requiring additional improvements in the basic internal combustion engine (ICE). This research specifically looks at long range, capital intensive solutions to major urban problem areas, rather than the easily implementable short range fixes that can be accomplished with limited available funds. This approach is intentionally taken to provide an overall framework for evaluation of what benefits may be expected and what limitations may develop, in the long term, from the necessary incremental approach to ground transportation improvements.

The research concentrates on providing policy guidance capabilities to evaluate various mixes of new technology with the more traditional improvements to the auto/roadway system. The analytical and computer simulation evaluation tools are utilized to develop a series of preliminary results. These initial results are in a form that can be useful to policy decision makers to gain a better understanding of the end results and consequences of the implementation of the various proposed transportation systems, regardless of their complexity. This information can be used to further identify the particular proposals that hold the greatest promise of significant improvement. This initial research effort should result in an understanding, from a gross systems view point, of the various policy issues involved and of the potential that some of the specific technologies and combinations of new and traditional approaches have to make significant contributions to the solutions to the problem areas mentioned above.

The CUTS research program has generated quarterly progress reports as well as this final report. In addition, the results of this research effort have been published and presented at two technical seminars. The overall CUTS research program is anticipated to continue over several years during which additional evaluation work will be accomplished in the areas of local and national policy issues and, on the other end of the spectrum, in the areas of specific component and subsystem configuration research.

There are many overall policy issues to be addressed. How many resources can be applied to find solutions to these problems? What changes are necessary to the existing institutional organizations? What are the national costs and benefits related to reductions in the balance of trade; to increased efficiency of individual time productivity; to maintaining the current level of individual mobility into the foreseeable future; to developing options for urban living patterns; to the reduction of the greenhouse effect; to the reduction of acid rain; to the reduction of health care costs due to air pollution and auto accidents? Obviously the policy list is long.

There is an equally long list of more detailed, component questions to be addressed with proposed transportation solutions. As far as the electrical systems and certain IVHS (intelligent vehicle highway systems) are concerned there are questions concerning the best techniques for distributing electrical energy from the power plant source to the moving vehicles. What kind of onboard energy storage is the best; battery, flywheel, heat, or fuel cell? What kind of each type is the best? What kind of lateral guidance should be used? How much reliability is necessary? What type of vehicle spacing control is best? What type of communication is needed for wayside and vehicle use? What type of control philosophy is best, distributed or centralized? How much of the existing traffic control systems can be used? What is the best type of navigation system and what is its adaptability to future developments? What are the best techniques for control of environmental contaminants from the primary energy producing facilities? Other advanced technology transportation systems, e.g. the use of alternative fuels, small public vehicle fleets, light rail urban integration and various special street use and roadway lanes, have equally long lists of technical hardware and systems issues to be investigated.

This research addresses certain issues which have the potential of alleviating some of the impact on the problems mentioned above. There are, of course, many other controllable local and regional issues which affect the economic well being of the region, such as education, water resources, health facilities, tax incentives, air access and general governmental climate. This research effort is specifically directed towards areas of ground transportation that have a direct impact on the problems mentioned. These proposed investigations do not encompass the full potential of the techniques to mitigate the negative impacts, but rather concentrate on developing the capability of evaluating the technical systems aspects of proposed alternatives for purposes of providing policy guidance. There are many other areas that need to be thoroughly investigated before definitive conclusions can be reached.

This report presents results of a research effort that is concerned with developing certain tools that can generate information that may be used by policy makers in deciding the desirability and utility of employing certain high technology options in solving ground transportation and congestion problems. These options include (IVHS), roadway powered electric vehicle systems (RPEV), light rail transit (LRT) and pricing among others. In addition to the primary concern of traffic congestion in urban areas, this tool can be used to advantage in addressing the policy issues surrounding technologies that affect other important concerns such as air quality improvement, petroleum resource conservation and traffic accident prevention. The policy guidance provided by the results of investigations using the methodologies developed by this research can be of value to policy makers throughout the country in both major urban areas and in rural areas that are experiencing congestion and related problems. The problems of automotive congestion and air pollution are typically persistent and do not lend themselves to solution by conventional means. The costs of inaction steadily mount and the traditional approaches to solutions are generally stop gap, unacceptable or ineffective. Current estimates of the cost of delay on freeways alone in the United States are approximately $10 billion annually and are expected to grow to $50 billion in the next 20 years. Estimates of annual costs to motorists resulting from navigational errors and direction finding problems are presently $45 billion. Additional substantial costs to motorists and the nation result from congestion and inefficient travel on urban arterial and surface streets due to poor signal timing, geometrics, and traffic regulations (Paper given by Lyle Saxton, Chief, Traffic Systems Division, FHWA, San Francisco, July 1989).

This research effort is a direct result of our existing environment. The congestion, pollution, safety and other serious problems facing significant sectors of the country are crying out for sound solutions. The transportation segment of the economy has the potential of providing plausible, economically realistic approaches to some of these solutions. This service delivery system contributes approximately 20 percent to the national GNP and offers employment to one in seven. It is important to understand that being a large and significant sector of the economy, it cannot be changed as a total unit. The changes that are desirable must be made incrementally. The private sector frequently is tied to quarter year profits and cannot adequately plan for the long term. Even so, the public sector must not look to the short term only, but provide a tax base that will extend over many years to make any attempt to modify the system viable.

The transportation service delivery system exists in a multi-objective environment. The objectives consist of: improved safety, increased mobility, shorter trip times, lower cost per passenger mile, reduced air pollutant production, reduced congestion, lower noise levels, increased convenience, reduced carbon dioxide production, reduced petroleum consumption and reduced consumption of other natural resources. As can be readily seen from the above list, many objectives are in direct conflict. The approach to progress in this environment must be to view the system in the context of opportunities and constraints. These multiple objectives must be achieved simultaneously within a given state of system development. The problems occur with the degree to which each objective is achieved at any given time. This condition makes the incremental approach to solutions even more important. The opportunities focus primarily on the possibility of contributing significantly to the very difficult problems facing the transportation industry. Many of the candidate solutions involve advanced technology concepts. The constraint environment in which the system exists involve the lack of effective institutional framework and the lack of sponsors, both public and private. The results of this research can provide the public policy decision makers with better tools with which to make their own evaluations of these proposed advanced technology solutions. In this way they can become better informed and therefore improve the institutional environment that can allow the transportation sector to evolve in an optimal manner maximizing the degree to which the many objectives are achieved and by maximizing the utilization of existing opportunities. The tools developed as a result of this research are designed to be able to assess the effects of various technology decisions on the operating environment directly. The research provides the results of the consequence analysis directly in graphical form in real time that can be readily understood by policy makers. This may be a mechanism that will allow closure to occur in such a multi-objective oriented environment.

The general approach to providing this capability is to calculate the systems and data results for the conditions under investigation and to present them in a weighted overlay format. The excessive capacity of specific parts of the urban area to absorb additional air pollution, or streets to accommodate additional traffic, for instance, can also be readily shown. The system performance and the consequences on the operating environment are calculated in near real time and the results are displayed directly on a CRT or may be printed. The results are presented in graphic form and can be interpreted immediately by policy decision makers as well as technicians.

CHAPTER 2

BACKGROUND

Development of long lead time transportation systems in this country face a formidable range of obstacles. One of the difficulties lie with the frequency that the government elected officials must seek reelection. Some are elected for only four years and some for six. In any event, the time required for development of advanced technologies such as IVHS and electric vehicle systems and the implementation of them into an effective transportation system is much longer than any of these terms. The natural pressure to show tangible results during one's term in office tends to favor the project that can be completed in one to four years. It takes a very unusual individual to promote a project that will not become a reality during that person's term in office; however, the best solution to the pressing problems associated with the existing transportation system require just such foresight.

The conventional thinking approaches to problems such as air pollution usually involve building new transit systems of one kind or another. Unfortunately, transit serves such a small percentage of trips in urban areas that even doubling would not make a significant difference. But, officials under pressure to do something by their constituents often are forced into committing huge sums of money to massive rail projects even though their contribution to the congestion and air pollution problems may be negligible. The primary problem with this approach is not that rail systems are inefficient, but rather that these projects consume too much of the available resources of the community for such small gains. These limited resources need to be placed in a more optimal program that has the potential for solving or at least making significant strides toward the solution of the congestion, safety, effectiveness, air pollution and other problems. In an editorial in the July, 1991 issue of the Transportation Quarterly, pp. 321, 322, Lawrence D. Dahms wrote that;

"The absence of an institutional mechanism capable of managing a metropolitan transportation system critically limits application of IVHS for congestion relief." He further stated in the same editorial that; "In short, the institutional mechanism required to provide a client for the emerging technology does not now exist. This problem does not even seem to have been recognized yet. It must be recognized and addressed soon in order to build the foundation if IVHS is to help provide congestion relief."

Given the institutions as they exist today, our Civil Engineering profession is primarily to blame for the problems of delay. We say, "Trust us, trust us! We will provide you with the best answers to your problems." So the policy decision makers say, "Ok, tell us what is the best solution to our problems of traffic congestion and air pollution." Our response is almost always, "Of course. We will be happy to. It will only cost you one zillion dollars and take two years!" When the policy decision makers are presented finally with the results, they say, "Yes, but what if ---." Our response is usually then, "Of course, we will be happy to address that issue. The answer to that question will take only another umpteen dollars and one more year." These results are like "snap shot" answers and in this context do not give enough feedback. This approach tends to develop advocates and opponents that always make the process more difficult and time consuming. Perhaps a few studies have not taken quite two years and have not cost quite a zillion dollars and perhaps the basic study did address some of the "what ifs", but these are some of the perplexing problems that are facing policy decision makers on a daily basis. During the time of the study process, information is learned, additional data is gathered, new political considerations arise and funds fluctuate. All of these tend to generate new questions concerning study results and there is frequently neither time nor money to obtain the needed answers to all of the "what ifs" that need to be answered if intelligent, informed decisions are to be made by the policy decision makers.

This self-indictment does not mean that these issues are unmanageable. The University of Colorado at Denver has been working hard conducting research into the areas of faster response to "what if" questions that might be posed by policy decision makers. Unfortunately, our current funding runs out at the end of this fiscal year. However, we have achieved major success in developing an analytical tool that has the potential of being a major aid in policy guidance in the field of urban transportation. The policy guidance tool being developed allows the policy decision makers to examine the effects of implementing various kinds of transportation systems, on air pollution, congestion and costs directly, in interactive mode. The results are displayed graphically on a CRT.

The effects of varying various transportation system parameters on carbon monoxide or travel time or capital costs for example, can be viewed directly, in graphic or pictorial form as soon as the system parameters are input into the model. This allows nearly instantaneous responses to the various "what if" questions and provides a method in which the various options can be explored thoroughly by the policy decision makers in a very short time. The various political, physical and environmental consequences of any implementation plan may be explored in real time.

CHAPTER 3

METHODOLOGY

The basic technique used in the analysis procedure is to model the area under study in terms of the transportation facilities in use in 1989 and for the years 1995 and 2010, and to collect the existing and projected air pollution, street and roadway performance, other transportation system performance (if desired) and cost data. These data are operated upon within a spreadsheet module to obtain the specific format of interest as a function of the applicable travel speed. The results of the spreadsheet module are fed into a graphics module to obtain the desired mapping properties. The results of this subroutine are then transferred to a drawing package and the results are displayed upon a CRT or plotted as desired (see Figure 1 for illustration of program architecture).

The base data for current and projected conditions are collected from the agencies that have responsibility for these areas. In the current research program, the metropolitan area of Denver is used. The Denver Regional Council of Governments, DRCOG, the Colorado Department of Transportation, CDOT, the Environmental Protection Agency, EPA, the Department of Public Works, DPW, and the Department of Public Health, DPH, provided the current and projected base data. These data provide a baseline condition for the region of conditions that may be expected to exist now and will exist in the future if no changes are made in the present plan. The program presents these data in graphical form that is readily understandable by policy decision makers even though they may not be fully versed on all the technical aspects of the techniques used. Once the base data are input into the spreadsheet module, they are operated on mathematically to obtain the precise format and levels to be used in the comparative analysis.

A competing system is chosen. This system could be a light rail transit corridor or network, some or all of an IVHS system, perhaps an electric vehicle system, or some alternate fuel system. It could be a new freeway segment or an automated people mover system or a proposed change in CBD parking policy. In any event, a competing or alternate system is picked. The performance and cost characteristics of the competing system are determined, either by directly entering them or by calculating them in an alternate system performance module. These results are then fed into the spreadsheet module for the initial manipulation. From there the results go into the graphics module and into the drawing module for display either on the CRT or to be plotted. It is generally advantageous to display the initial results on the CRT because it can be immediately determined if the desired results are being achieved. Input parameters to the competing system may be varied and the results observed on the CRT within a matter of a few minutes. In this way the "what if" questions may be immediately investigated. The results of the competing system are displayed against a background of existing and projected system and/or specific standards or goals. The differences become obvious and the input parameters to the competing system may be adjusted to achieve the optimal performance.

The basic procedures for obtaining the output graphics have been used for many years. The classic approach of seeking opportunities within the operating constraints in a weighted overlay context is used. The output parameters of both the competing system and the existing/projected system are weighted according to their relative importance. The resulting data are presented then in a superimposed format so that the most important characteristics become the dominant characteristics. In this way, a realistic assessment can be made of the competing systems' performance relative to the existing condition.

CHAPTER 4

STUDY APPROACH

The technologies addressed in the initial analyses are the electrification and the automation of the roadway vehicle system. The models being developed allow a variety of technologies to be addressed if their attributes can be adequately described analytically. For example, a system of hydrogen fueled vehicles also can be analyzed, with the tools developed, to provide the policy guidance required for the technical portion of the decision making process. The model is designed to provide the policy decision makers with a full range of consequence analyses.

There are other groups in the nation, see Appendix B for summary, that are conducting studies, research and development in the areas of automotive electrification and automation. The U.S. Government (DOT) spent $2.3 million in fiscal year 1990 on IVHS research. Funding grew to $20 million in fiscal year 1991. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) established an IVHS program of approximately $660 million over the six year authorization period. Work in the area of automation (IVHS) is also being carried out in Europe and Japan. This major European cooperative initiative into advanced automobile-highway automation is now in its early stages. It involved 19 countries and is estimated to cost $700 million over a seven year period. See a description of the foreign efforts in Appendix B.

The research effort, based at CUTS, has had a close cooperation particularly with the groups in California, where most of the research and development in the fields of highway-vehicle electrification and automation in the United States is being carried out. The other efforts have been primarily emphasizing concept research and hardware development whereas this effort has been organized specifically to develop tools that can be readily used by policy decision makers to form a basis upon which they can evaluate the merits of the advanced technology concepts and systems versus the more conventional solutions to the problems of congestion and air pollution.

CHAPTER 5

RESULTS

The research effort to date has produced an embryonic policy guidance model. Base data concerning street and roadway performance, costs and air pollution for the Denver metro area have been entered into the model. Any or all of that data can be manipulated in the spreadsheet module and passed to the graphics module. The graphics module can generate output in the form of constant value "contours" illustrating the weighted overlay results, or as three dimensional surfaces representing the values of roadway performance, costs or the various components of the air pollution generated. These data can also be passed to the drawing module and illustrated on the CRT or drawn on a plotter. Various values such as maximum allowable values of CO may be shown superimposed and the areas where the value is exceeded are identified. The next step is to superimpose the weighted values of all of the parameters being investigated in an overlay technique and to highlight the areas in the region that have the worst problems. As the values of the design parameters of the alternate mode are varied, the effect on the most severely affected regions of the metro area may be observed. This procedure is accomplished in an interactive mode so that the results of any input modification can be almost immediately learned.

As is frequently the case, as work progressed into the research tasks, it became increasingly more obvious that the goals set at the beginning of the research program were too optimistic and, once again, it has been established that research does not necessarily follow an arbitrarily predetermined schedule. It has taken far more effort to establish the existing and projected conditions in the Denver metropolitan area than was initially allocated. The following is a list of specific results obtained from the research effort to date:

1. The existing and projected congestion, performance, capital cost and air quality data for the Denver metropolitan area have been collected. Illustrative graphical output has been generated on the CRT and on hard copy.

2. Mathematical simulation models of the electrified roadway-vehicle system have been defined and coded in FORTRAN for use with a microcomputer.

3. Preliminary comparison results indicate that the advanced technologies studies can offer significant savings over conventional approaches to solving the congestion and air pollution problems.

CHAPTER 6

DISCUSSION

The general approach to the research effort is to organize the work into two broad areas of activity. One area is set up with a student team, headed by a student group leader and then he reports to the Research Associate, to collect data and characterize the existing and projected conditions of 1989, 1995 and 2020 for metropolitan Denver. The other area is headed directly by the Research Associate and is responsible for establishing the significant attributes and developing the mathematical modeling and coding of the advanced technology systems. This team is also responsible for technical coordination with other research organizations in the nation and world. The program management and coordination function, the financial administration and the overall project organization, direction and review is provided by the Principal Investigator.

Data Collection

The data gathered by the student group are broken into three distinct areas of emphasis: cost, congestion-performance, and pollution. The student group interacted with local political and engineering organizations in obtaining the requisite data.

Several methods of contact are used to correspond to the requirements of the different organizations being solicited for information. These methods include mail, telephone, and personal visits. These organizations respond by either giving the group the needed data or by allowing the group to hand copy the existing unpublished data within their offices. The organizations include: the Colorado Department of Transportation, the Health Department, the Denver Regional Council of Governments, the Environmental Protection Agency and suburban city engineering departments as well as other various state and municipal agencies.

The data collecting process is often painstakingly slow and tedious, requiring many hours of hand copying from unpublished agency files. Sometimes however, it is obtained in the desired form and requires little manipulation. Most of the data collected from the Denver Regional Council of Governments requires hand copying. Since this constitutes the greatest single source of required data, a significant amount of time is spent obtaining this information.

Other collected data was either mailed directly to the group or was picked up by one of the groups' members. Cost and pollution data were obtained primarily from the Health Department, Department of Transportation and the Environmental Protection Agency.

The unprocessed data are entered into data base files with coordinate designations. Each major street intersection coordinate is defined and is tagged with the point attributes. The point attributes are cost, congestion-performance and air quality associated with the particular time period and location. These coordinate designations enable the computer program being used to read the file, and identify the corresponding data appropriate to the points on the map.

The student group leader is responsible for the coordination and supervision of the group's activities. The group leader also functions as a liaison between the group and the faculty members who are associated with the project. Various data collecting tasks, as well as miscellaneous functions, are delegated through the group leader to the different members in the group, but each of the group members is also flexible enough to assist in other areas as needed for a task to be accomplished. The group leader also coordinates efforts with faculty members assisting in the project in setting up the digitizing and cogo functions in the computer. The established Metropolitan Area Road and Highway Map is currently resident in the computer.

The data necessary to analyze the cost for 1989, 1995, and 2020 were supplied by the Denver Regional Council of Governments (DRCOG) and the Colorado Department of Transportation (CDOT). The cost data associated with major and minor arterials as well as expressways and highways were loaded into data files. The cost is divided into capital and maintenance costs. The capital costs relate to the sum of money spent for building, rebuilding, and repair. The maintenance costs are the costs associated with maintenance and services necessary for the operation of the system. The total cost is the sum of both maintenance and capital costs. All costs, including projected costs, are presented in 1989 dollars.

Several capital and maintenance related operations are reviewed and compared for analysis. These range from litter removal to the construction of paved roads. The total cost of these operations is divided by the number of miles and the number of associated lanes. This leaves the costs data in terms of dollars per lane-mile.

The data associated with volume, capacity and congestion is obtained from the DRCOG. These data were collected by the four student group members at least once per week. The volume-capacity data were hand copied from existing DRCOG documents. This long and tedious process of data collecting consumed a significant amount of the student group's total available time. The process of hand copying required that the streets be traced, labeled, and identified. The policy of the DRCOG prohibits any removal of, or mechanical copying of their unpublished material.

It was necessary to process the volume related data by locating, labeling and editing the expressways, highways, major and minor arterials that are used in the development of the other data. Volume-capacity ratios are recorded for each applicable intersection by taking the average of the largest values for both of the intersecting streets. Generally the streets are oriented orthogonally in the east-west and north-south directions. The data are entered into tables that list the intersection, the direction of traffic flow, and the volume-capacity ratio. Maps which reflect present, 1995, and 2010 projections are used to organize the data for transcribing to tables. These tables are then used to make the computer input more convenient.

Average daily traffic (ADT) is also analyzed. It is inputed into the computer system for the three years of interest. All data associated with ADT's were obtained from DRCOG in the form of wall maps.

The air quality data are associated with the four major pollutants: nitrous oxide, carbon monoxide, particulate matter and hydrocarbons. These air quality data are also broken down into the years 1989, 1995 and 2020. There are two categories of air quality data: (1) the New Denver Airport Environmental assessment data and (2) the emission factors gram/mile data. The New Denver Airport Environmental Assessment data includes carbon monoxide and particulate matter projected for 1995 and 2010 (the 2010 data were in turn projected to 2020). These data are represented on a grid projected on a map of the Denver metropolitan area. Concentration levels of pollutants are read from any intersection on the grid. The second category, the emission factors gram/mile, are calculated from empirical sources. A calculation procedure obtained from DRCOG is used to calculate the emission factor gram/mile data. Results derived from this procedure are a function of both volume-capacity and the average travel speed for the intersection. The concentration levels are calculated from the obtained results. The results of the air pollution, both existing and projected are directly stored into another computer file for additional manipulation.

Transportation Systems Evaluations

Several transportation systems have been evaluated with the procedures developed in this research program. The systems evaluated are:

- Light rail transit, initial phase Metro Area Connection (MAC). This system is evaluated at both 50 percent capacity and at 100 percent capacity ridership.
- A fully implemented light rail transit network operating at a ridership of 50 percent capacity and at 100 percent capacity.
- An electric vehicle system that receives electrical energy from the roadway and has unlimited range is evaluated. This system is evaluated at 50 percent and 100 percent of predicted market penetration. The predicted steady state market penetration for this system is about 90 percent of the passenger vehicle fleet trips being made with electric vehicles.
- Certain features of an Intelligent Vehicle Highway System (IVHS) are evaluated. The advantages of automated short headway keeping systems are examined.

Advanced Technology Simulation

Roadway Powered Electric Vehicle Technology. The advanced technologies that are initially analyzed are the roadway powered electric vehicle, RPEV, concept and the Intelligent Vehicle Highway System, IVHS, concept. The optimizing FORTRAN program is used to calculate the vehicle size, power and energy requirements for operation on any specific section of roadway. The program also calculates the size and cost of the roadway electrification portion of the system. The current version of this program module describes the micro problem of the RPEV system, i.e., it calculates the performance, costs and air quality effects for a single vehicle traveling on a specific route. This information is fed into another module that aggregates the results into a macro version according to the predicted travel demand data. This macro version of the simulation is used to generate data similar to and in the same format as the existing and projected data that has collected, analyzed, formatted and loaded into the computer. The results are then directly compared and displayed graphically and/or in a tabular form that is suitable for guidance of policy makers. The results show direct comparisons between the baseline case, which is primarily concerned with conventional solution approaches, and the advanced technology (RPEV) approach as far as cost, performance and change in air quality are concerned.

Vehicle-Highway Automation. Most of the work carried out so far in the area of IVHS has been concerned with data collection. This includes leaning what work is being done in this field in other parts of the country and world and coordinating with these groups. The performance level of current technology in the IVHS area has been described analytically in preliminary form. A projection of capabilities applicable in 1995 and 2020 is made and incorporated into the analytical model. This description will be coded into the RPEV simulation model. The results from this model can be used to conduct a thorough consequence analysis considering cost-effectiveness of the advanced technologies and comparing those values directly to the conventional solution approaches. A summary of some of the work being done in the U.S. in the field of IVHS is presented in Appendix B.

CHAPTER 7

RESULTS OF INITIAL INVESTIGATIONS

Several initial studies of transportation system implementation within the Denver Metropolitan region have been conducted. The results of these investigations are presented in graphical form. The results are shown both in two dimensional representation showing lines of isovalues superimposed upon the Denver Metropolitan area and as a three dimensional "net" draped over the Denver Metropolitan area indicating the higher values of the variable with a higher peak in the net.

Base Line or Null Case

Figure 2 indicates the areas of the study region that normally exceed the Federal limits for CO on a high pollution day in 1989 and represents existing conditions in 1989. The areas along the central east-west belt of Sixth Avenue, especially around the major north-south cross streets and downtown are well above the standards. During these conditions, there also was a prevailing southerly wind that drifted high concentrations to the north and west. Figure 3 indicates the areas of concentrations of CO that exceed the Federal standards for 1995 with no major improvements to the existing transportation system. As can be noted the increased volumes of traffic along the I-25 corridor and the increased activity at the airport begin to show up as significant problems. The downtown and the connection to Boulder also experience high concentrations during high pollution days. The Sixth Avenue beltway still shows up as a major problem area. Figure 4 indicates a general deterioration of the entire metropolitan area by 2010 and nearly all of the area will exceed the Federal standards for CO on a high pollution day.

Figure 5 indicates the areas that exceeded the Federal standards for hydrocarbon concentrations for the base line case in 1989. In this figure, a similar pattern to the CO concentrations is noted. The Sixth Avenue corridor and downtown are problem areas as well as the north-west segment. Again, the problem in the north-west is probably caused by the prevailing winds. Figure 6 indicates the problem areas for hydrocarbons in the year 1995. Increased activity in the vicinity of the airport shows up prominently in the base line case. In Figure 7 it is noted that most of the metro area has concentrations of hydrocarbons that are in excess on the Federal standards on a high pollution day for the base line or null case.

Figure 8 indicates the areas where the concentrations of nitrides of oxygen (NO_x) exceed the Federal standards. The Sixth Avenue belt, the oil refinery areas north of downtown as well as the downtown area show up as problem areas on a high pollution day in 1989. Figure 9 shows large areas that are in excess of the Federal standards for NO_x in 1995. Figure 10 indicates a continuation of the area wide deterioration of conditions with even higher concentrations of NO_x over most of the metropolitan area by 2010.

Figure 11 shows the areas that experience a high concentration of airborne particulate matter for the base line case in 1989. Figure 12 illustrates the concentrations of the airborne particulate matter for the base line case projected to 1995. The airborne particulate matter concentrations for the year 2010 is indicated in Figure 13. In this figure, the additional activity at the new Denver Airport is showing up clearly.

Metro Area Connection Light Rail Project

An analysis was conducted to determine the effects of air pollution on the Metro Area Connection (MAC), Regional Transportation District, light rail project. The conditions investigated are for full implementation of the first phase but only 50 percent of the projected ridership, and for full implementation of the first phase but for 100 percent of the projected ridership. The results of the change from the base line case for the 50 percent ridership were not discernable so the graphical output is not presented here. The results of the change from the base line case for 100 percent projected ridership can be noticed only in tabular form, however the graphical output is presented in Figure 14 for concentrations of CO for the year 1995. As can be seen by comparison with Figure 3, there is almost no difference in the levels or patterns of concentration. Figure 15 shows 100 percent of projected ridership for the MAC light rail system for the year 1995 for concentrations of hydrocarbons. Again the change from the base case is almost nonexistent. Figure 16 indicates the NO_x, and airborne particulate matter for the MAC at 100 percent projected ridership for the year 2010. This case has assumed that no additional expansion of the MAC system occurs which may not be a realistic assumption and rather than assume various levels of LRT development with time, a fully developed system is considered. This fully developed system is similar but not necessarily identical to the Denver Regional Council of Governments fully expanded plan for LRT.

Fully Developed Light Rail Transit Network

The Light Rail network used in this example is a 37 mile system. The conditions examined are those with the total length in place but with a gradual growth in projected ridership. Those of 25 percent, 50 percent, 75 percent and 100 percent projected ridership are evaluated. Figures 22 through 25 indicate the levels of concentration of CO for the year 1995 for 25 percent through 100 percent projected ridership respectively. As can be seen, the levels of concentration of CO greater than the Federal Standards decrease as the ridership increases. However, even at 100 percent projected ridership, there are significant large areas that exceed the standards in the Valley Highway area, the Boulder Turnpike area, downtown, and the refinery areas. Figures 26 through 29 indicate the isolevels for hydrocarbon concentrations that exceed the Federal standards at riderships of 25 percent, 50 percent, 75 percent and 100 percent of the projected ridership for the year 1995. Some improvement in the HC concentrations can be noted as the ridership increases to the 100 percent level. With the Light Rail system fully implemented, there are still many areas in the metro area that exceed the Federal standards on a high pollution day.

Figures 30 through 33 indicate isolevel concentrations of NO_x that exceed the Federal standards for projected riderships of 25 percent, 50 percent, 75 percent and 100 percent of the estimated peak ridership for the year 1995. The fully implemented Light Rail system causes a reduction in the concentration levels that exceed the Federal standards even though there are large areas that still are well above the Federal standards on a high pollution day.

Figures 35 through 37 illustrate the isolevel concentrations of airborne particulate matter for 25 percent, 50 percent, 75 percent and 100 percent projected ridership for the year 1995. As can be noted, there is little if any change in the concentration isolevels for particulate matter as the ridership increases. This indicates that a significant amount of the airborne particulate matter is not a strong function of automobile traffic volumes. Figures 38 through 40 show the isolevels of CO concentrations for the fully implemented Light Rail system for the year 2010. It can be seen that there are wide areas of the Metro area that exceed the Federal Standards by the year 2010. As the ridership on the Light Rail system increases from 25 percent to 100 percent of projected values, the levels of concentrations generally decrease but are still in excess of the Federal Standards in many areas. Figures 41 through 43 show the isolevels of HC for the Light Rail system in the year 2010. As can be seen, the concentrations of HC generally improve as the ridership grows from 25 percent to 75 percent of the projected values but there is still widespread violation of the Federal Standards on the high pollution days. Figures 44 through 47 indicate the isolevels on NO_x concentrations for the fully implemented Light Rail system for the year 2010. As can be seen, the concentrations of NO_x generally are reduced as the ridership increases from 25 percent to 100 percent of projected values. Even at 100 percent projected ridership, the concentration levels of NO_x are in excess of the Federal Standards over most of the Metro area in 2010. Figures 48 through 51 indicate the isolevels of concentrations of airborne particulate matter for the fully implemented Light Rail system for the year 2010. It can be noted that there is little change in the levels of airborne particulate matter as the ridership increases from 25 percent go 100 percent of the projected Light Rail ridership.

Roadway Electric Powered Vehicle Alternative

This alternative is one in which vehicles that utilize the internal combustion engine for propulsion are gradually replaced with vehicles that utilize electric propulsion. The electrical energy is supplied to the vehicles through the roadway with inductive couplers. This allows the streets and highways to be used by other vehicles and pedestrians as well as electric vehicles. This system also allows the electric vehicles to have unlimited range within the operating area of the metropolitan region. The distribution system for the electrical energy also could be provided in the Interstate Highways for intercity travel (see Appendix A for a more detailed description of this alternative). This analysis is concerned only with the Denver Metro area.

Market penetration studies have indicated that the steady state maximum condition for this type of electric vehicle is one where the electric vehicles account for about 90 percent of all trips. The market penetration studies also indicated that this steady state value would require about 20 years or so to achieve depending upon the legislative pressures and economic incentives/disincentives provided. This alternative emphasizes the condition where trips other than transit trips are used. With transit alternatives, a doubling of the usual ridership still results in a system that serves less than 10 percent of the total trips. This system attribute inherently limits the potential gains that can be achieved. By examining a system that can serve up to 90 percent of the potential trips, the other end of the effectiveness spectrum can be observed. Figures 52 through 55 indicate the CO concentration isolevels that are greater than the Federal standard in the year 1995 with the electric vehicle system implemented. As can be seen, there are significant reductions in the concentration levels of CO relative to the Base Line case even at the low level of 25 percent implementation. At the 50 percent level of implementation, there is a single point near the refinery area that still exceeds the Federal standards during a high pollution day. At the 75 percent and 100 percent levels of implementation there is almost no area that exceeds the Federal Standards for CO concentrations, even on a high pollution day. Figures 56 thought 59 indicate the isolevels of concentration for hydrocarbons for the year 1995. At the 25 percent level of implementation, significant gains can be observed relative to the Base Line case. Referring to Figure 56, it can be seen that the major problem area is in the vicinity of the refinery section. At the 100 percent implementation level, the only area that exceeds the Federal Standards is near the refineries. Figures 60 through 63 show the isolevels of NO_x that exceed the Federal Standards on a high pollution day for the year 1995. Figure 60 indicates the isolevels of NO_x for 25 percent implementation of the electric vehicle system. Significant improvements can be noticed relative to the Base Line case even at the 25 percent implementation level. At the full implementation condition, there are no areas that exceed the Federal Standards, even on high pollution days. Figures 64 through 67 show the isolevels of concentrations of airborne particulate matter for the year 1995. There is some improvement in the airborne particulate matter as the system is implemented more fully. Even at 100 percent implementation, there are still significant amounts of airborne particulate matter in the Metro area. This indicates that much of the airborne particulate matter is not a function of the type of energy used for transportation. Much of this material is caused by blowing dust and debris that is injected into the air by vehicle tires.

Figures 68 through 71 show the isolevels of CO that are above the Federal Standards for the year 2010. Figure 68 indicates significant improvement relative to the Base Case for only 25 percent implementation of the electric vehicle case. With 50 percent implementation there is almost no area that exceeds the Federal Standards even on a high pollution day and when there is 100 percent implementation, there is no area that exceeds Federal Standards.

Figures 72 through 75 shows the isolevels of hydrocarbon concentrations that exceed the Federal Standards in the year 2010. Figure 72 indicates those areas that still exceed the Federal Standards on a high pollution Day with a 25 percent implementation level. The downtown areas as well as the new airport area still have problems at the 25 percent implementation level. Figure 75 indicates that at the 100 percent implementation level nearly all areas have excess capacity to absorb additional HC without exceeding existing Federal Standards. Figures 76 through 79 show the isolevels of NO_x concentrations that exceed the Federal Standards in 2010. Figure 76 indicates that there can be significant improvement relative to the Base Line case with a 25 percent implementation level. There are almost no areas that exceed the Federal Standards at the 50 percent implementation level. Figures 80 through 83 show the isolevels of concentrations of airborne particulate matter for the year 2010. It can be seen that there is some improvement in the airborne particulate matter concentrations as the implementation approaches 100 percent. This indicates that solutions other than changing the transportation energy source are required to effectively solve the airborne particulate matter problem.

Weighted Combination Studies

In addition to examining each parameter of evaluation separately as in the above studies, it is possible to examine several parameters simultaneously. These parameters can be weighted relative to their determined importance. For example, if congestion were perceived as much more important than air pollution or costs, the congestion values could be increased by a single factor and another parameter such as airborne particulate matter, which may be perceived as much less important, could be reduced by some other factor. The cumulative results are then combined and presented in graphical format for study and evaluation. Figure 84 shows the results of such a calculation for the case of 2010 NO_x + PM + NS V/C + EW V/C + CO +2(HC). In this example HC is considered to be twice as important as any of the other parameters. Of course, any of the parameters could have been weighted at any value or in any combination. These assumptions are all incorporated into the displayed results so that the troublesome areas can be readily identified and possible solutions formulated. This feature is especially useful in evaluating systems such as transportation systems that exist in multi-objective environments.

In addition, certain other results on the operating environment of the system being examined can be determined. It can be shown just where in the Metropolitan Area there exists, or will exist, regions of low pollution, low congestion or low cost where these parameters could be increased and still be within the Federal Standards. For example, if it became necessary to locate some industry that produced certain emissions of HC, it would be possible to determine which regions would be able to accept the facility, given local terrain and wind conditions, and still remain within the Federal Standards. Other examples could just as readily be analyzed. Perhaps the permissible locations of a trucking terminal or a new freeway segment could be determined in the same way. Figure 85 indicates the amounts of reserve capacity, relative to the Federal Standards, for CO in the year 2010 with a 50 percent implementation of a RPEV system. As can be noted, the highest band level (the widest lines) represents those areas that exceed the Federal Standards on a high pollution day. Clearly, another facility or operation that produced CO would not be desirable in any of those regions.

The next lower band (next thinner lines) represents those regions that have between zero and 10 percent reserve capacity before Federal Standards are exceeded. It would not be desirable to plan locating any additional facilities or operations that produce CO within these regions because Federal Standards may be reduced in the future and some capacity should be reserved for normal growth of existing activities.

The next lower band (next to the most narrow lines) represents areas that have 10 percent to 20 percent reserve capacity of CO. Perhaps it might be possible to locate some CO producing facilities within these regions; however, the most desirable regions are located within the lowest band (thinnest lines) that has an excess of 20 percent capacity of CO. The same type of study could be performed for any other evaluation parameter or combination of parameters.

Other Alternative Systems Considered

In ongoing studies, with the model developed, other alternative solutions to the urban congestion and pollution problems are being examined. Among these are IVHS techniques and pricing. The IVHS areas that are of particular concern are the minimum time route selection systems and the short headway systems. Both of these systems will tend to improve the congestion problem as well as have secondary effects on pollution improvements. The pricing system can be used to control congestion and safety as well as control the peak conditions for the reduction of air pollution. These investigations have not been completed at this time but it is anticipated that the results of these studies will be made available in a later report.

APPENDIX A

Roadway Powered Electric Vehicle Technology

Roadway powered electric vehicle (RPEV) utilize a technique whereby electrical energy is distributed in the roadway for vehicle use. It is distributed via electrical conductors buried beneath the surface of the roadway. The electrical energy is transferred to the road vehicles via an electromagnetic field created by electricity flowing through the conductors. This electromagnetic field density above the roadway is shaped and amplified by field shaping laminations around the conductors. The electrical energy is transferred to the vehicle by a pick-up coil on the bottom of the vehicle that is positioned one to two inches above the roadway surface. The electrical energy transfer is via noncontacting techniques and the electrical conductors can be fully insulated. This makes the system compatible with other common roadway uses such as nonelectric vehicles and pedestrians.

The RPEVs obtain their propulsion and accessory energy from the onboard power conditioner which in turn receives power from the pick-up coil. This energy is used to charge small onboard batteries, or other onboard energy storage devices, in addition to power the propulsion and energy systems. This configuration allows the RPEVs to operate for short distances, perhaps a few miles, away from the roadways that have embedded electrical conductors. This feature allows the system to operate with only the major freeways, expressways and arterials to be electrified.

APPENDIX B

IVHS Technology

A four year program of applied technology research and development on intelligent vehicle highway systems (IVHS) began in 1990 and led to a large demonstration project in Southern California in the mid 90's. This project is still presently underway and its applied technology started with a small electrified roadway project in Los Angeles in the summer of 1989. The program is sponsored by the local power and water districts as well as California's Department of Transportation (Caltrans). The State of California is sponsoring the automation program and provides a controlled access highway facility in the San Diego area (I-15 HOV lanes) to carry out staged experiments leading to a first generation IVHS that can be demonstrated.

U.S. Programs

The California Program on Advanced Technology for the Highway (PATH) was established in 1986 by Caltrans. A portion of the R&D effort in PATH is being carried out by the Institute of Transportation Studies at the University of California in Berkeley. This program is directed specifically to employing RPEV and IVHS technologies to seek solutions to traffic congestion, air pollution, parking and cleaner energy for transportation. The program is being funded by the U.S. Department of Transportation (FHWA and UMTA) and Caltrans.

Other California programs are:

Project	-	Integrated TSM for special events, Anaheim, CA
Pathfinder	-	in-vehicle navigation system, LA, CA

Other IVHS U.S. programs are:

INFORM	-	Route guidance, Long Island, New York
TRANSCOM	-	Automatic toll collection and traffic information, New Jersey and Metro New York

GUIDESTAR	-	ATMS/ATIS congestion reduction and safety improvement, Minnesota Department of Transportation
I-95 Intermodal Mobility Proj.	-	ATMS/ATIS to maximize person through-put, Philadelphia, PA
Urban Congestion Alleviation	-	Video Imaging Detection System, I-95 VA
Integrated System TravTek	-	Route guidance and "yellow pages," Orlando, FL
ADVANCE	-	Navigation system, Chicago, IL
IVHS Operational Field Test Program	-	36-month operational field test of low cost methods of communicating advisor information to motorists, I-94 Corridor, Detroit, MI
FAST-TRAC	-	Route guidance and driver info. system using Ali-Scout, Oakland County, MI
Urban Congestion Alleviation Demonstration	-	Changeable message signs and highway advisory radio, I-95 in Baltimore, MD
HELP/Crescent	-	AVI, AVC and WIM truck identification, classification and weighing program, western part of U.S.
Advantage I-75	-	AVI truck program, FL to Quebec

Some background information on foreign IVHS programs is presented next. The foreign programs seem to be well funded and are well organized.

Europe:

Most of the European IVHS programs are included in the umbrella EUREKA program. EUREKA is a $5 billion, 19 country program to stimulate cooperative research and development between industries and governments in Europe with the goal of improving European industrial competitiveness. PROMETHEUS is a major IVHS program under EUREKA, but in addition there are also the following European active research programs:

EUROPOLIS - a $150 million, seven year research project to design automated road systems for the next century and develop technologies to automate the driver functions;

CARMINAT - a four year research project to develop in-vehicle electronic navigation and communications systems;

ATIS - an $8.5 million, five year project with the objective of providing pre-trip information on road traffic conditions to tourists; and

ERTIS - a $2.7 million, three year project to develop a common road information and communications system for motor carriers across Europe.

Two IVHS programs not associated with EUREKA are ALI-SCOUT and AUTOGUIDE:

ALI-SCOUT - a route guidance system developed in Germany by Bosch/Blaupunkt and Siemens. This system uses infra-red transmitters and receivers to transfer navigation information between roadside beacons and on-board displays in appropriately equipped vehicles. Earlier versions of the ALI system were tested along a 60-mile stretch of the German autobahn in the North Rhine-Westphalia region. The more advanced ALI-SCOUT system was tested in Munich, and, most recently, in Berlin.

AUTOGUIDE - another route guidance system developed in England also using infra-red transmitters and receivers. Currently, a pilot test is underway in the Westminster section of London and in a corridor between London and Heathrow Airport; it is anticipated that roadside beacons will cover the entire London area and then the entire country by the early 1990s.

PROMETHEUS

The most important European IVHS program is PROMETHEUS, which stands for PROgraMme for European Traffic with Highest Efficiency and Unprecedented Safety. It is a large scale research project within the larger EUREKA program. PROMETHEUS is principally a traffic system incorporating IVHS technology. A consortium of European automobile companies, suppliers, electronic firms, and university research institutes has been formed to carry out the objectives of this program.

The goal of the PROMETHEUS research effort is to design "intelligent vehicles" and electronic traffic flow detectors that improve communications between drivers and provide automatic crash avoidance. The general objectives of the PROMETHEUS programs are to improve traffic safety, efficiency, and convenience, and to reduce environmental effects of automobile travel, such as air pollution. Safety is a key element of this project, and a specific goal has been targeted to reduce European traffic casualties 50 percent by the year 2000.

A major economic objective of PROMETHEUS is to improve European competitiveness in the world automotive electronics industry. The goal has been established of achieving dominance in this industry by European firms within the next decade. For these competitive reasons, non-European firms have been strictly prohibited from participating in this program (an exception is Opel, a General Motors European Division, but there are some restrictions placed upon Opel participation).

PROMETHEUS began in 1986 and is a seven-year, $800 million program. Program objectives are formulated by a 11-member steering committee consisting exclusively of vehicle company representatives. The various European governments relate to the PROMETHEUS steering committee through the PROMETHEUS Council, consisting of government representatives. The steering committee defines the programs of basic and industrial research. The various governments help coordinate the basic research activities along with the research community. PROMETHEUS will support the development work up to the point where the companies involved decide upon the appropriate technology. The various private companies are thus free to launch new products on the market in competition with each other.

PROMETHEUS is conceived as a European-wide traffic management and control system using three major levels of information transfer of communication.

1. Intelligent driver aids on board the vehicle, assisting the driver by providing backup control;
2. Communication networks between vehicles; and
3. Communication and information systems interlinking vehicles and roadside facilities.

Japanese Programs:

Japan has two major IVHS programs:

1. AMTICS—Advanced Mobile Traffic Information and Communication System
2. RACS—Road-Automotive Communication System

Both of these programs emphasize communications and traffic control and are intended to contribute to improvements in Japanese traffic congestion. Traffic congestion in Japan is considerably more severe than in the United States which increases their priority for developing technologies that will lead to some alleviation of this problem. Japan also has given technological innovation in the automotive industry a high priority in order to maintain their major role in the world automobile industry. Unlike the European PROMETHEUS project, the Japanese have expressed interest in sharing information and having cooperative research.

AMTICS - is a relatively sophisticated traffic control system sponsored by National Policy Agency, the Ministry of Posts and Telecommunications, the Japan Traffic Management and Technology Association, and 59 private companies. AMTICS transmits traffic congestion information from a traffic control center to an in-vehicle navigation system. The information shown on a display within the vehicle uses the telecommunication terminal system planned by the Ministry of Posts and Telecommunication Services. The AMTICS system has static information and dynamic information. The static information component uses in-vehicle compact disc systems (CD-ROM) and in-vehicle video display terminals to display road maps, local traffic regulations, the location of parking lots, hospitals, gas stations, tourist information, etc. The dynamic component will use roadside beacons to provide real-time information on traffic conditions, temporary events that might affect traffic conditions, weather and accident warnings, parking space availability, and the like.

The basic design of this system was completed, and production of the pilot units began in October 1987. Pilot experiments were started in April 1988, in central Tokyo. Twelve companies developed pilot systems engineered to basic functional specifications. Each of these companies is carrying out production activities. The pilot experiments, which used 11 passenger cars and a bus, were completed in June 1988. During this experiment, various types of basic data were collected to develop design specifications for subsequent implementation. At this time, the network for traffic data acquisition has been completed on a large scale.

RACS - is the Road-Automotive Communication System (RACS). This is a parallel research underway using a different communication technology. This program is sponsored by the Public Works Institute of the Ministry of Construction, the Highway Industry Development Organization, and 25 private companies.

RACS is composed of roadside communication units (beacons), car units, and system center. The system is designed for collection and provision of information through communication between the beacon and the car unit. It provides information concerning navigation, roadside information and messages directly.

The navigation methodology uses autonomous dead reckoning by means of the car unit only. However, the dead reckoning navigation accumulates positional error. In this system, this positional error will be corrected with the positional data received from the roadside beacons.

The roadside information beacons are connected to an information center to update dynamic information such as correct road traffic information and current parking space information. The car unit receives this data and provides appropriate information to drivers. Further, in combination with the on-board navigation system, the roadside communication beacons allow the exchange of information between the systems center and individual automobiles. This allows individual car locations to be monitored as well as the collection of detailed road traffic data and the distribution of information.

APPENDIX C

Selected Bibliography

1. "A Method of Utilizing Possible Alternative Energy Sources in Ground Transportation," William R. Hamilton, P.E., University of Colorado Ph.D. thesis, 1987.

2. "Santa Barbara Electric Vehicle Project," Ross, H.R., Hamilton, W.R., Santa Barbara Metropolitan Transit District, Santa Barbara, CA, and Howard Ross Associates, Palo Alto, CA, 1981.

3. "Characterization of the Dynamic Roadway Powered Electric Vehicle System," Salisbury, J.D., Mullinhoff, D., Walter, C.E., Lawrence Livermore Laboratory, Livermore, CA, 1981.

4. "Projected Electrical Characteristics of the Cynamic RPEV System," Salisbury, J.D., Walter, C.E., Lawrence Livermore Laboratory, Livermore, CA, 1981.

5. "Highway Electrification and Automation, Planning Implications For Southern California," Southern California Association of Governments, Los Angeles, CA, 1984.

6. "Management of Public Works," Sam M. Chistofano, Editor, International City Management Association, 1986, ISBN 0-87326-048-1.

7. "Standard Specifications for Road and Bridge Construction," State Department of Highways, State of Colorado, Denver, CO, 1986.

8. "Principles of Highway Engineering and Traffic Analysis," Fred C. Manning and Walter P. Kilcreski, John Wiley and Sons, 1990, ISBN 0-471-63532-4.

9. "Light Rail Transit: Planning and Technology Special Report," National Academy of Sciences, Transportation Research Board, Washington, D.C., 1988, ISBN 0-309-026802-7.

10. "Urban Transportation Modeling and Planning," Peter R. Stopher and Arnim H. Meyburg, D.C. Heath and Company, 1975, ISBN 0-669-969451-9.

11. "The 1987-1988 Metro Denver Brown Cloud Study Final Report," DRI Document No. 8810, Vol. I, II, and III, Metro Denver Brown Cloud Study Inc., Denver, CO, 1989.

12. "Airshed Modeling of Denver for Carbon Monoxide: A Comprehensive Overview," Colorado Department of Health, Air Pollution Control Division, Technical Services Program, Denver, CO, February 1986.

13. "Emissions Impact of Roadway-Powered Electric Buses, Light Duty Vehicles and Automobiles," Mark Miller, Victor Dato and T. Chira-Chavala, Program on Advanced Technology for the Highway (P.A.T.H.), Institute for Transportation Studies, University of California at Berkeley, Richmond, CA, January 1992.

14. "Colorado Air Quality Report," Colorado Department of Health, Air Pollution Control Division, Technical Service Program, Denver, CO, 1987.

15. "Report to the Public 1989," Colorado Department of Health, Air Quality Control Commission, Air Pollution Control Division, Denver, CO, 1990.

16. "National Transportation Strategic Planning Study," U.S. Department of Transportation, U.S. Government Printing Office, 1990, 717-000/27045, Washington, D.C., March 1990.

17. "Air Pollution-Transportation Linkage: How Vehicle Travel on Our Roads and Highways Affects the Air We Breathe," Pam Burmich, State of California Air Resources Board, Sacramento, CA, 1992.

18. "Transportation Improvement Program 1989-1993," Five Year Fiscal Program of Highway and Transit Projects, Denver Regional Council of Governments, Denver, CO, January 1989.

19. "Annual Report to the General Assembly of the State of Colorado on Vehicle Emissions Inspection and Maintenance Programs," Colorado Department of Health, Air Quality Control Commission, Air Pollution Control Division, Mobile Sources Program, Denver, CO, December 1990.

20. "Mobility," Denver Regional Council of governments," Denver, CO, December 1989.

21. "Trip Generation: Different Rates for Different Densities," Panos D. Preedourous, University of Hawaii at Manoa, Department of Civil Engineering, Submitted at the 71st Annual Meeting of the Transportation Research Board, Washington, D.C., November 30, 1991.

22. "National Cooperative Highway Research Program Summary of Progress," Transportation Research Board, National Research Council, Washington, D.C., December 31, 1991.

23. "Data for Decisions, Requirements for National Transportation Policy Making," Special Report 234, Transportation Research Board, National Research Council, Washington, D.C., 1992.

Agency Information Sources

Denver Regional Council of Governments
Department of Planning
2480 W. 26th Ave.
Suite 200-B
Denver, CO 80211

Colorado Department of Transportation
Division of Transportation Development
Division of Environmental Analysis
Division of Road Construction
Division of Road Maintenance
Division of State Traffic Volume
Division of Transit Planning
Division of Transportation Development
Division of Traffic Engineering Studies
4201 E. Arkansas Ave.
Denver, CO 80222

Colorado Department of Health
Air Pollution Control Division
4210 E. 11th Ave.
Denver, CO 80220

Regional Transportation District
Light Rail Transit Construction Department
1600 Blake St.
Denver, CO 80202

City and County of Denver
Department of Health and Hospitals
Air Quality/Environmental Protection Division
605 Bannock St.
Denver, CO 80204

Environmental Protection Agency
Certification Division
2565 Plymouth Road
Ann Arbor, MI 48105

Environmental Protection Agency
Air and Toxic Division
Air Programs Branch
999 18th St.
Denver, CO 80204

United States Department of Transportation

Urban Mass Transportation Administration
555 Zang St.
Lakewood, CO 80226

Colorado Department of Motor Vehicles
Data Services
Emissions (Air) Program
Motor Vehicle Administration
140 W. 6th Ave.
Denver, CO 80204

Colorado Air Pollution Control Division
Ptarmigan Place
3773 Cherry Creek North Dr.
Denver, CO 80206

The City of Arvada Traffic and Transportation Department
8001 Ralston Rd.
Arvada, CO 80004

Colorado Department of Revenue
General Tax Information Department
Mileage and Fuel Taxes
1375 Sherman St.
Denver, CO 80204

Metro Denver Brown Cloud Study Inc.
General Information Division
1600 Sherman St.
Denver, CO 80203

APPENDIX D

FIGURES

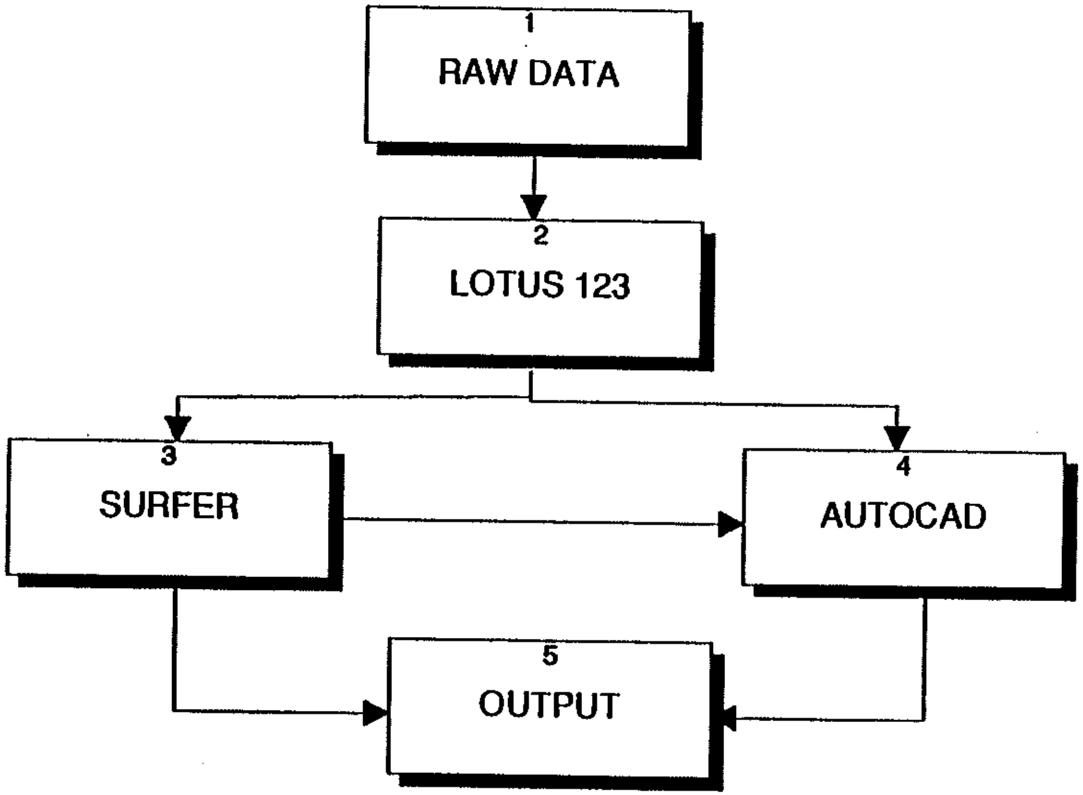
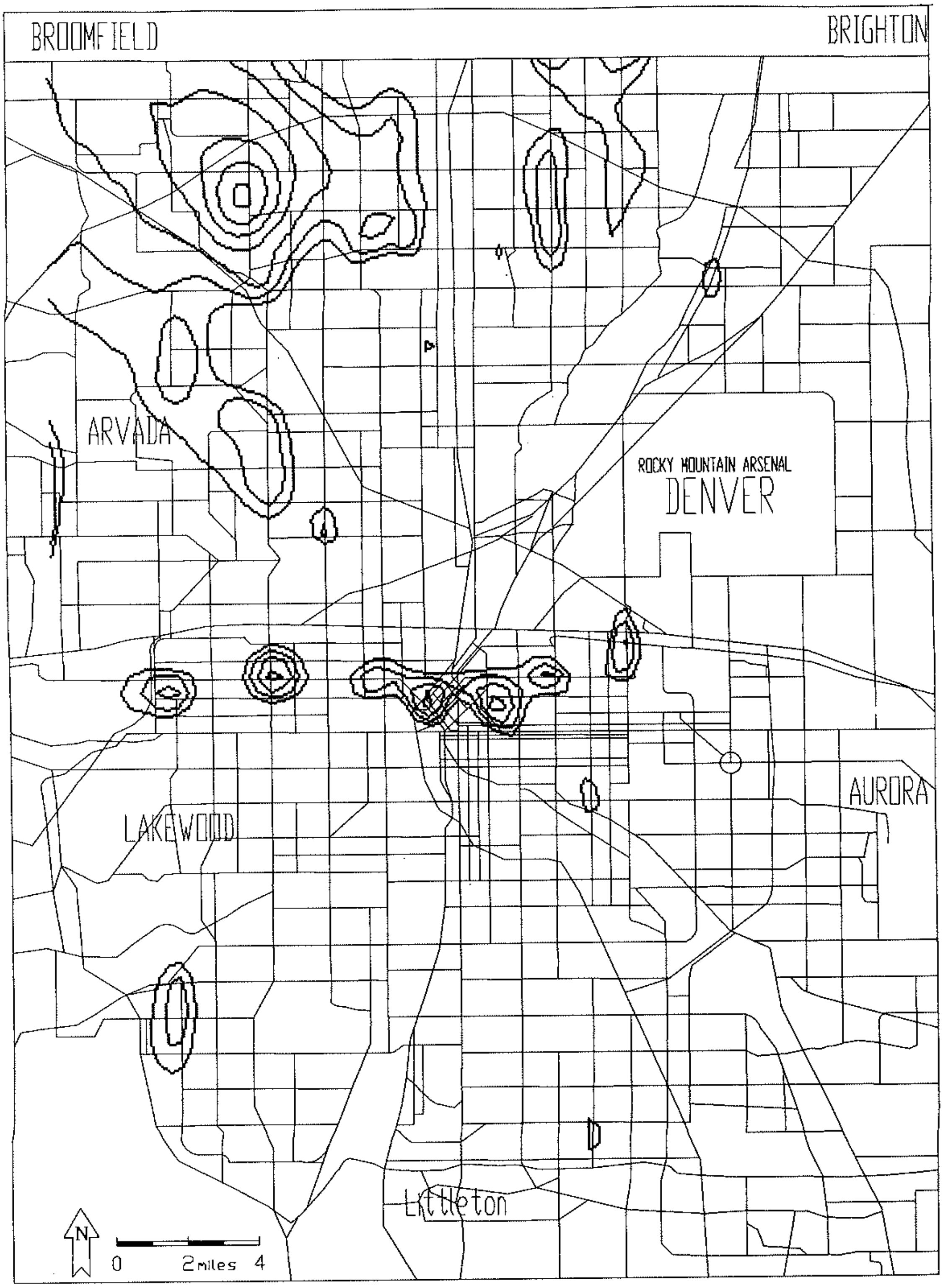
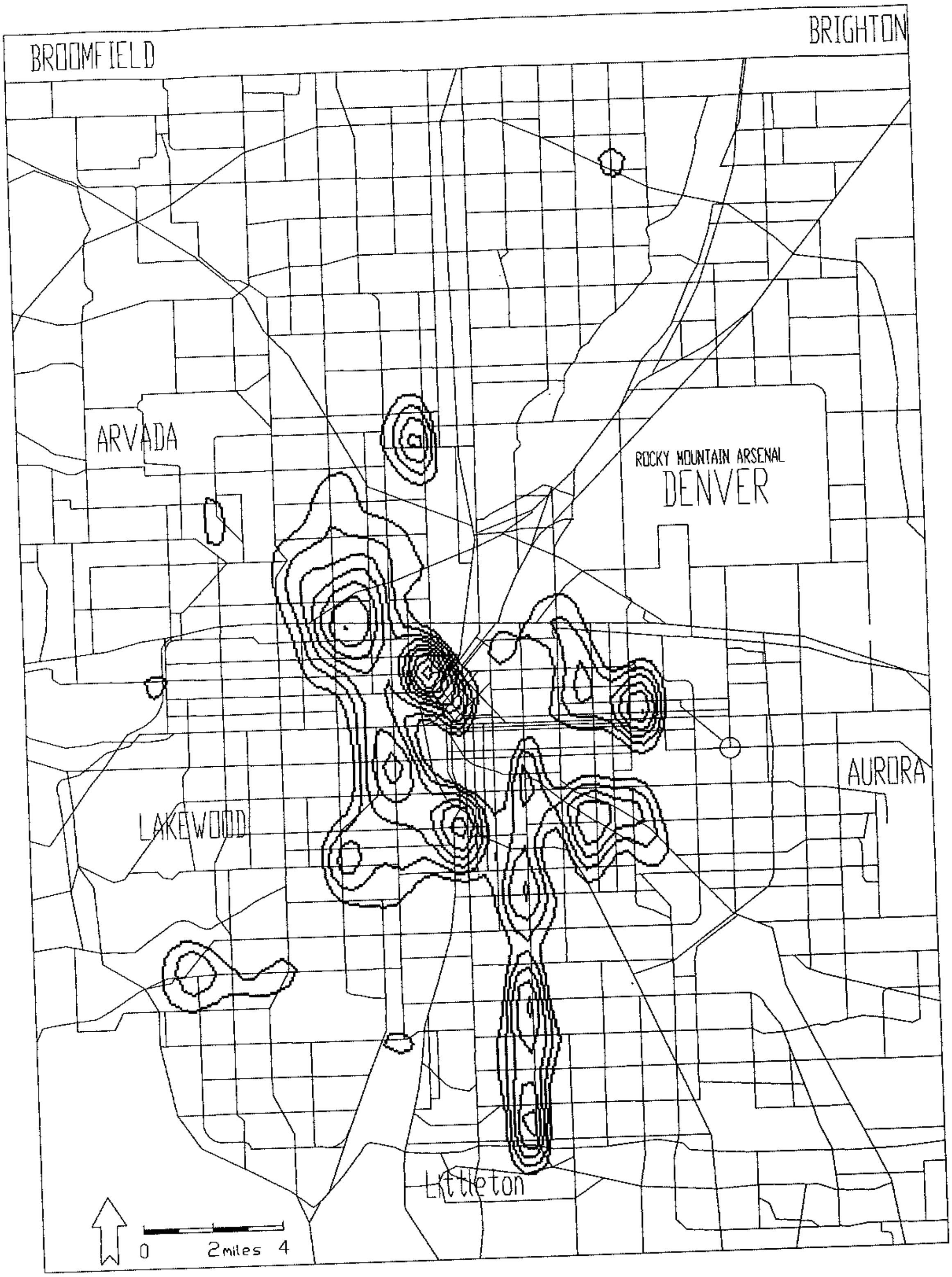


FIGURE 1 PROGRAM ARCHITECTURE



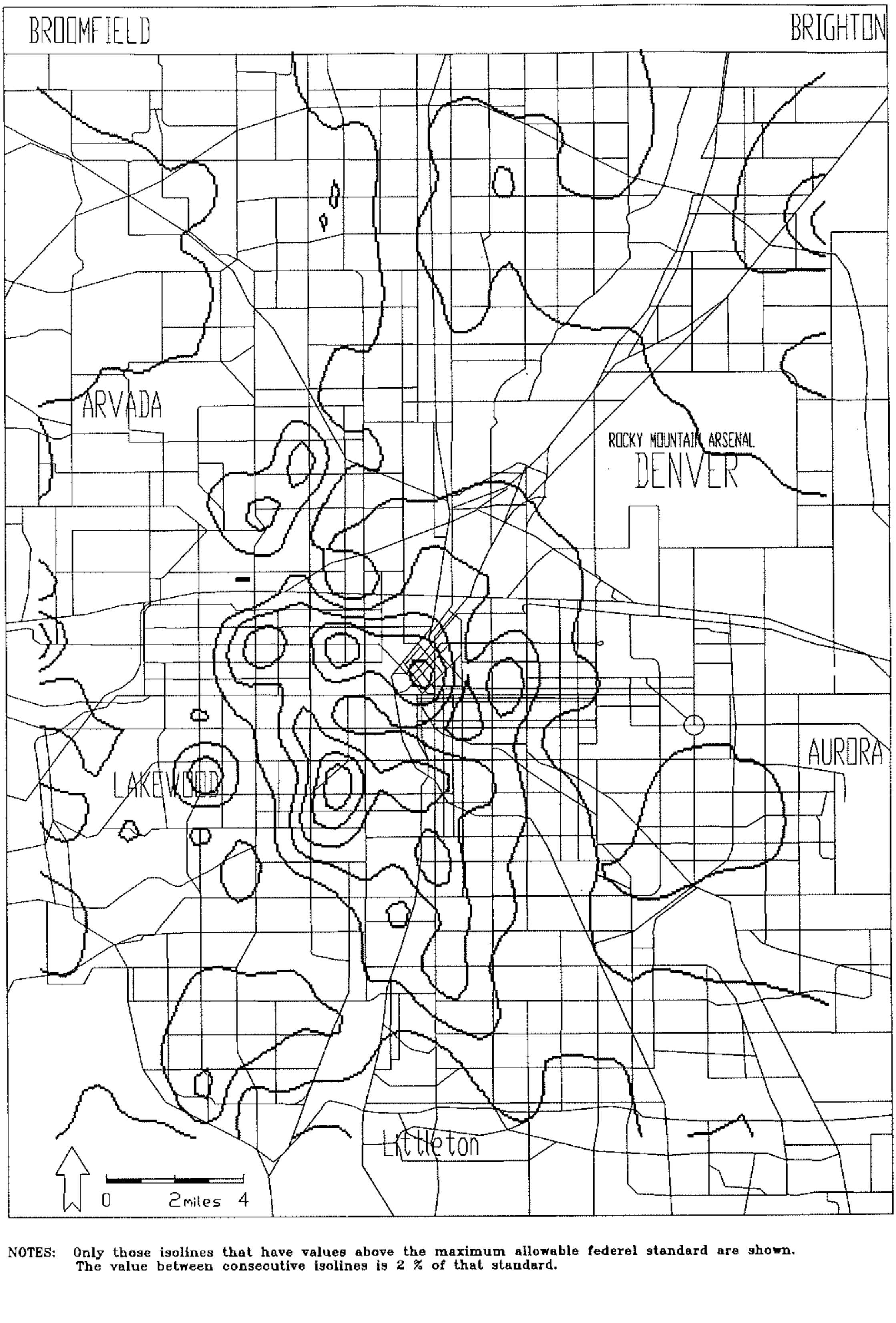
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

Figure 2. Baseline Case 1989 CO



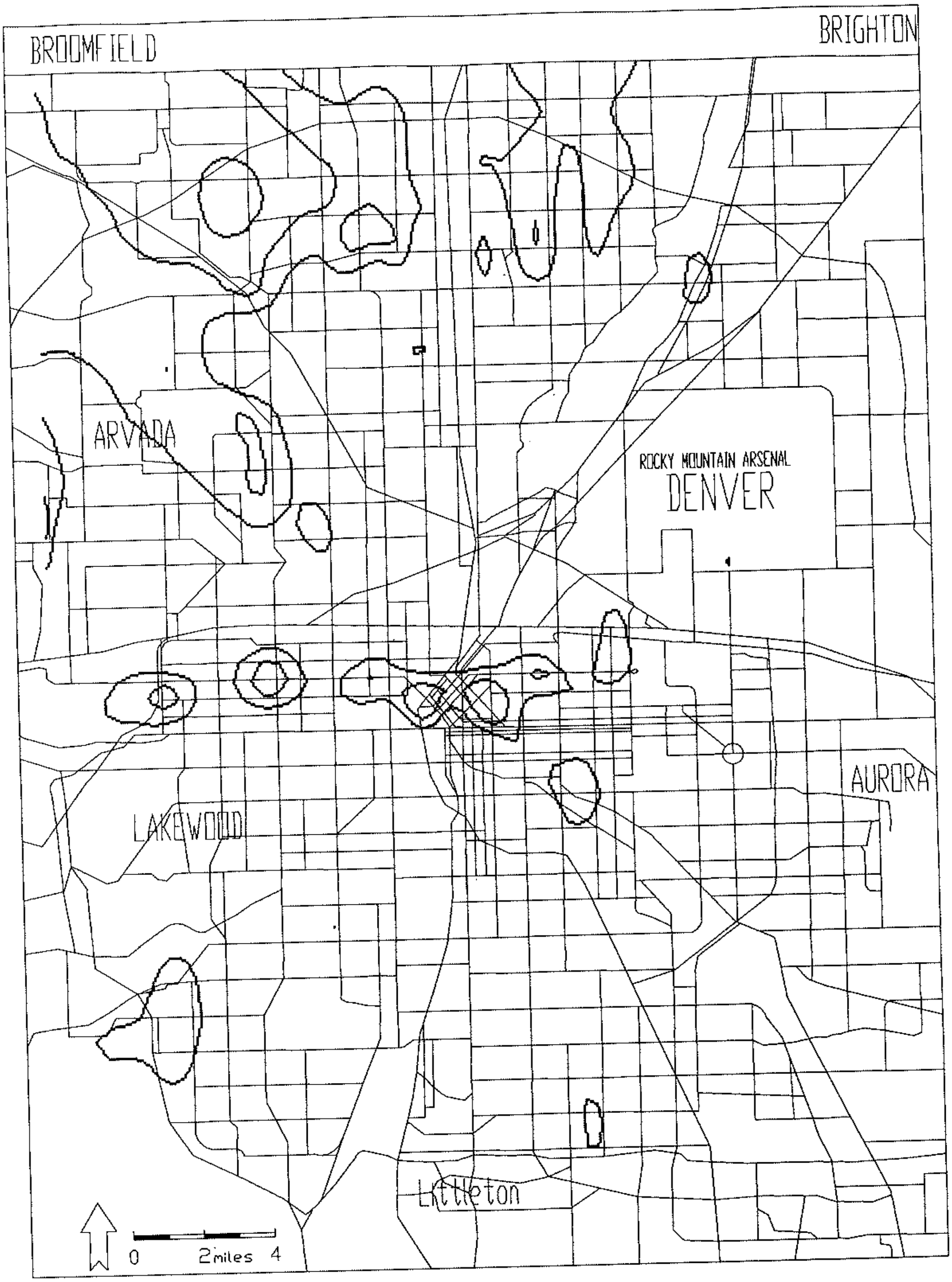
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

Figure 3. Baseline Case 1995 CO



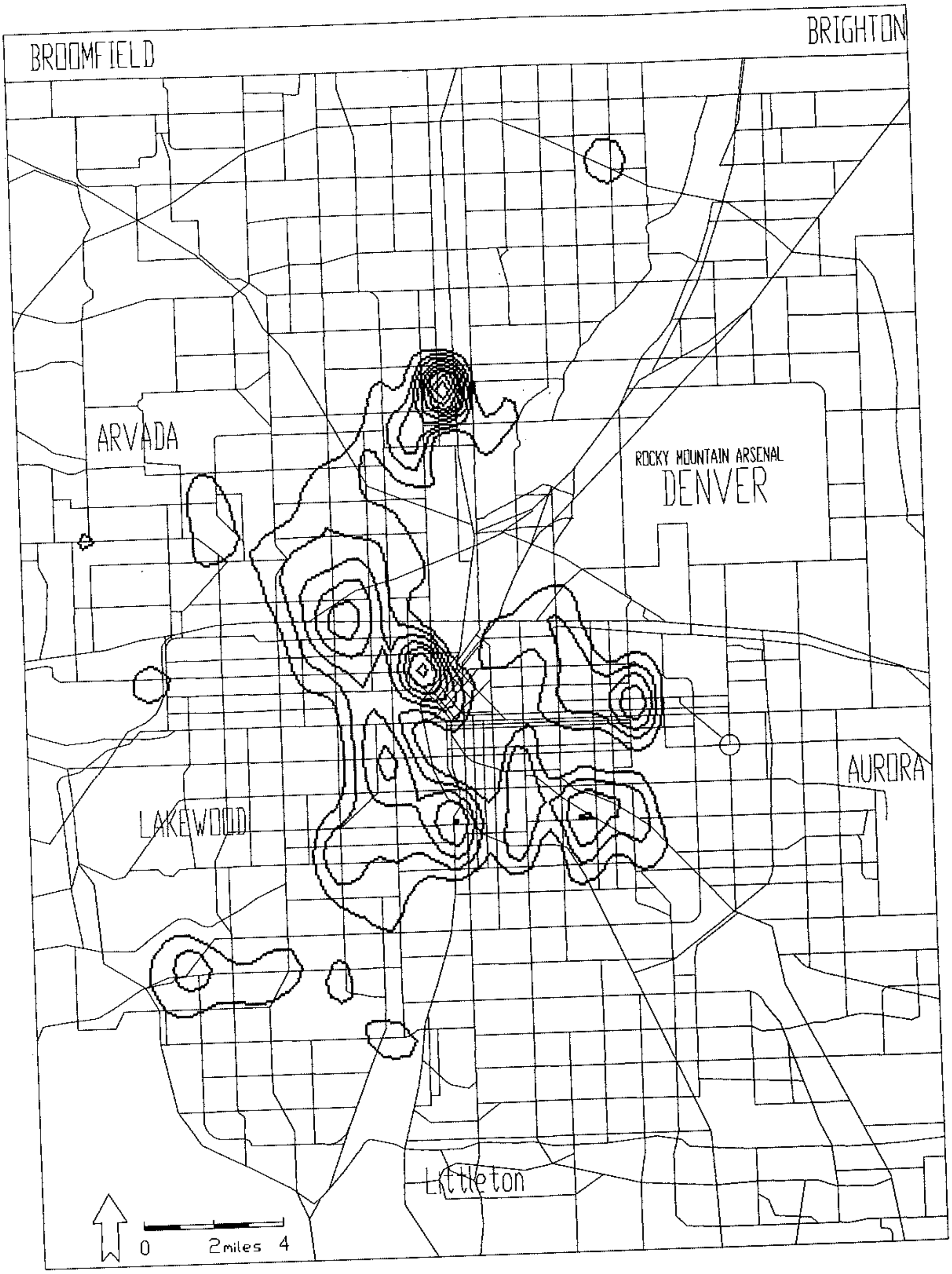
NOTES: Only those isolines that have values above the maximum allowable federel standard are shown. The value between consecutive isolines is 2 % of that standard.

Figure 4. Baseline Case 2010 CO



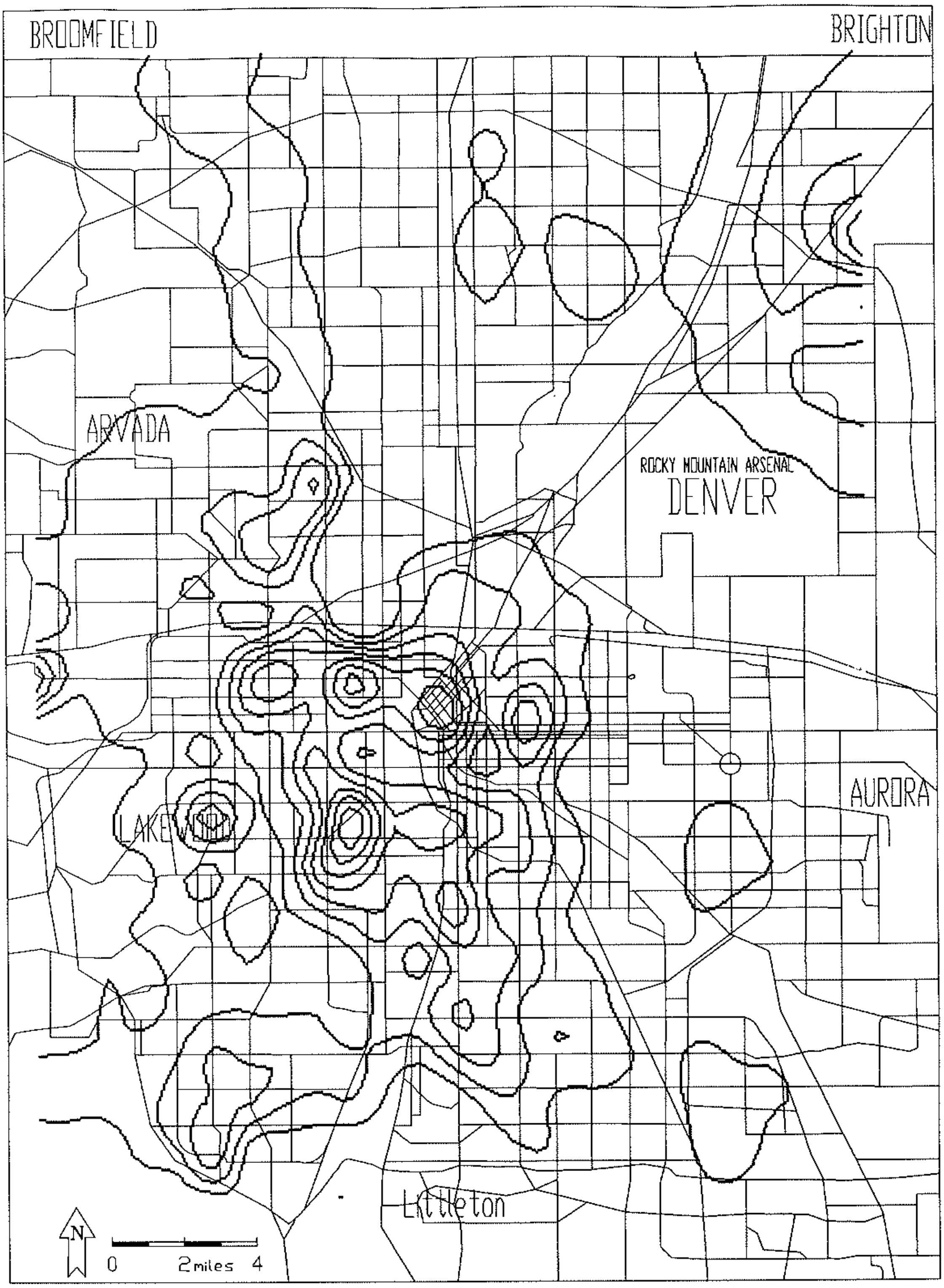
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2.5 % of that standard.

Figure 5. Baseline Case 1989 HC



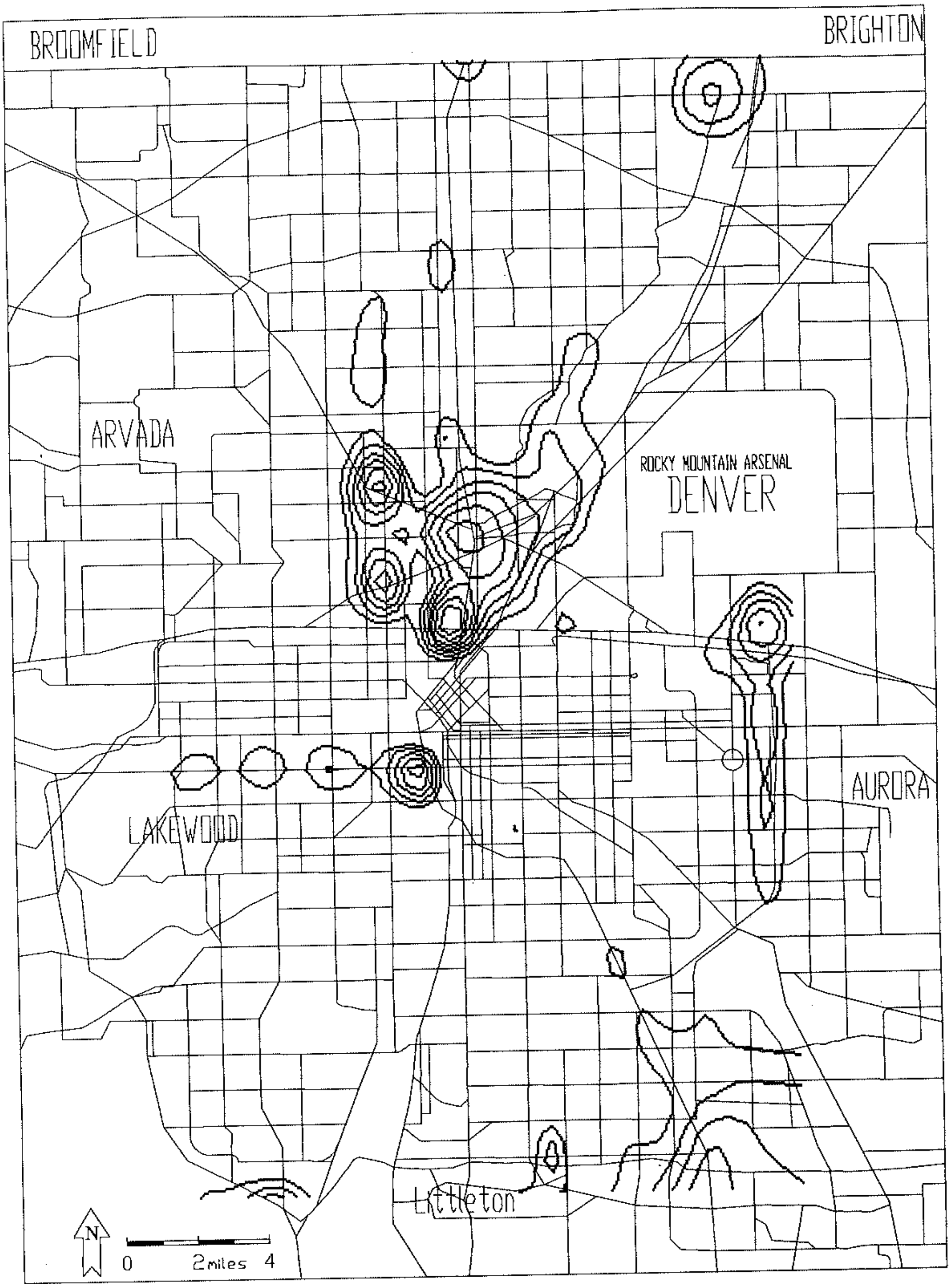
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2.5 % of that standard.

Figure 6. Baseline Case 1995 HC



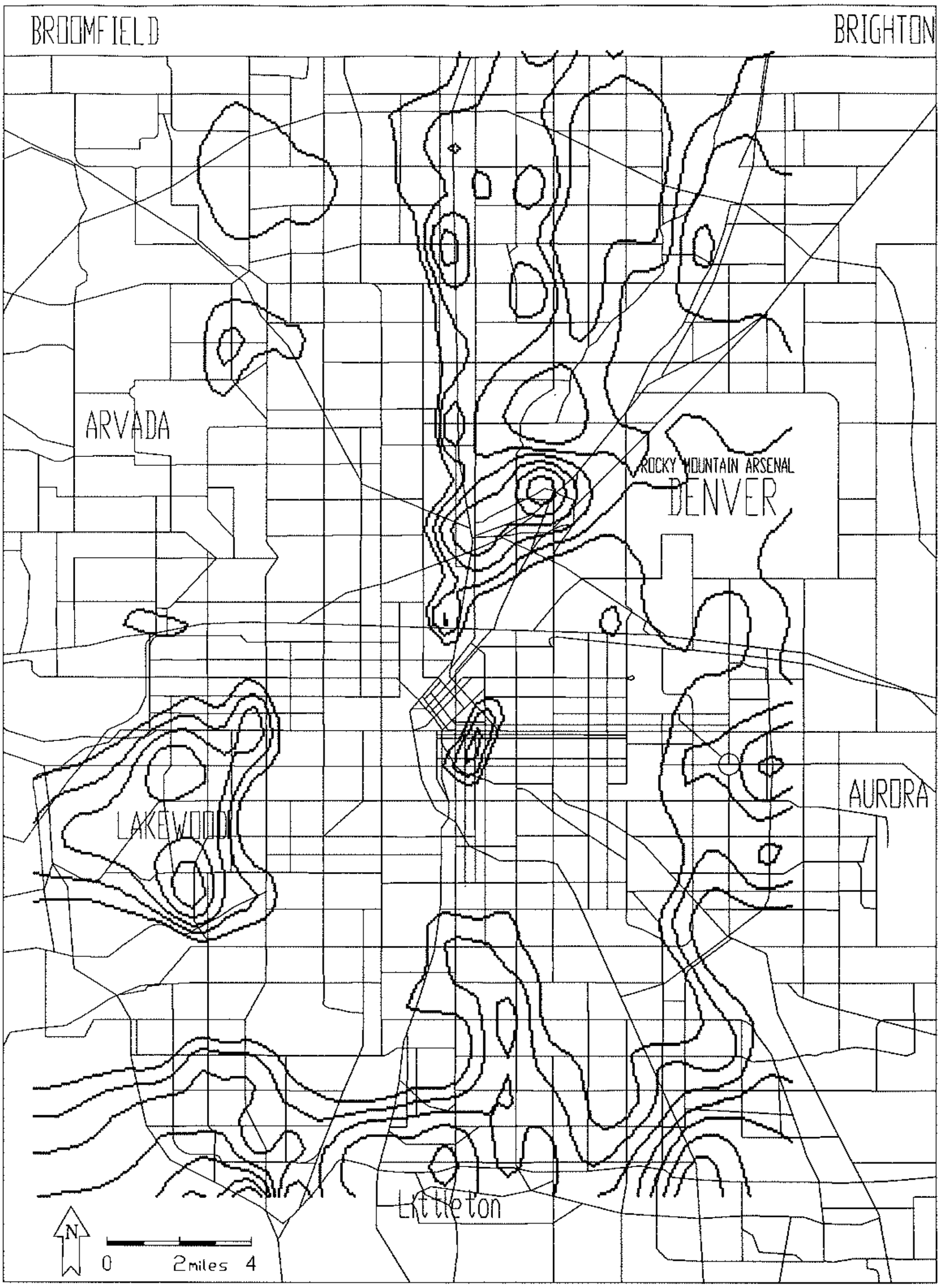
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2.5 % of that standard.

Figure 7. Baseline Case 2010 HC



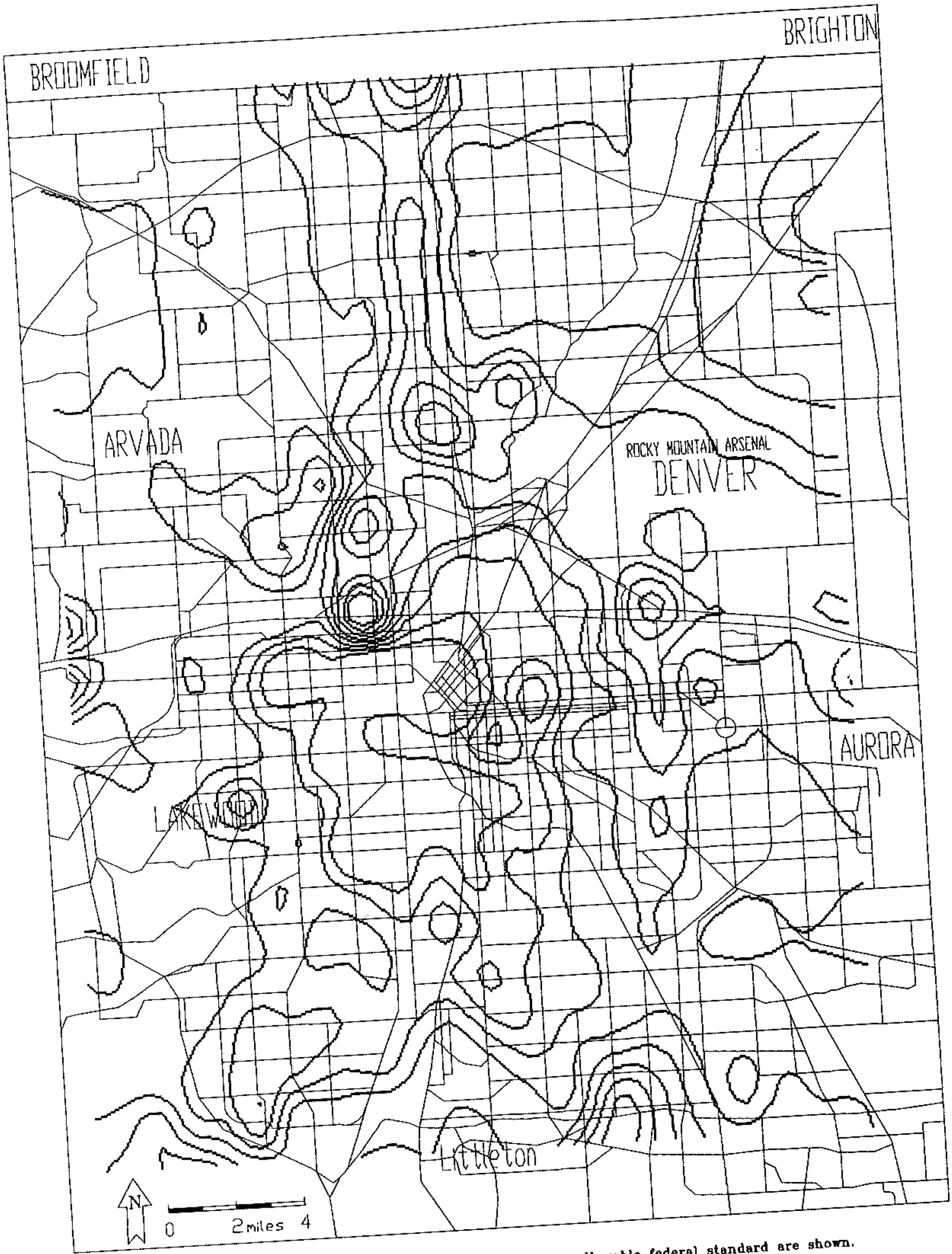
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 8. Baseline Case 1989 NO



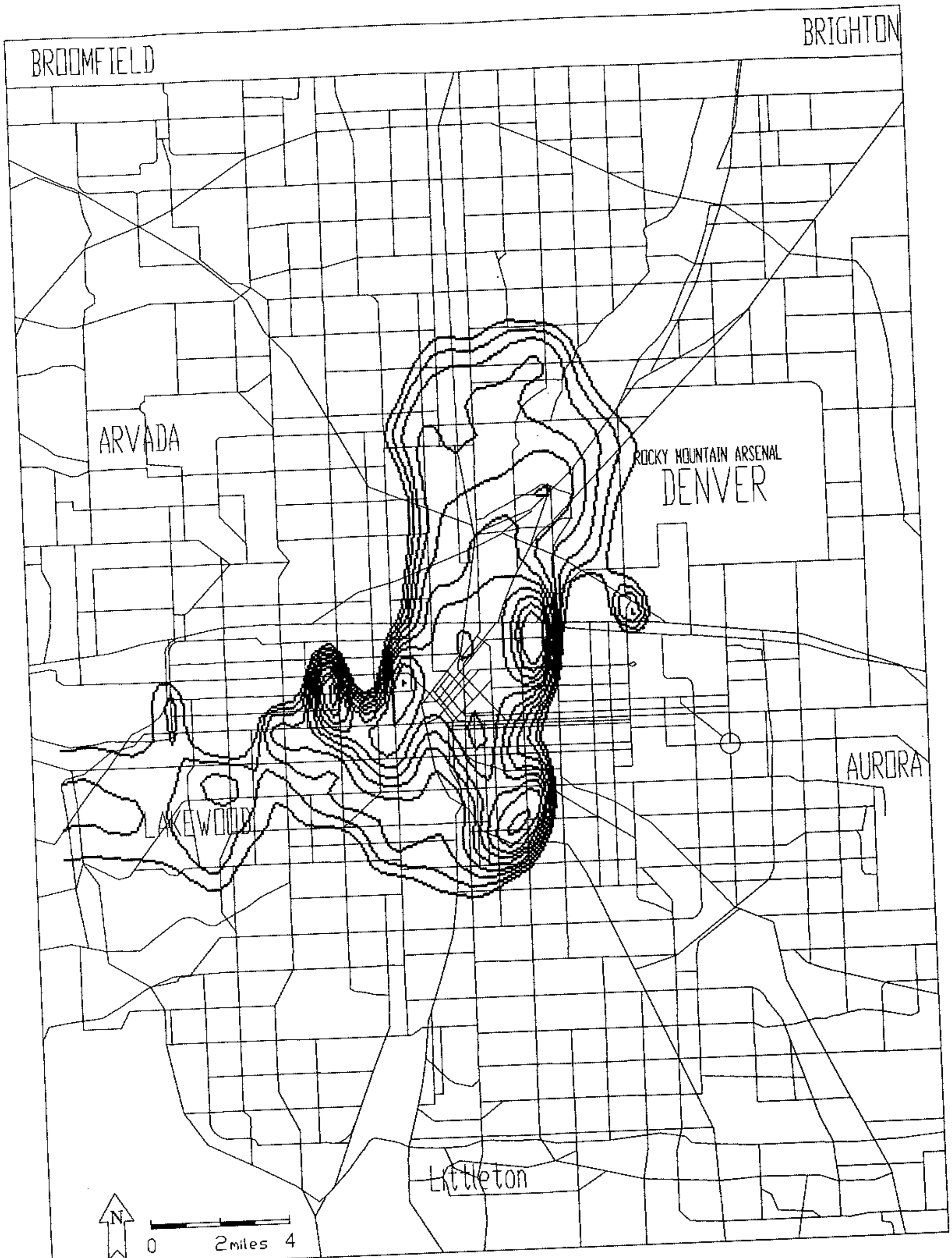
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 9. Baseline Case 1995 NO



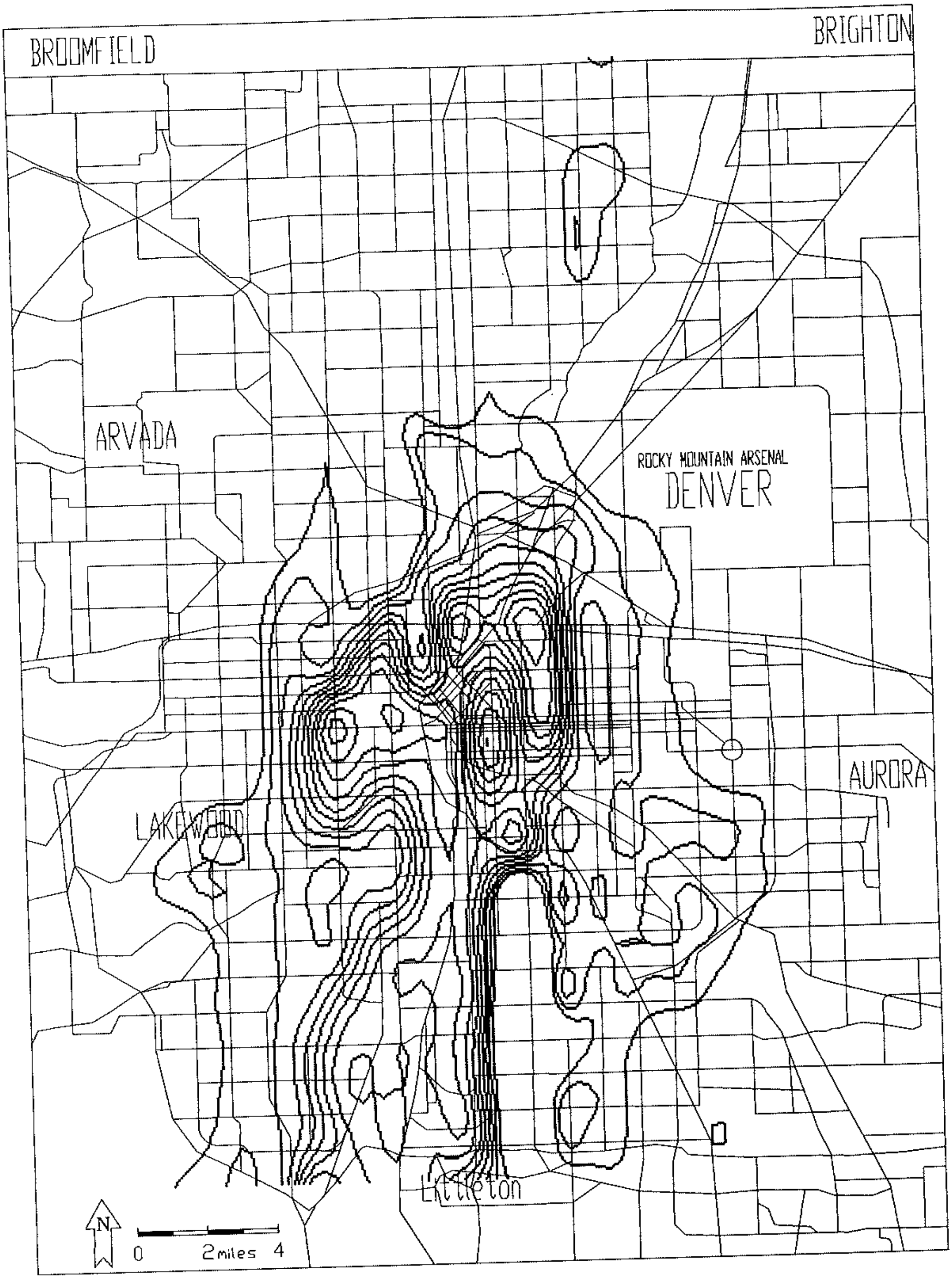
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 10. Baseline Case 2010 NO



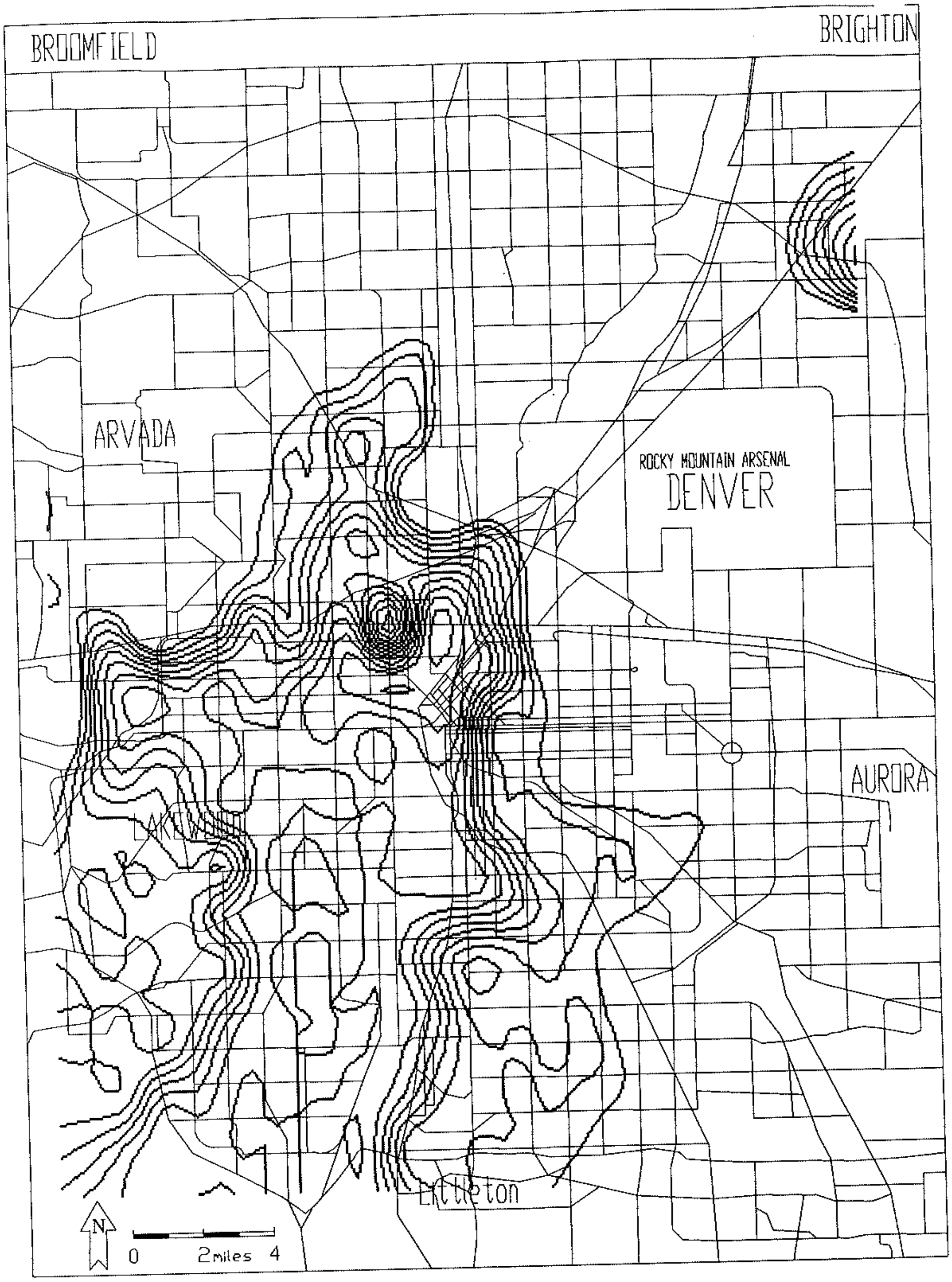
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 0.5 % of that standard.

Figure 11. Baseline Case 1989 PM



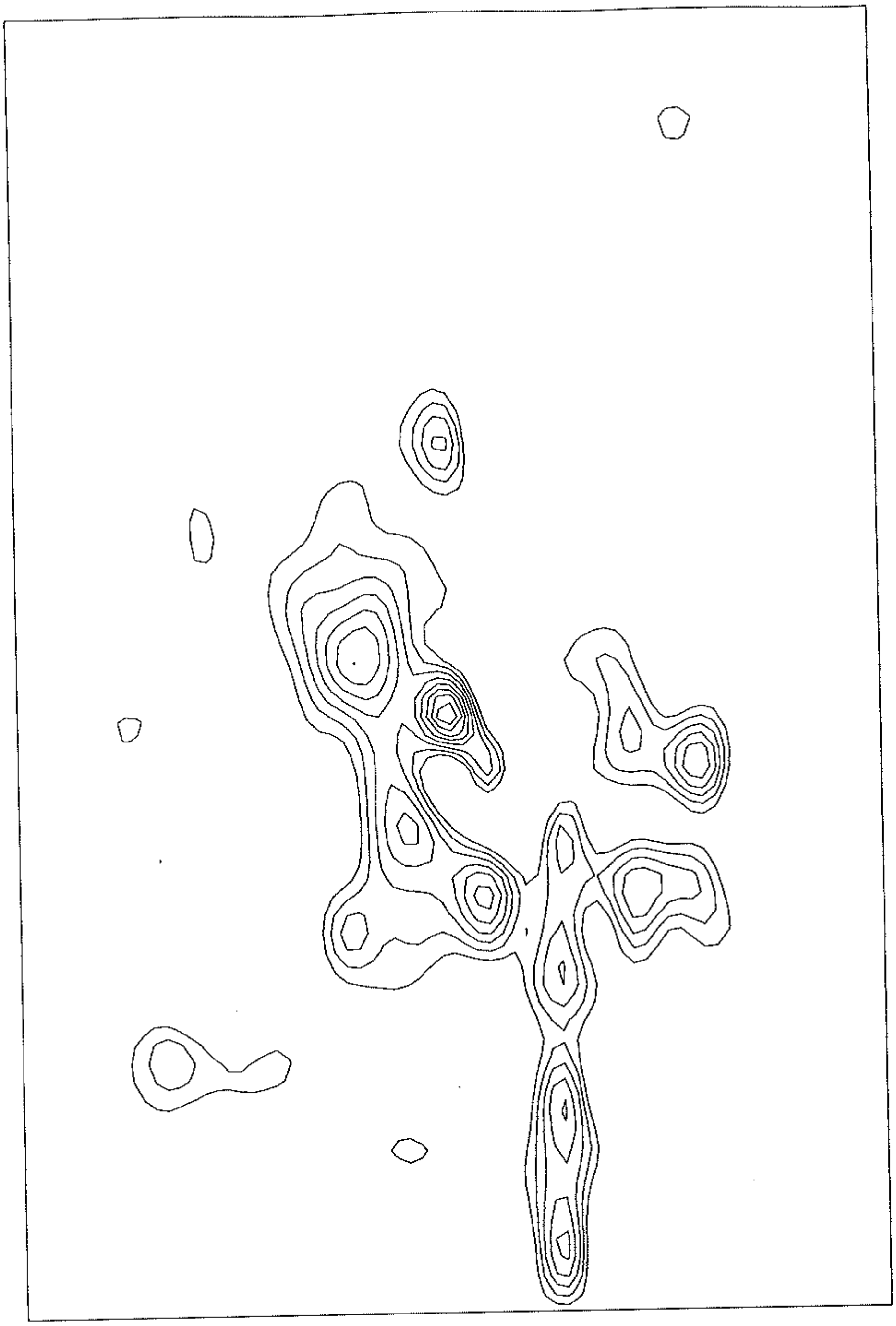
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 0.5 % of that standard.

Figure 12. Baseline Case 1995 PM



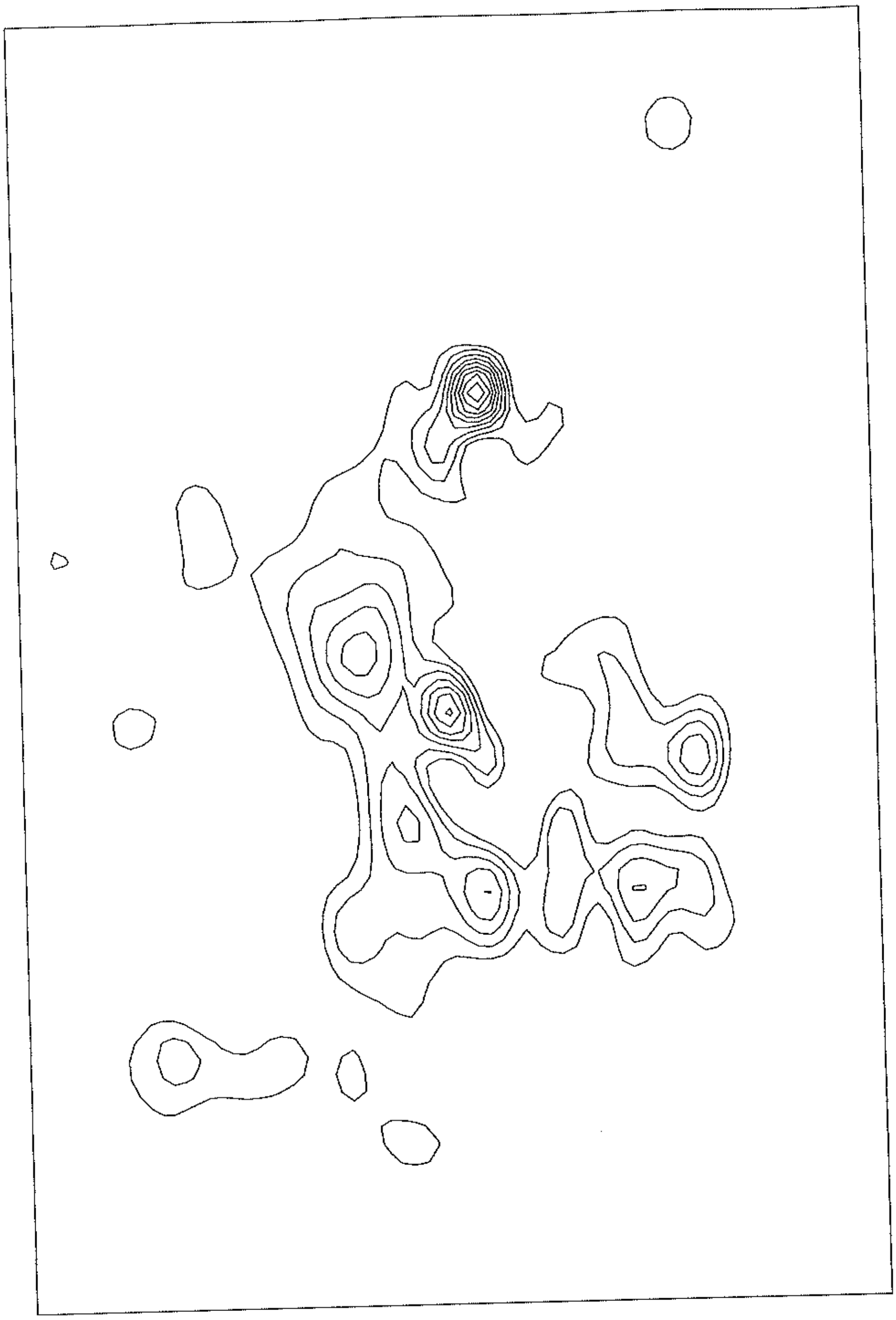
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 0.5 % of that standard.

Figure 13. Baseline Case 2010 PM



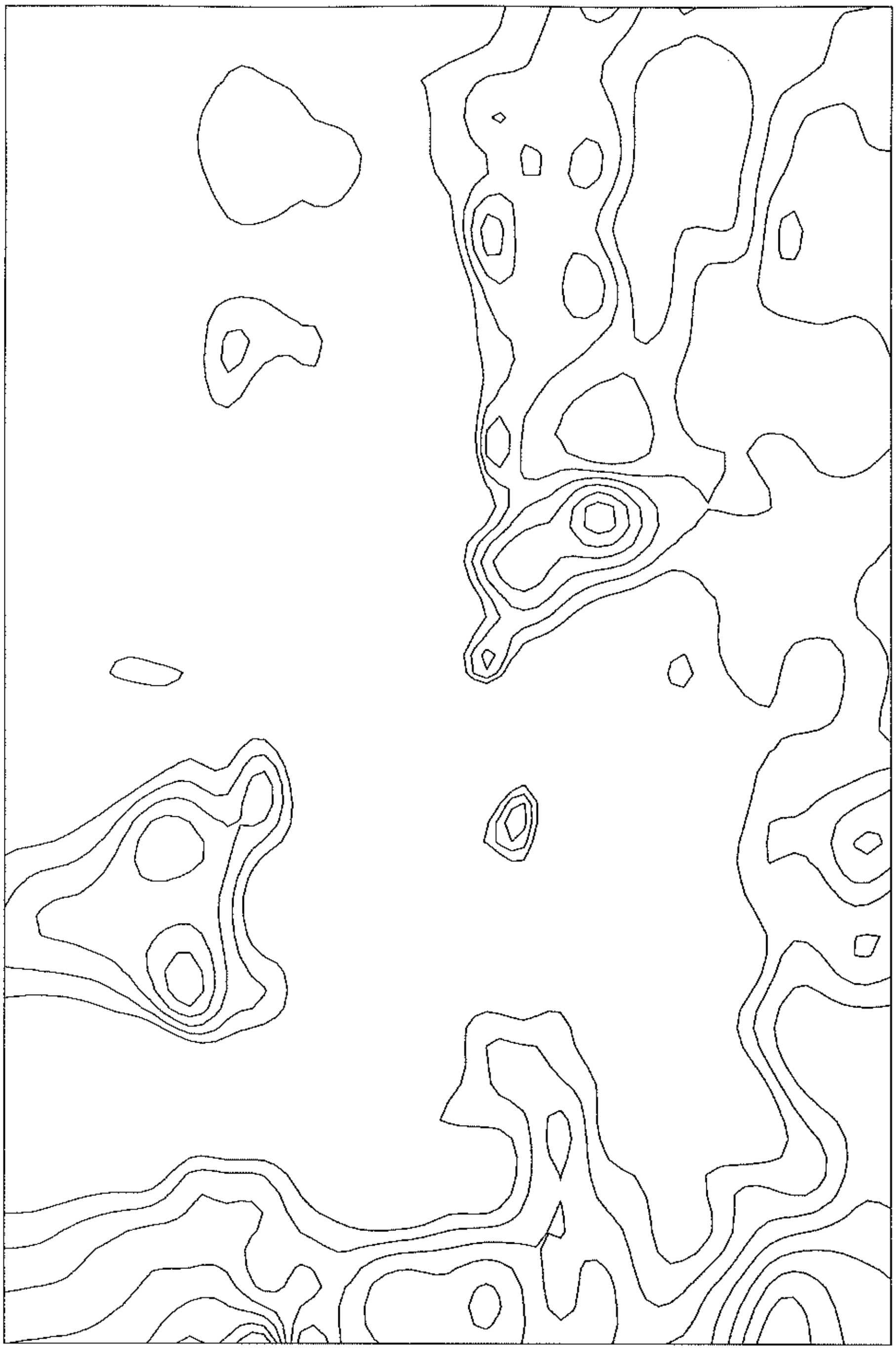
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 2 % of that standard.

Figure 14. Metro Area Connection 1995 CO



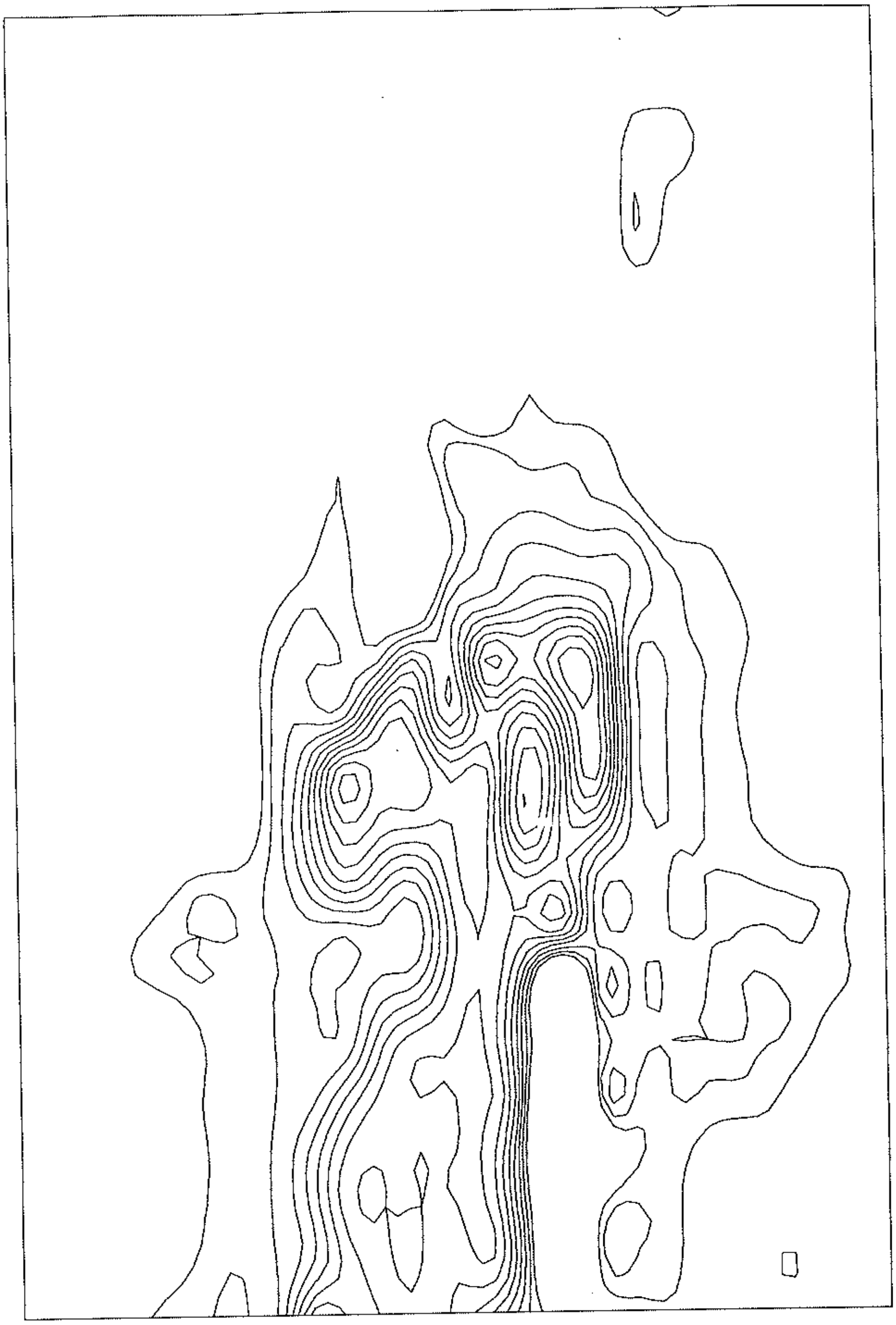
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2.5 % of that standard.

Figure 15. Metro Area Connection 1995 HC



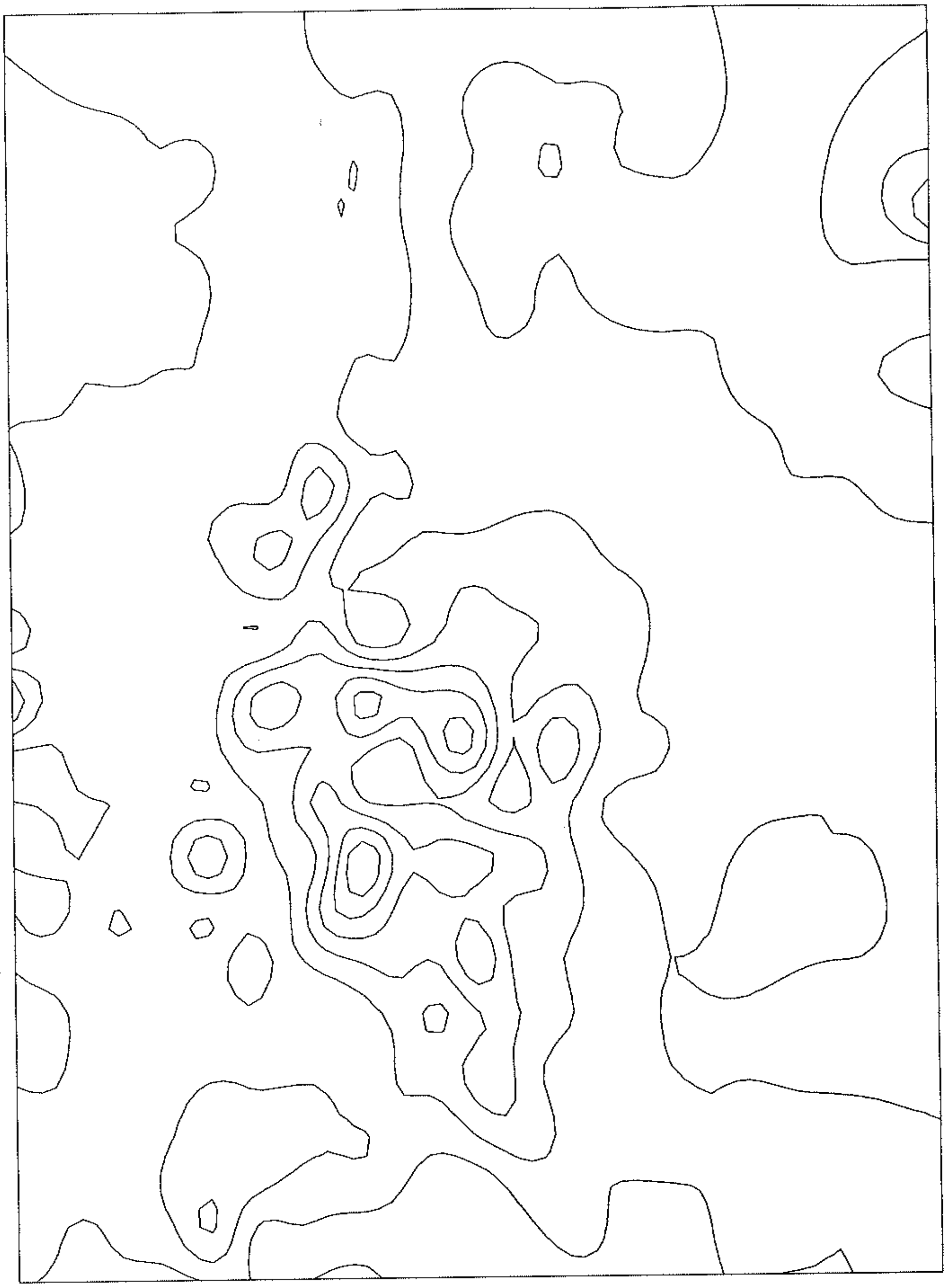
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 16. Metro Area Connection 1995 NO_x



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 0.5 % of that standard.

Figure 17. Metro Area Connection 1995 PM

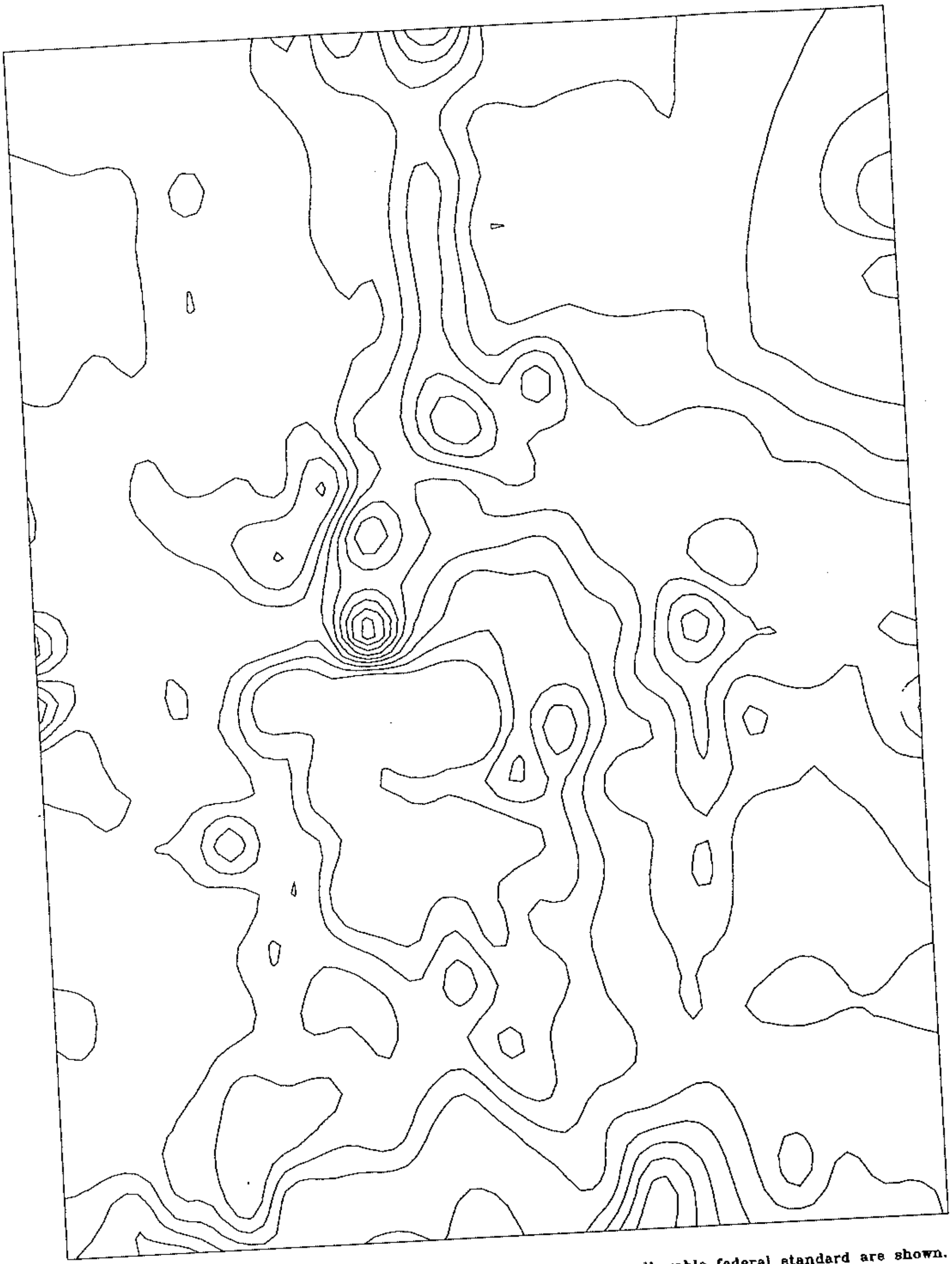


NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

Figure 18. Metro Area Connection 2010 CO

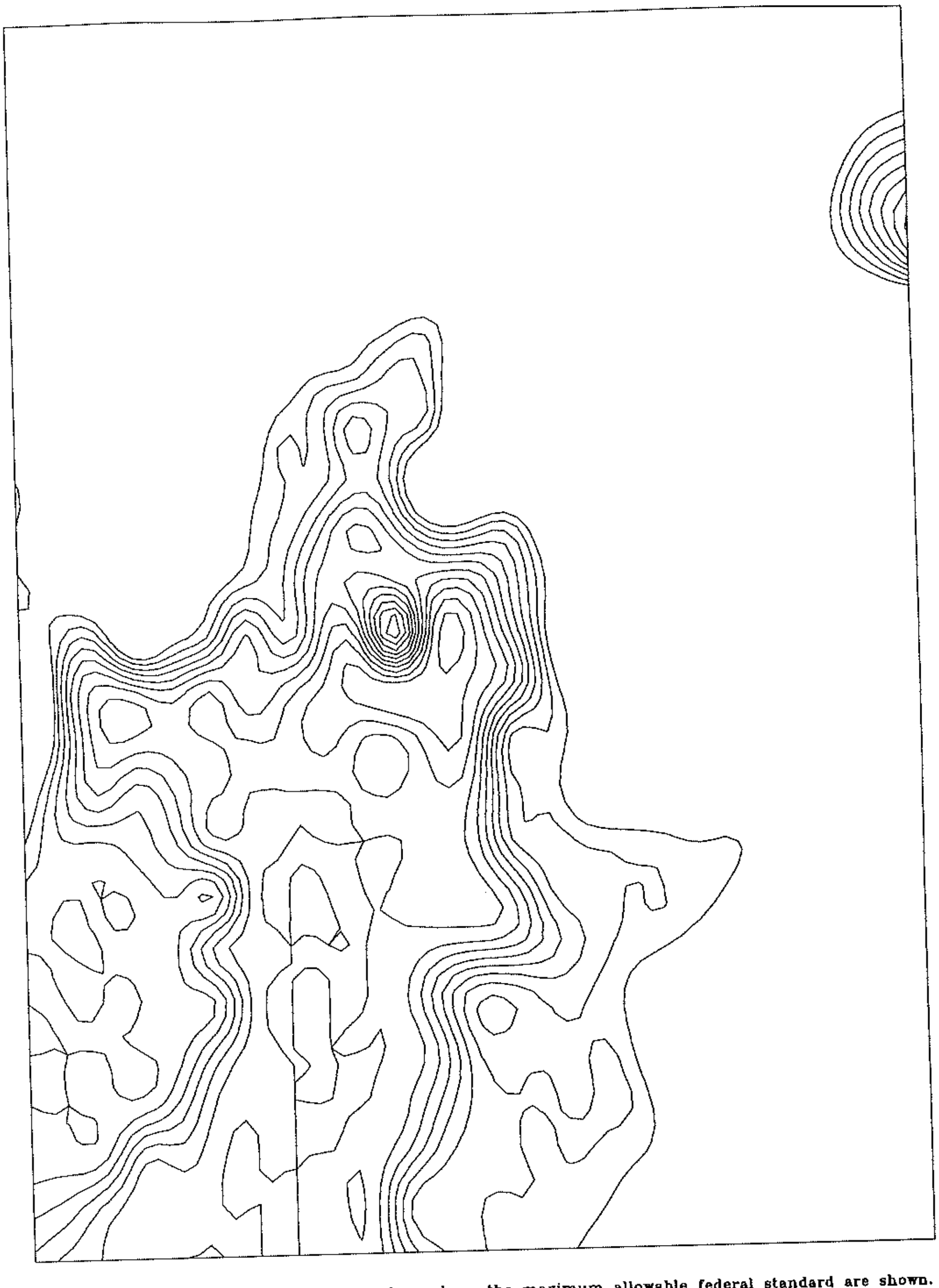
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2.5 % of that standard.

Figure 19. Metro Area Connection 2010 HC



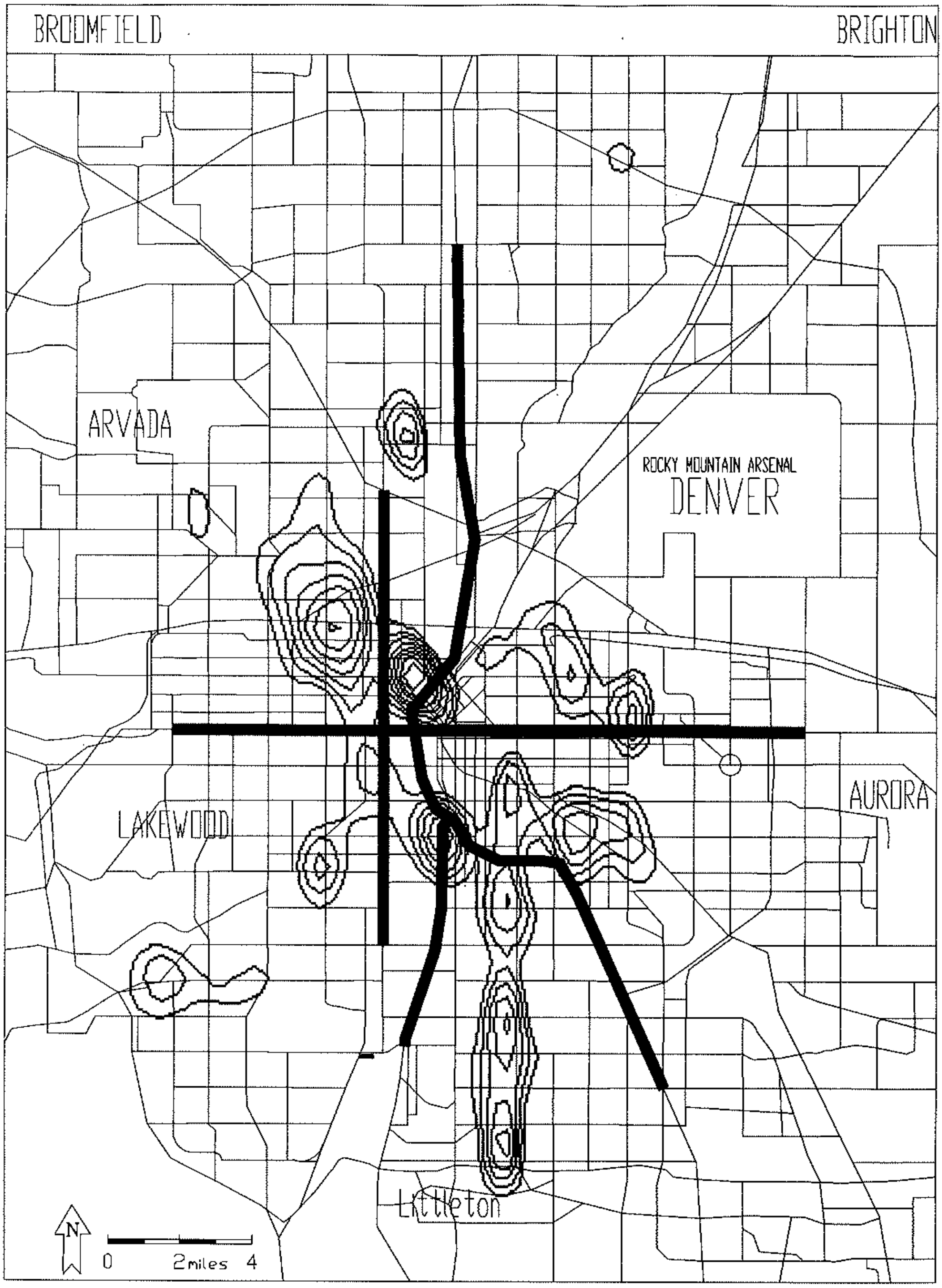
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 1.5 % of that standard.

Figure 20. Metro Area Connection 2010 NO_x



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 0.5 % of that standard.

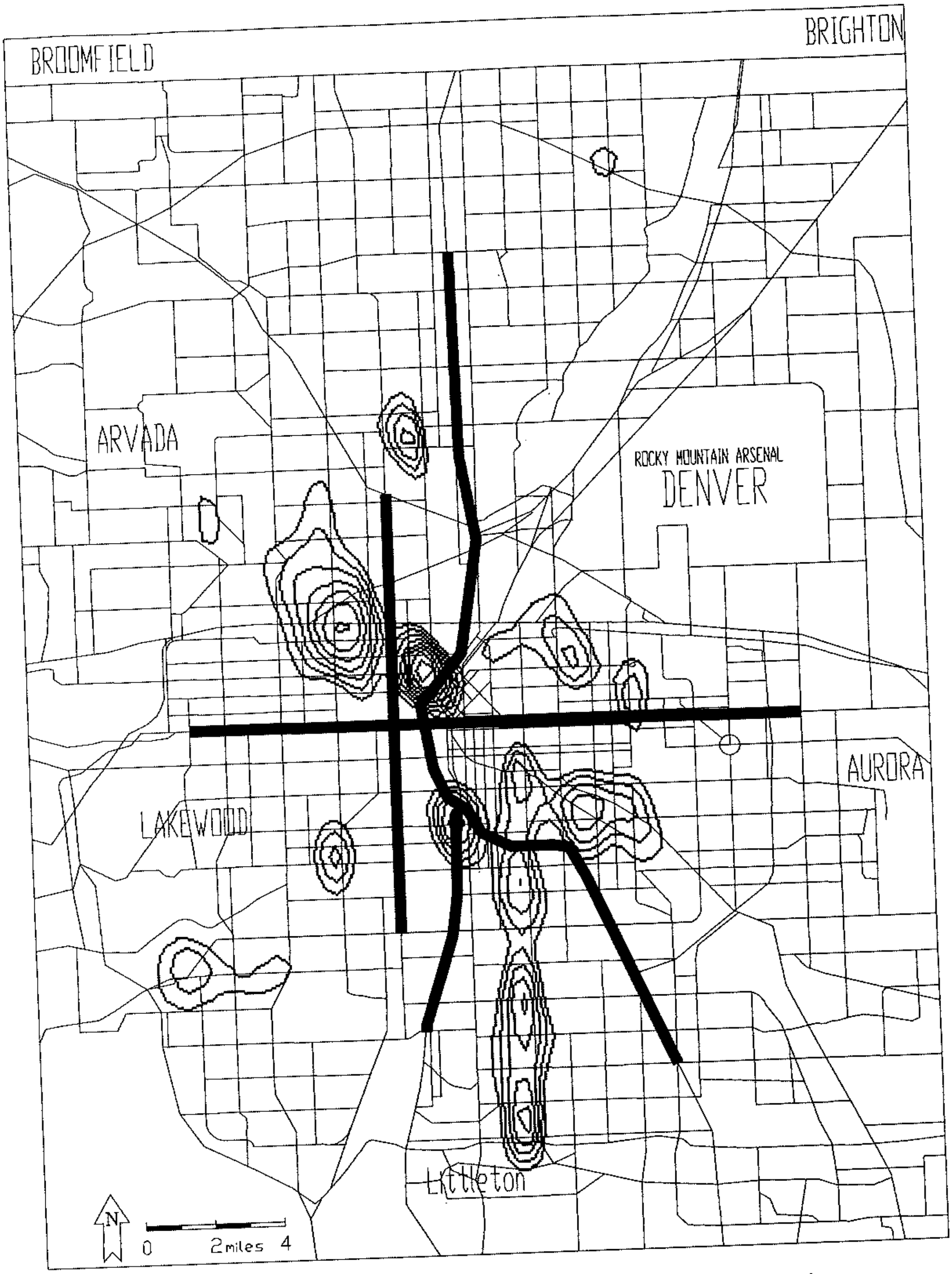
Figure 21. Metro Area Connection 2010 PM



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

LRT system

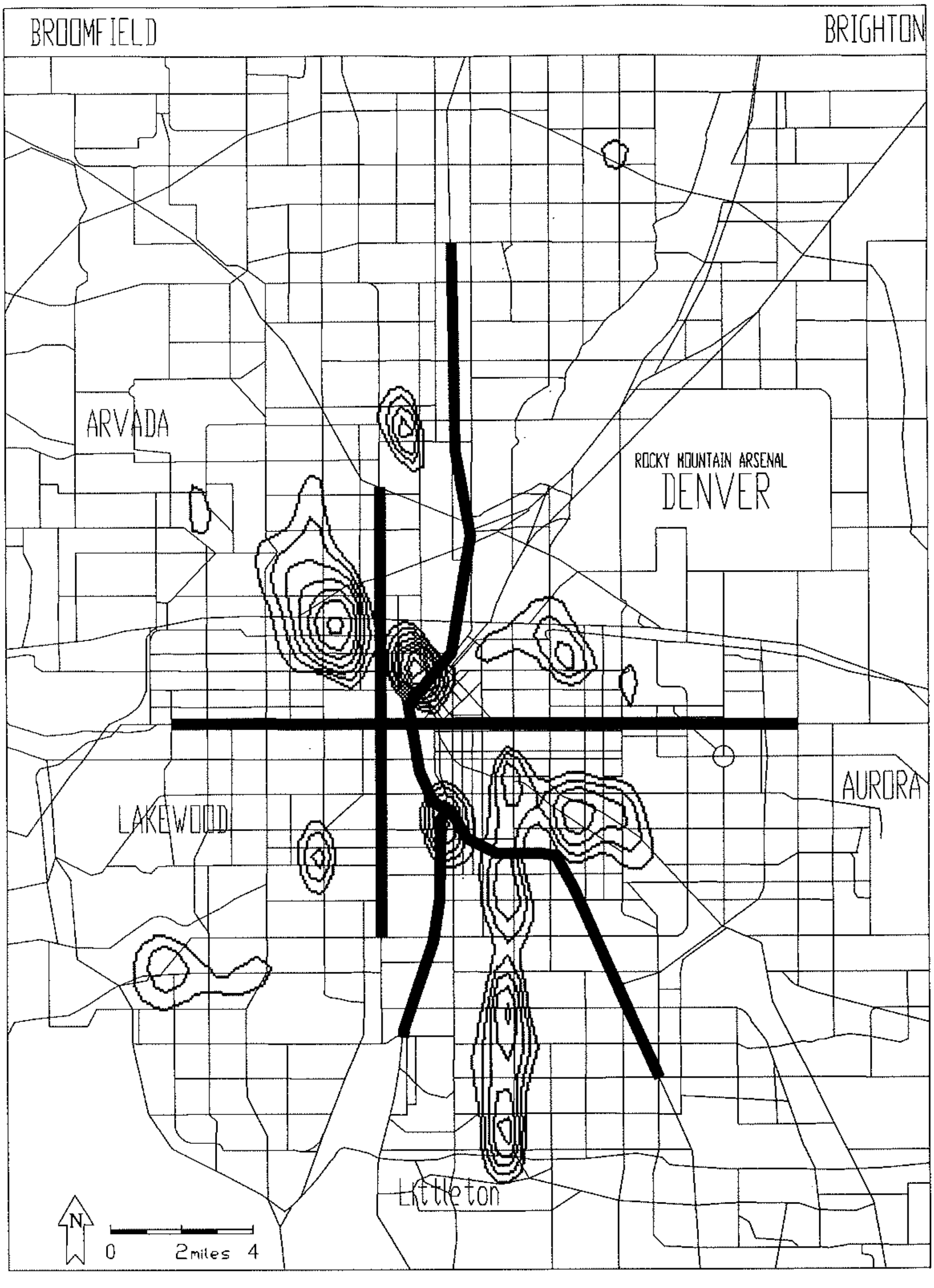
Figure 22. LRT Full Network 1995 CO 25% Ridership



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

LRT system

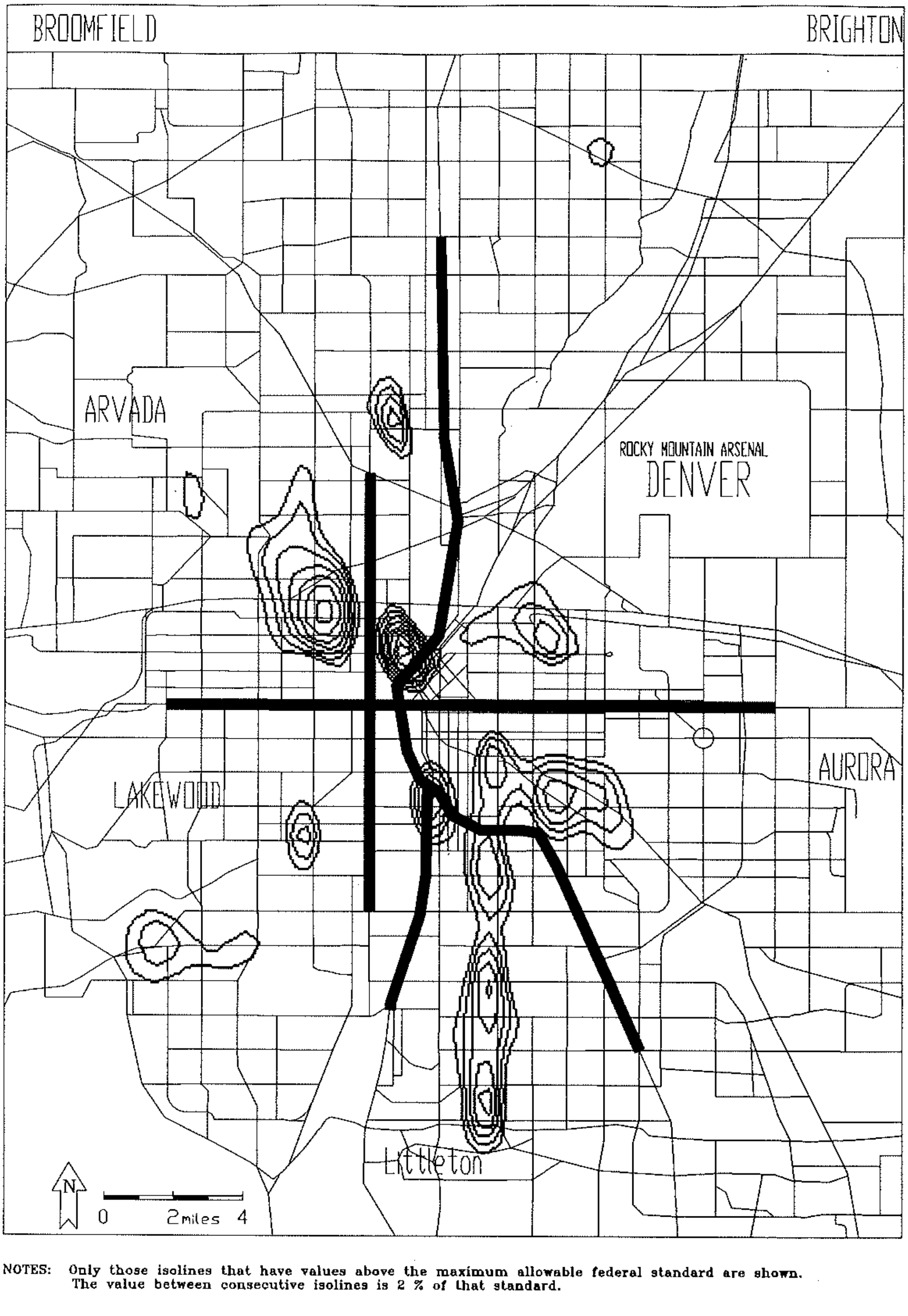
Figure 23. LRT Full Network 1995 CO 50% Ridership



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

LRT system

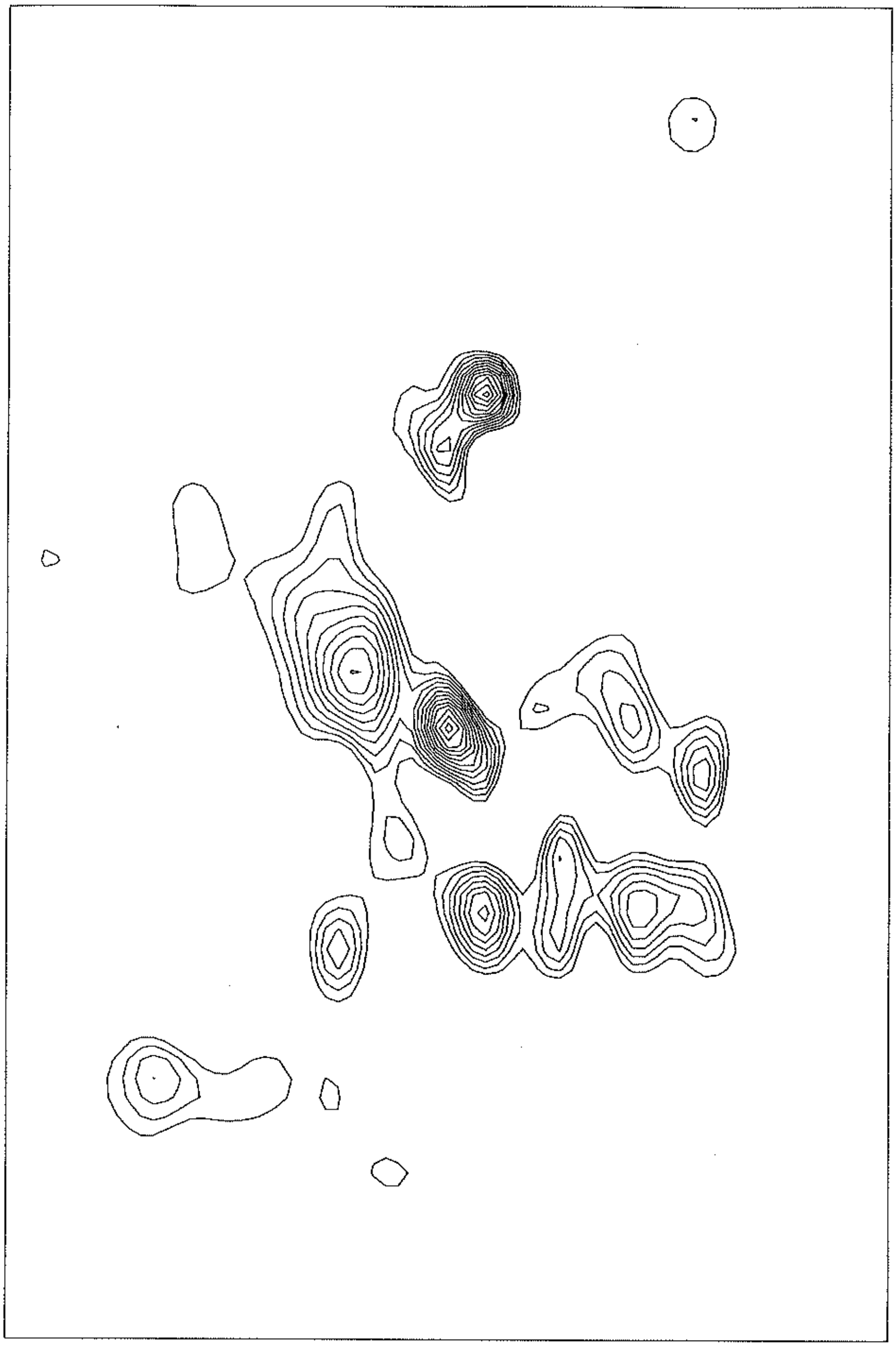
Figure 24. LRT Full Network 1995 CO 75% Ridership



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

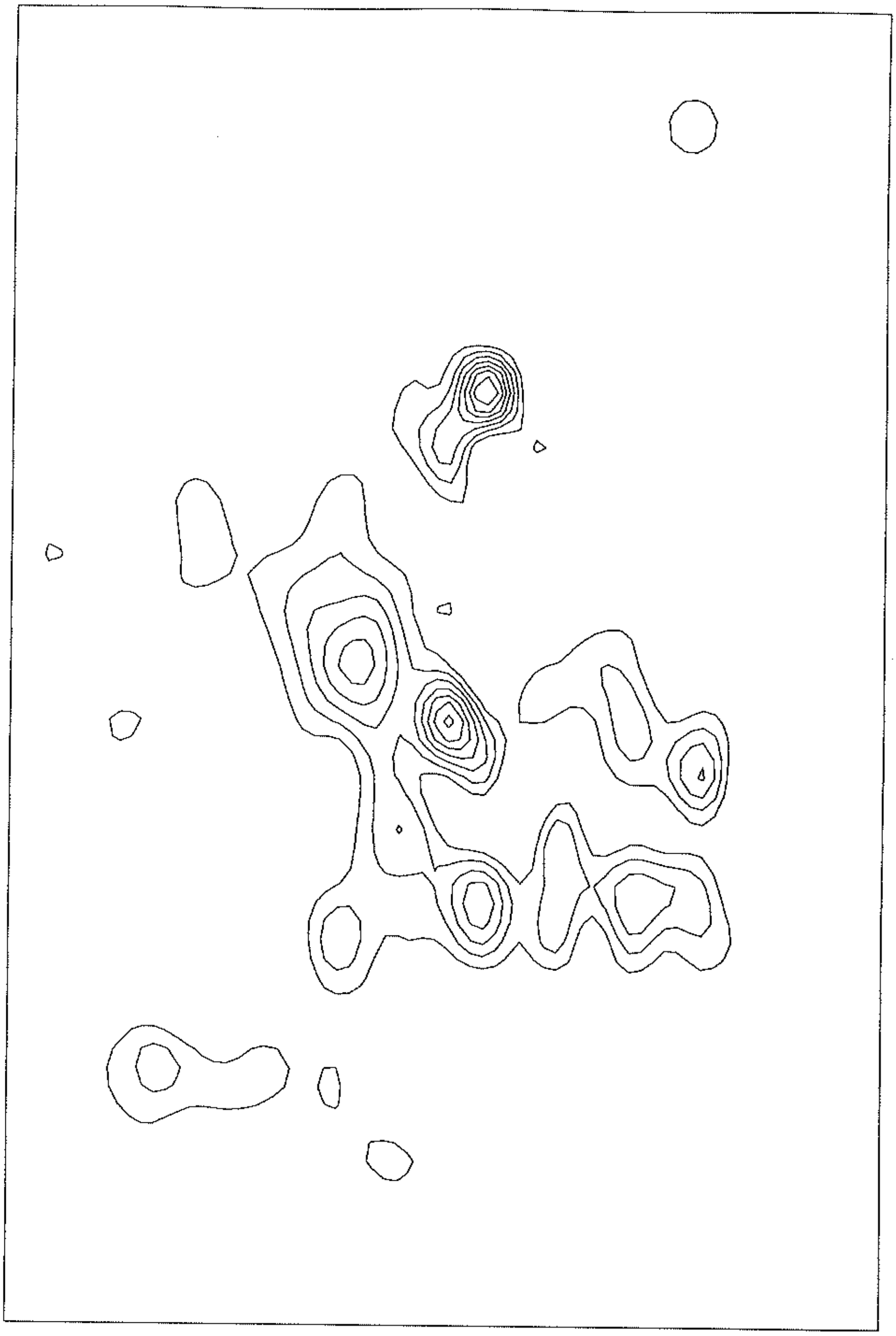
LRT system

Figure 25. LRT Full Network 1995 CO 100% Ridership



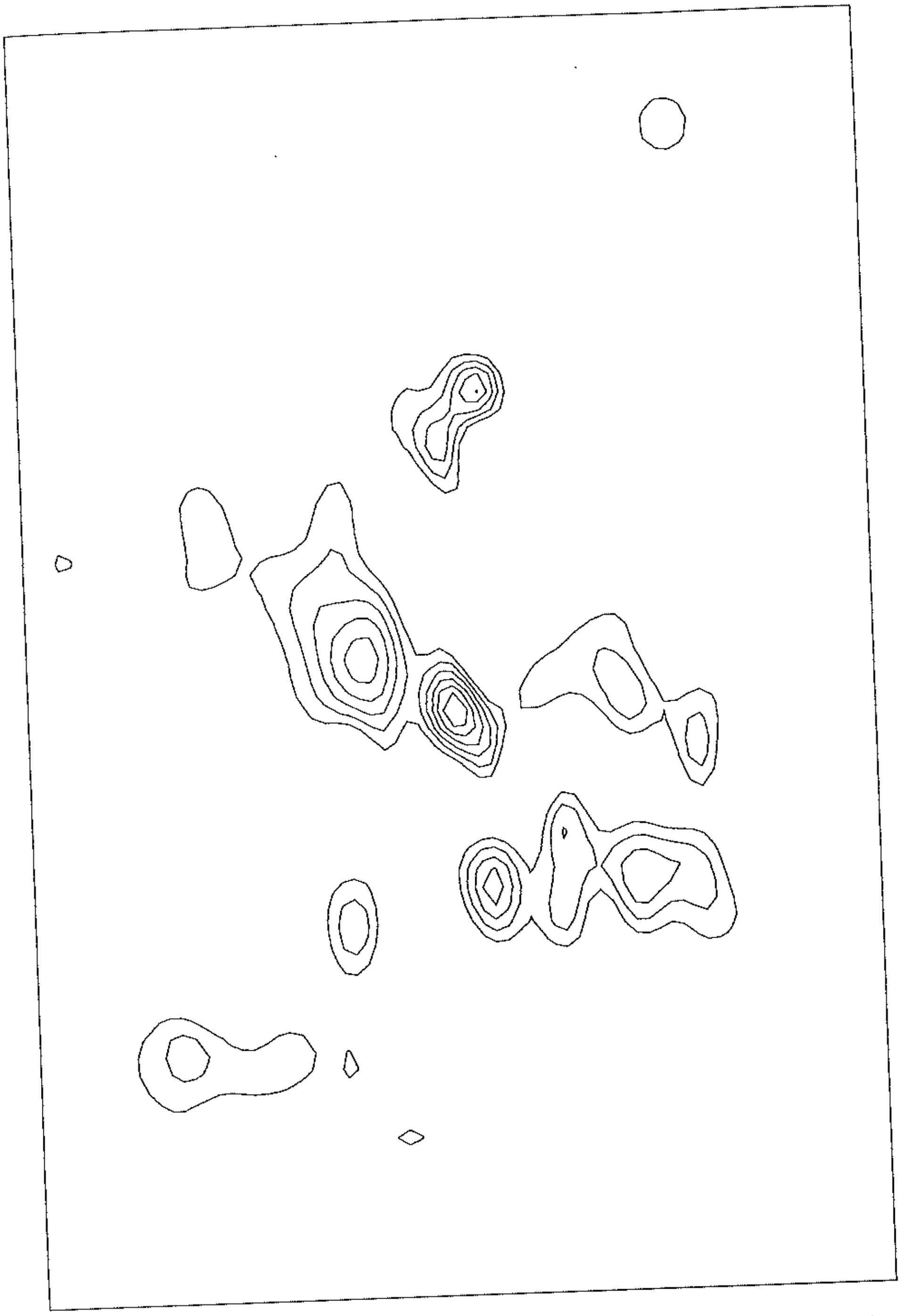
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2.5 % of that standard.

Figure 26. LRT Full Network 1995 HC 25% Ridership



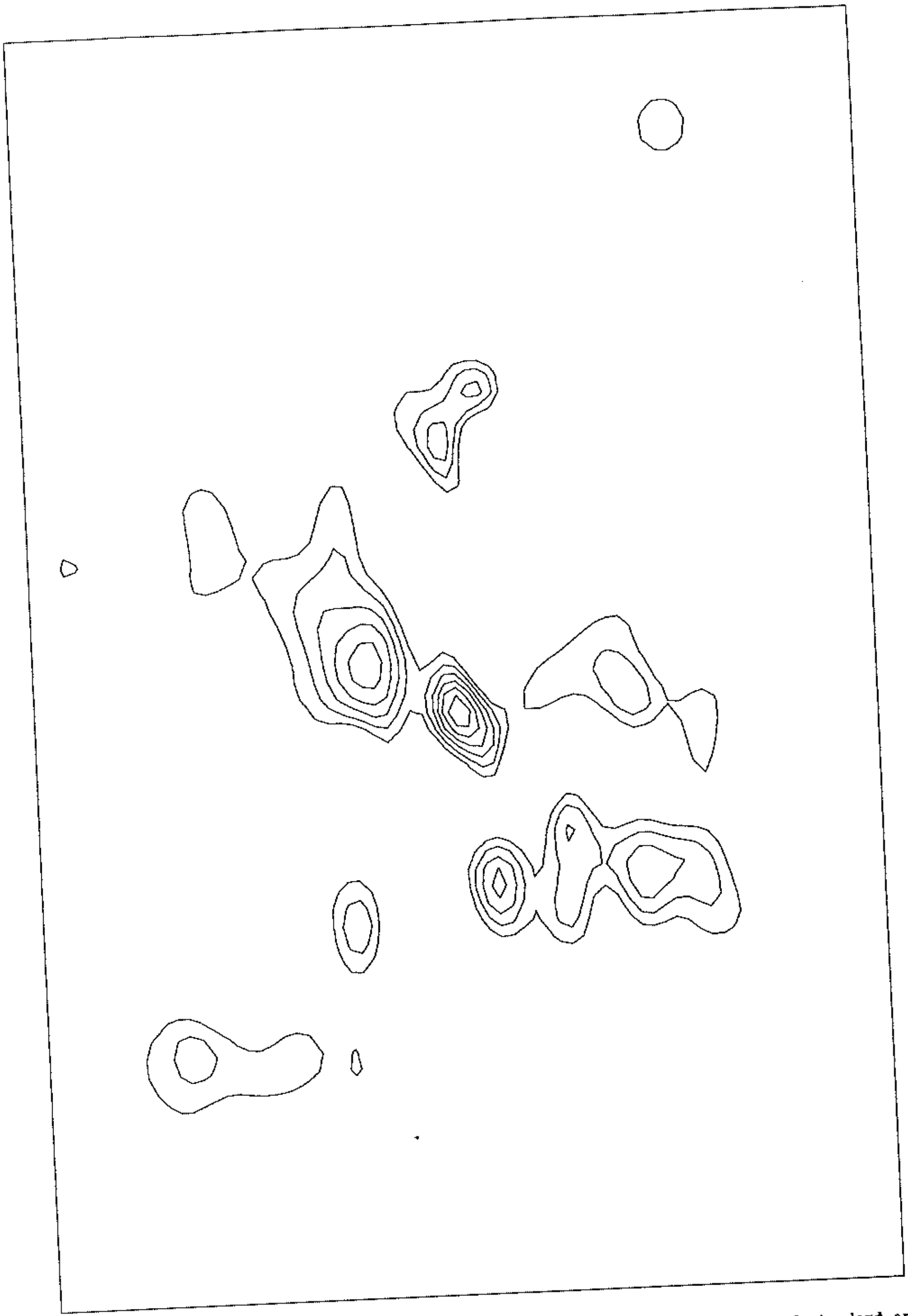
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2.5 % of that standard.

Figure 27. LRT Full Network 1995 HC 50% Ridership



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 2.5 % of that standard.

Figure 28. LRT Full Network 1995 HC 75% Ridership

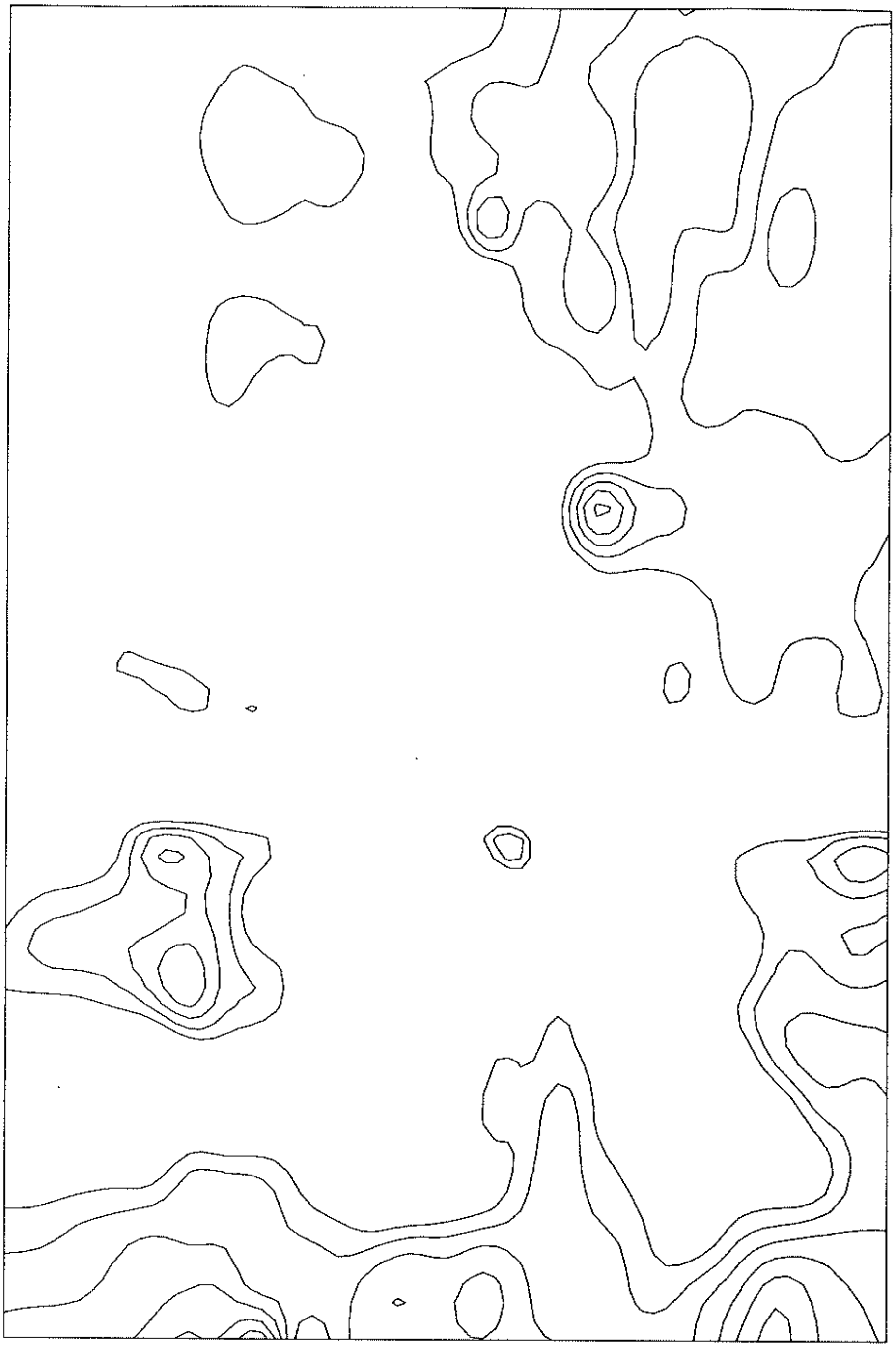


NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 2.5 % of that standard.

Figure 29. LRT Full Network 1995 HC 100% Ridership

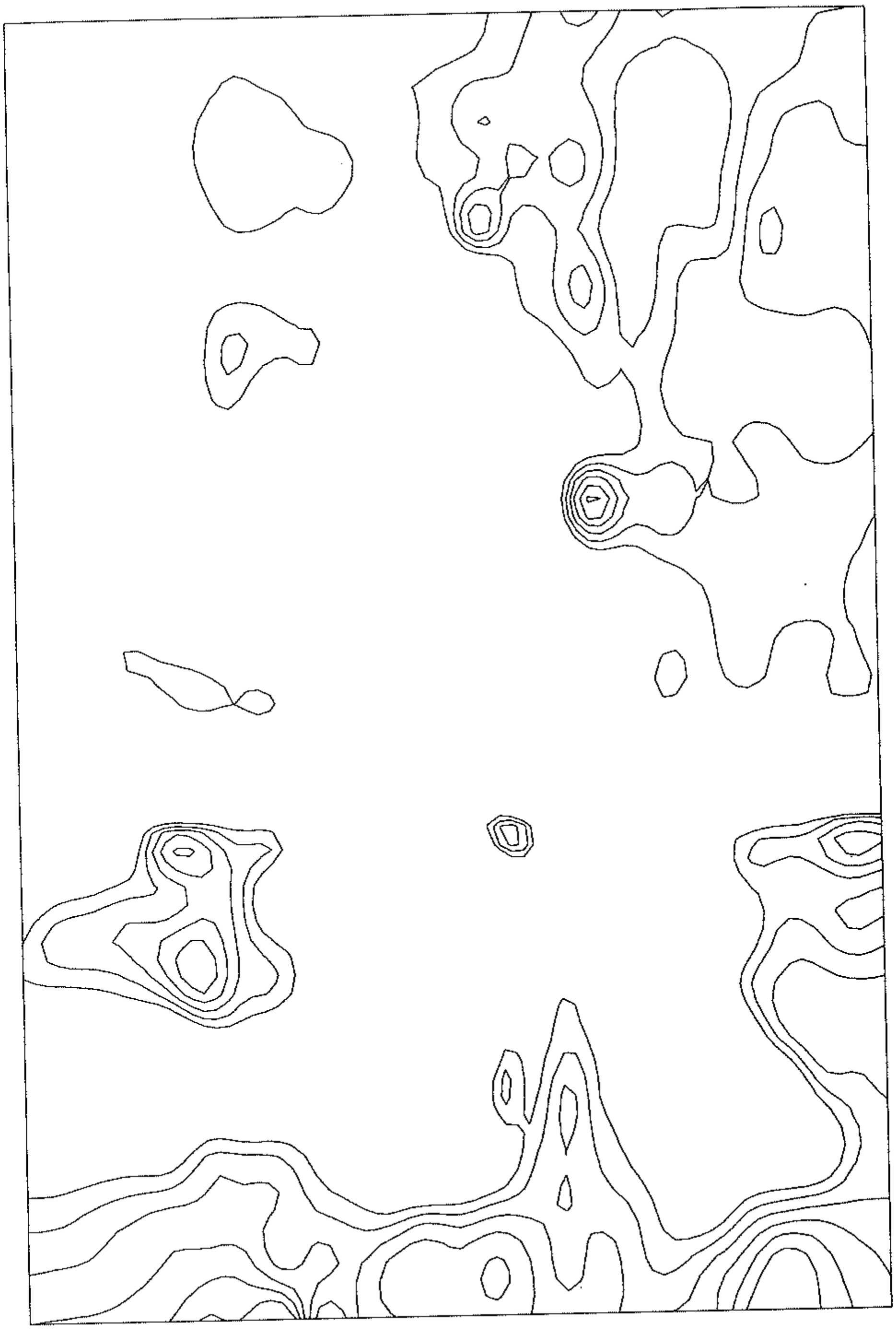
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 1.5 % of that standard.

Figure 30. LRT Full Network 1995 NO_x 25% Ridership



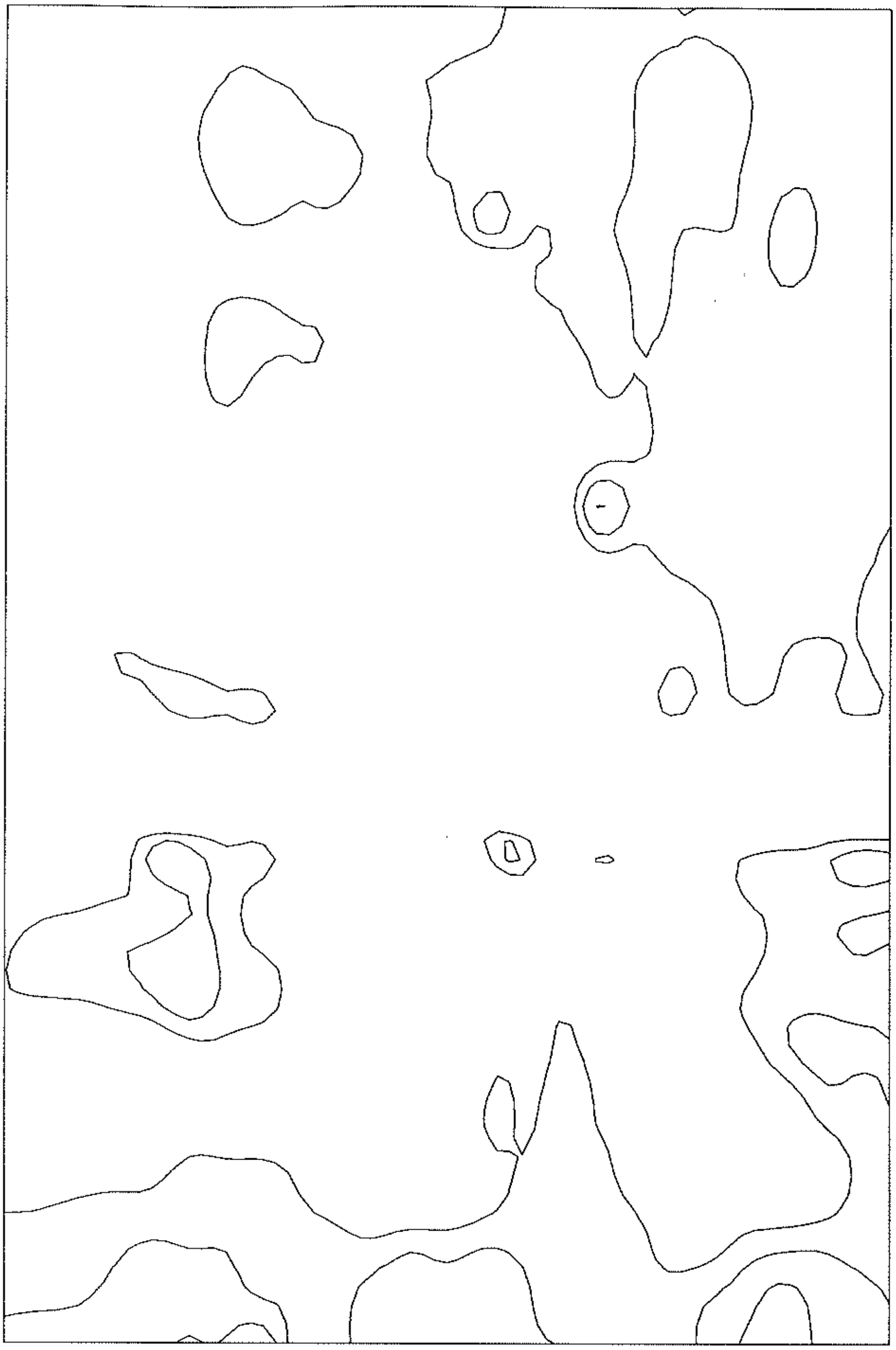
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 31. LRT Full Network 1995 NO_x 50% Ridership



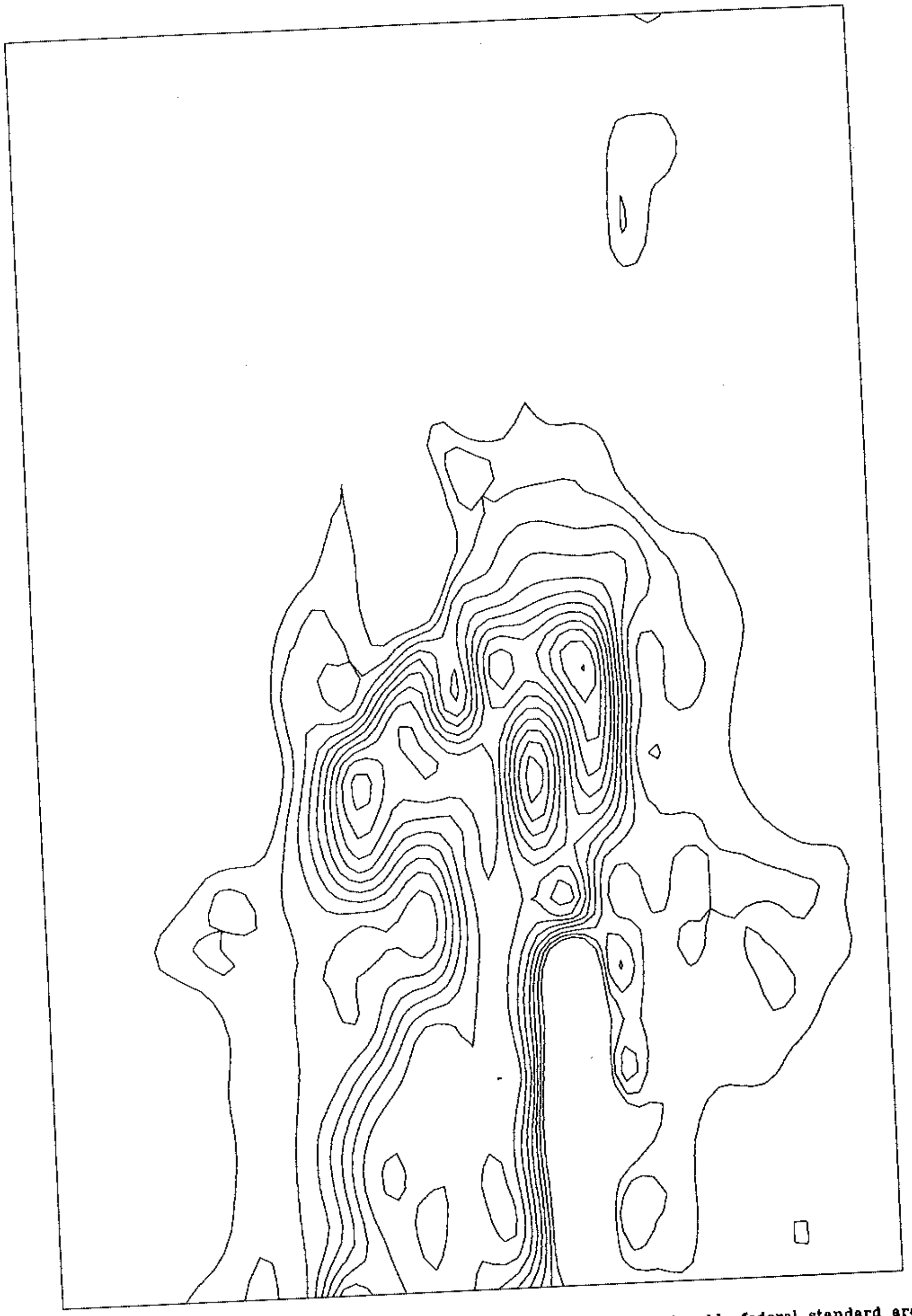
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 32. LRT Full Network 1995 NO_x 75% Ridership



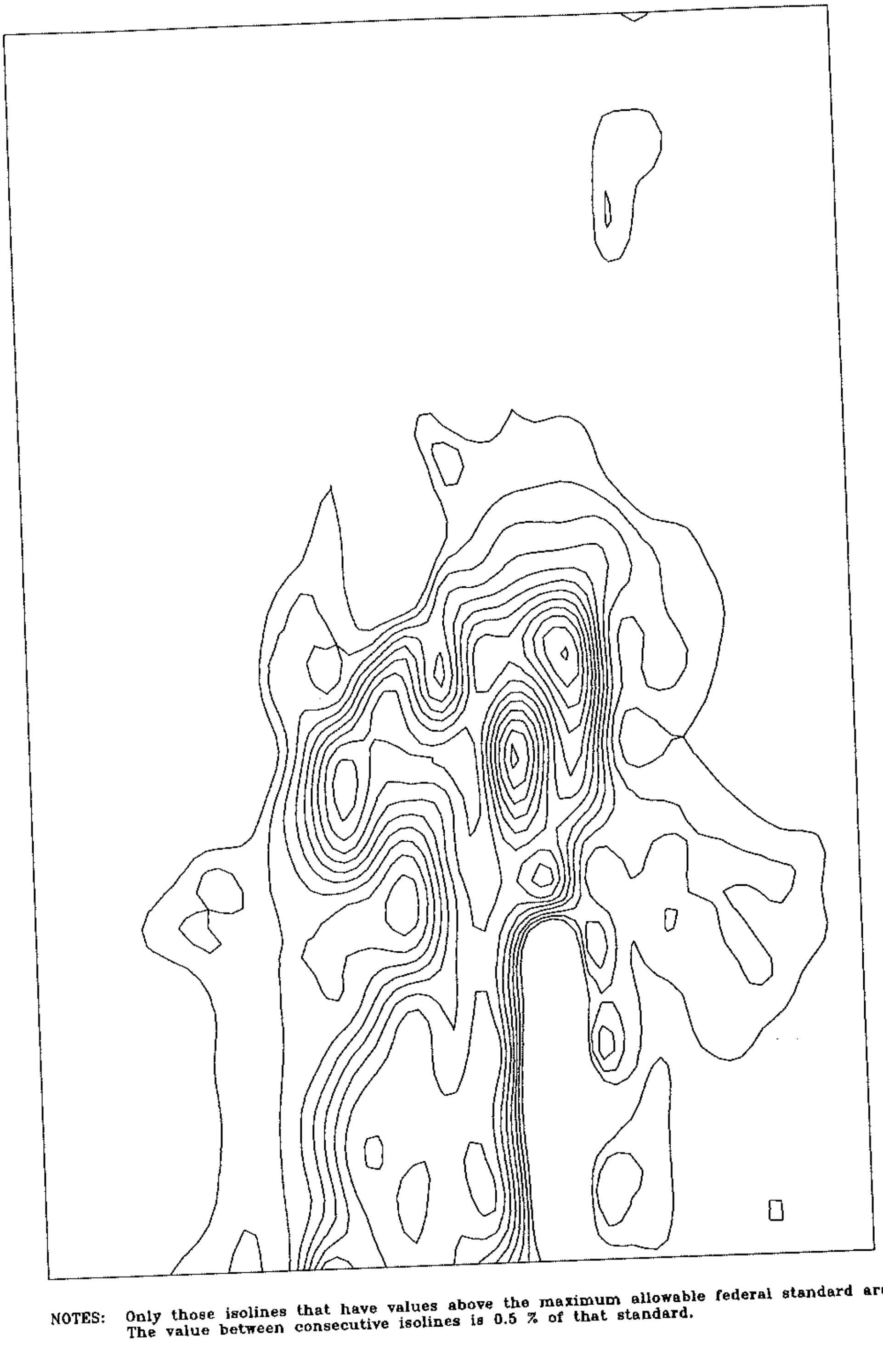
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 1.5 % of that standard.

Figure 33. LRT Full Network 1995 NO_x 100% Ridership



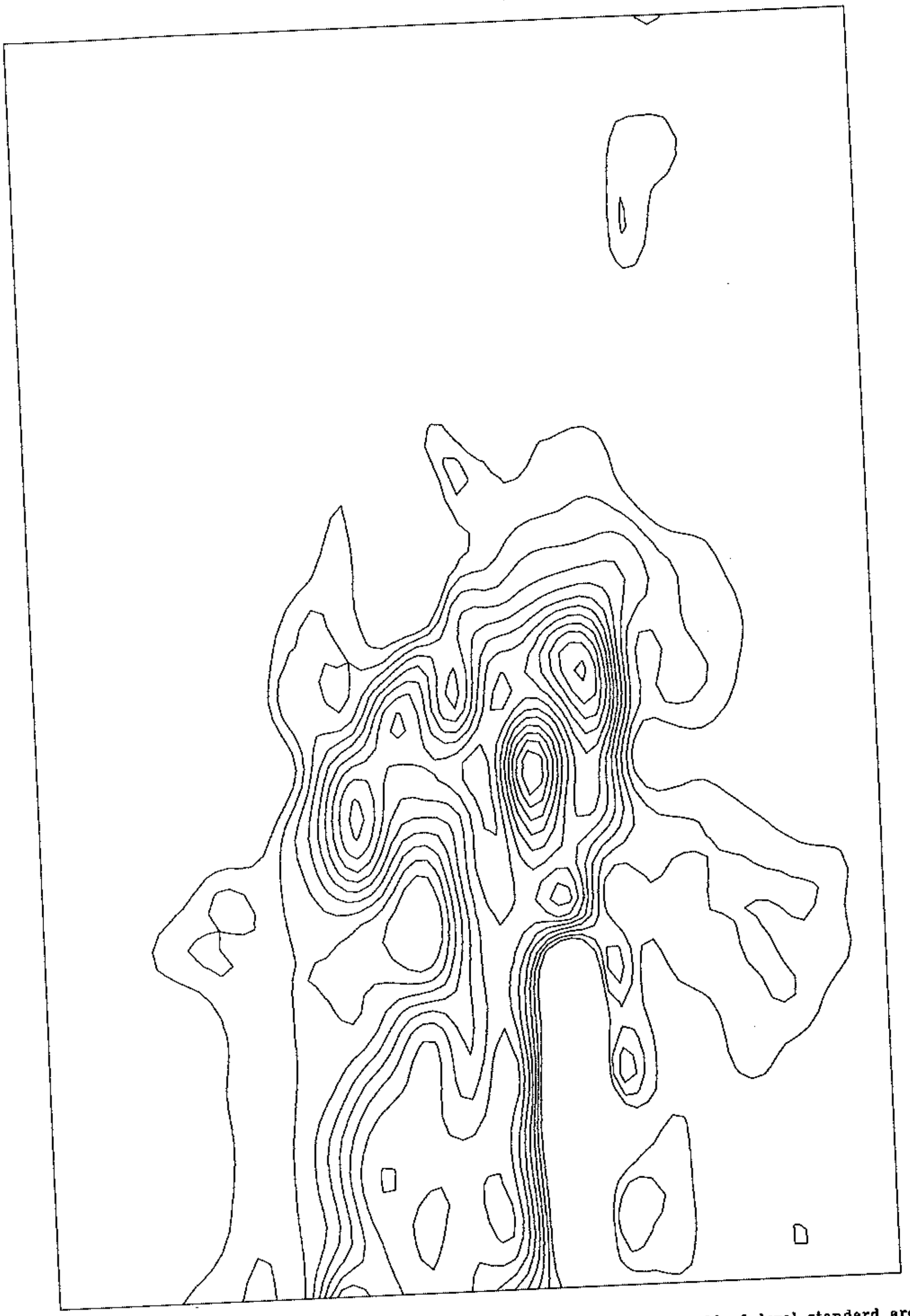
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 0.5 % of that standard.

Figure 34. LRT Full Network 1995 PM 25% Ridership



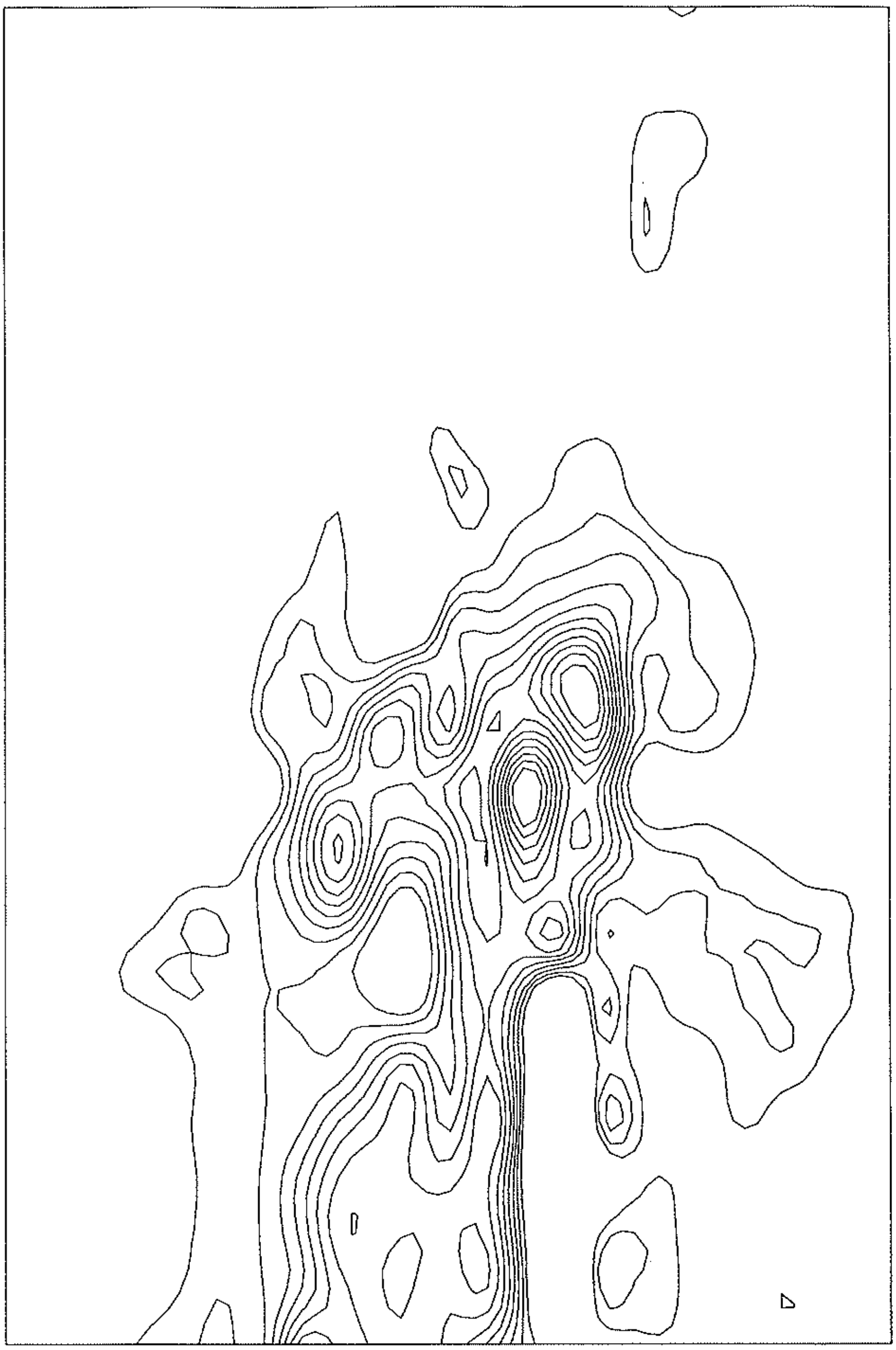
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 0.5 % of that standard.

Figure 35. LRT Full Network 1995 PM 50% Ridership



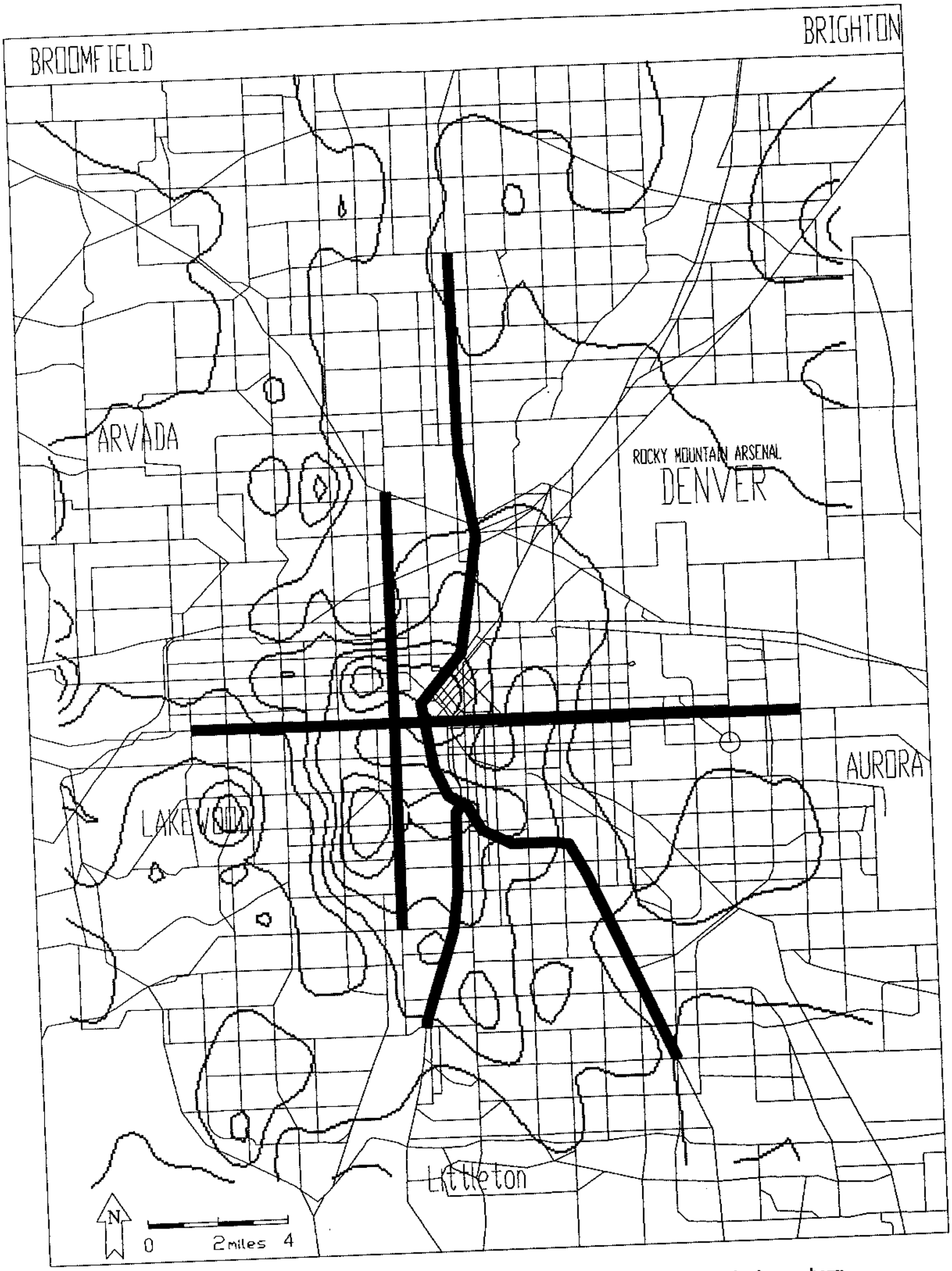
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 0.5 % of that standard.

Figure 36. LRT Full Network 1995 PM 75% Ridership



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 0.5 % of that standard.

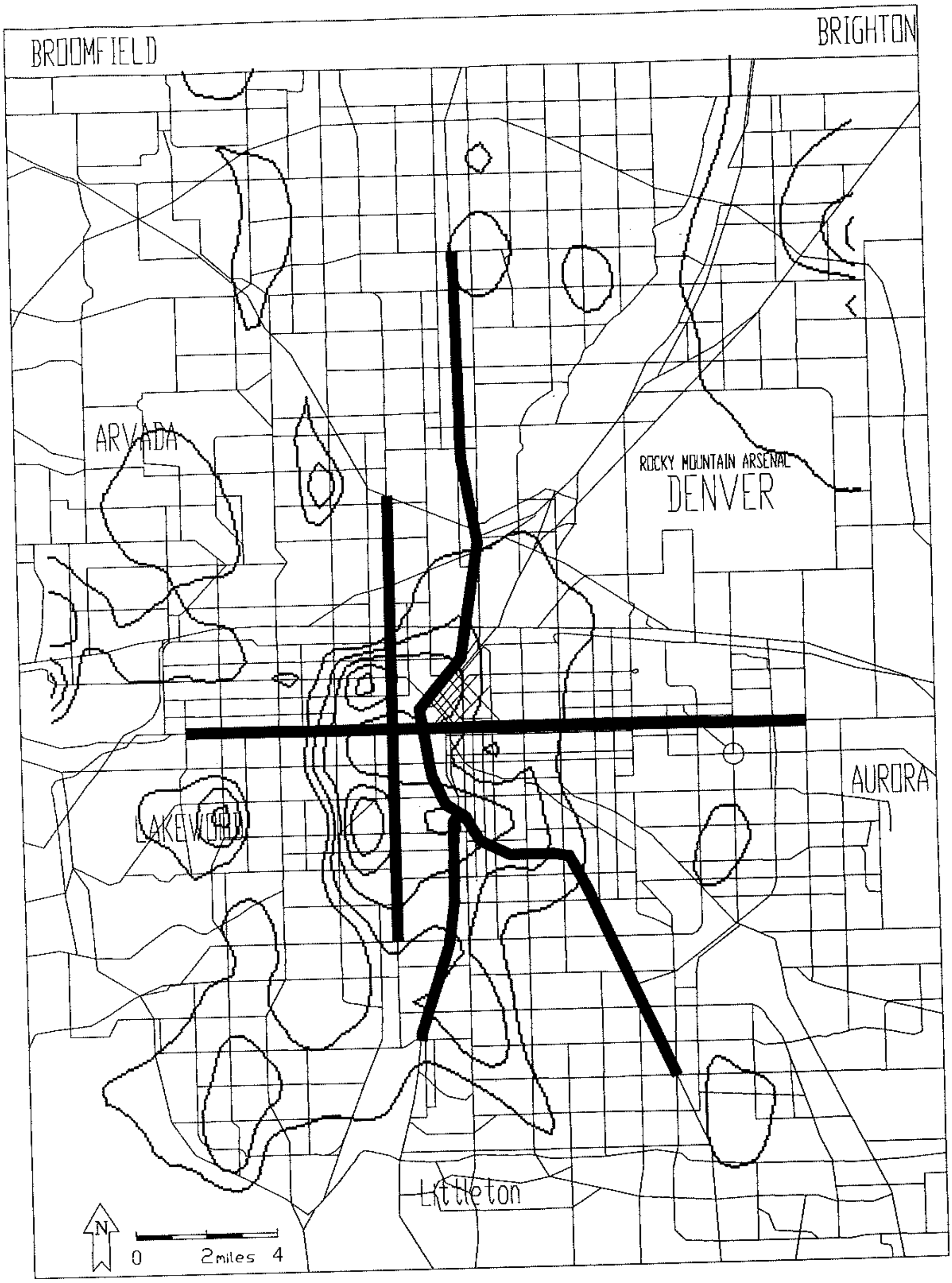
Figure 37. LRT Full Network 1995 PM 100% Ridership



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

LRT system

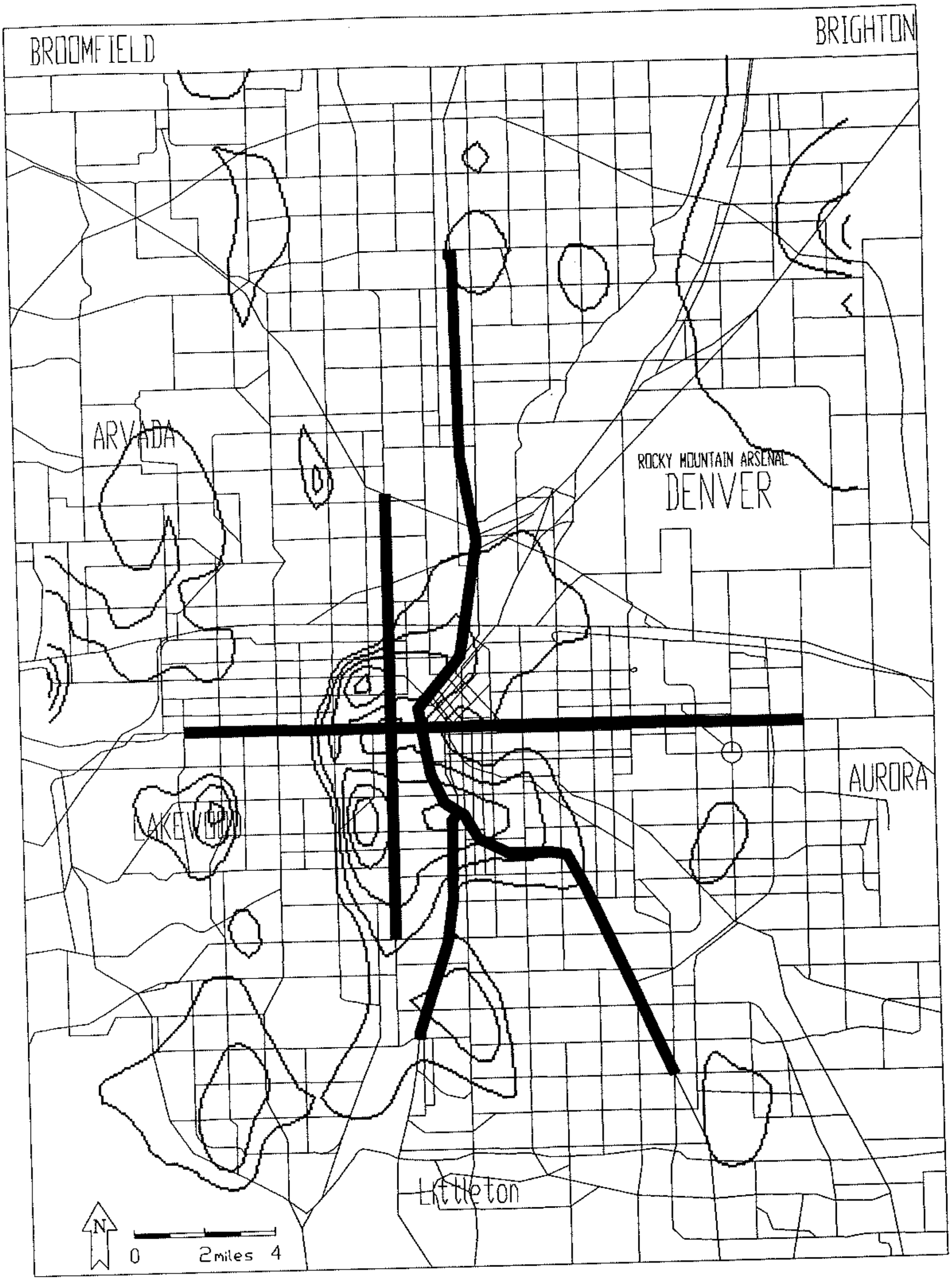
Figure 38. LRT Full Network 2010 CO 25% Ridership



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

LRT system

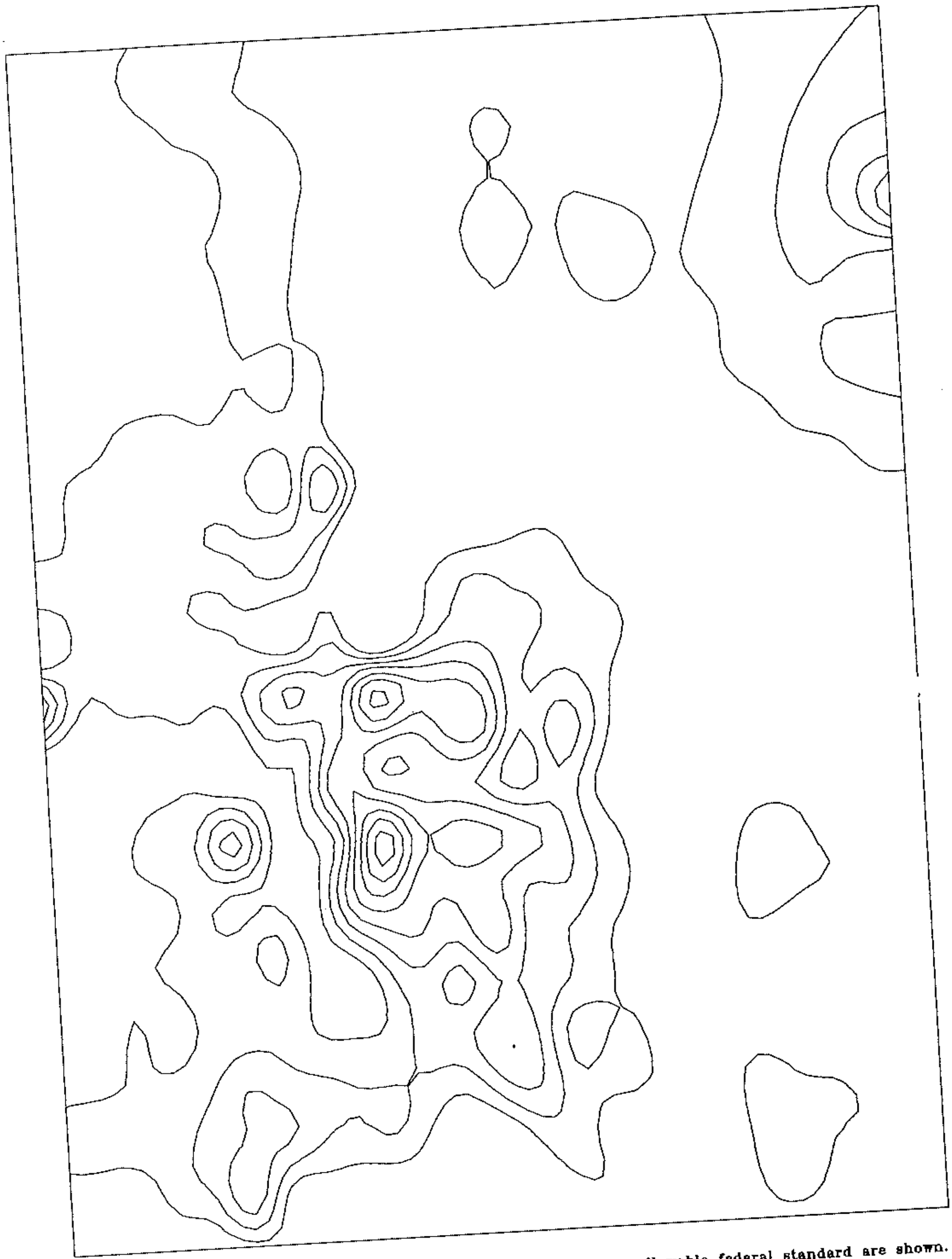
Figure 39. LRT Full Network 2010 CO 50% Ridership



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

LRT system

Figure 40. LRT Full Network 2010 CO 100% Ridership

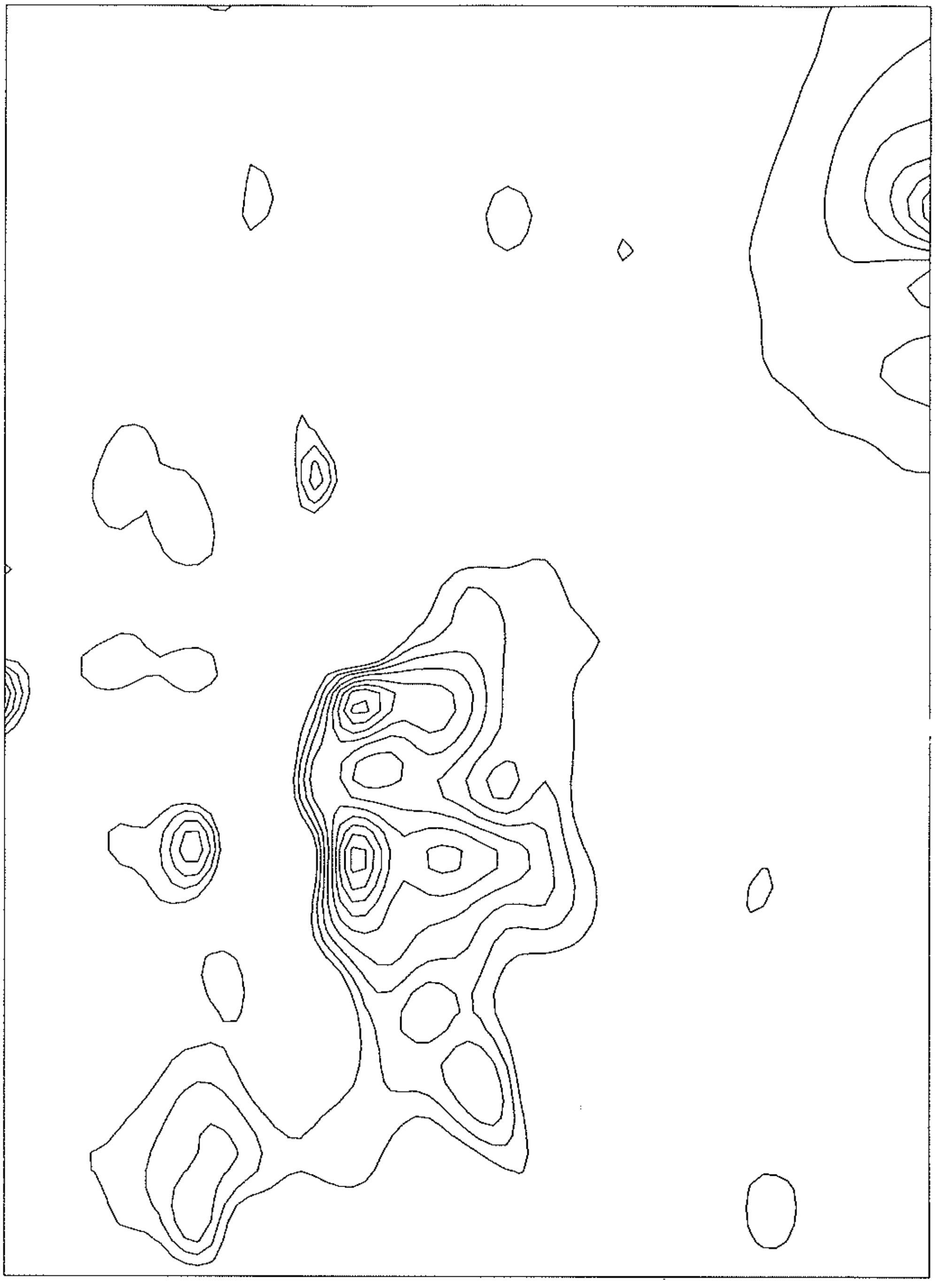


NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2.5 % of that standard.

Figure 41. LRT Full Network 2010 HC 25% Ridership

NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2.5 % of that standard.

Figure 42. LRT Full Network 2010 HC 50% Ridership



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2.5 % of that standard.

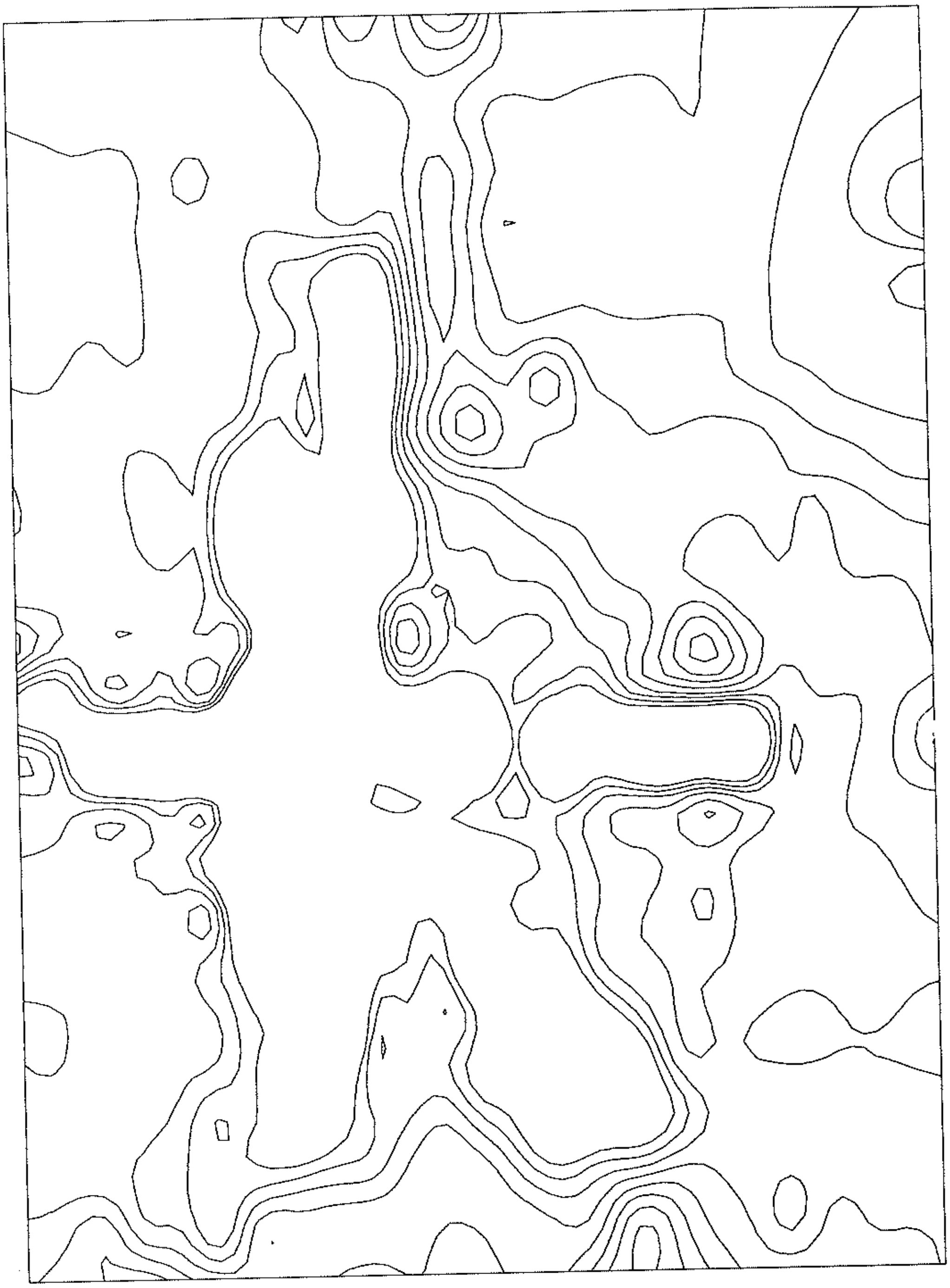
Figure 43. LRT Full Network 2010 HC 75% Ridership

NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 44. LRT Full Network 2010 NO_x 25% Ridership

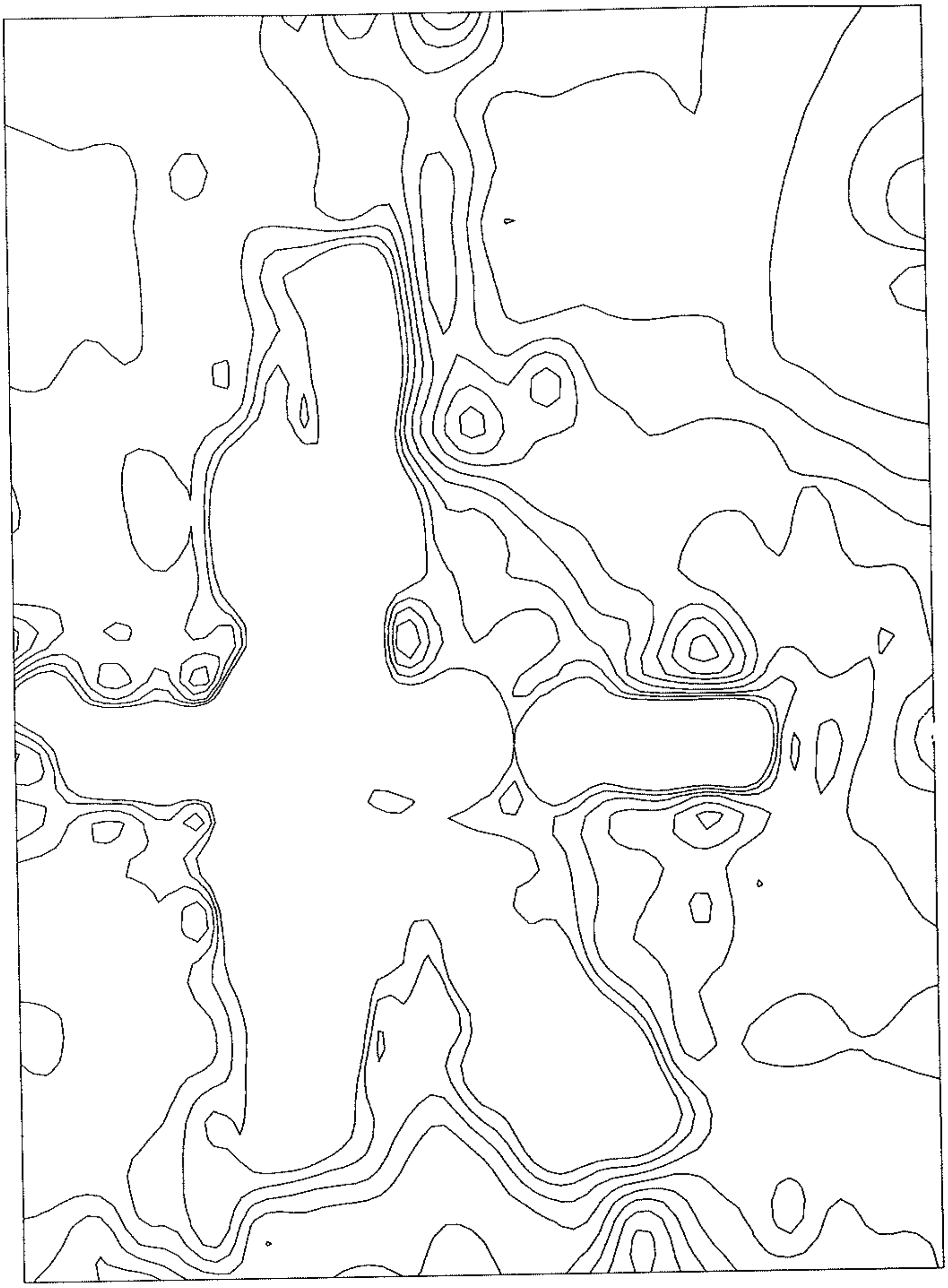
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 45. LRT Full Network 2010 NO_x 50% Ridership



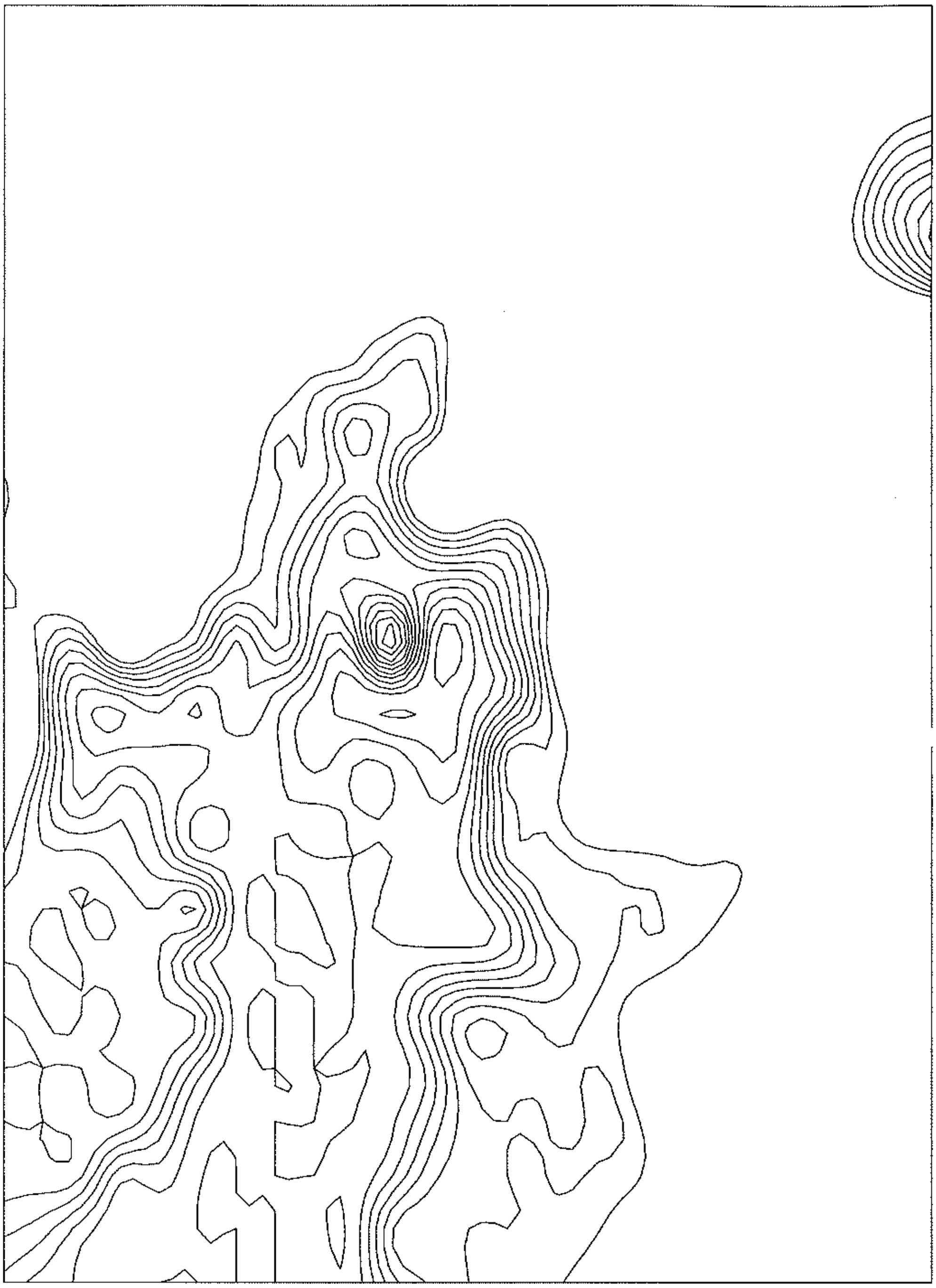
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 46. LRT Full Network 2010 NO_x 75% Ridership



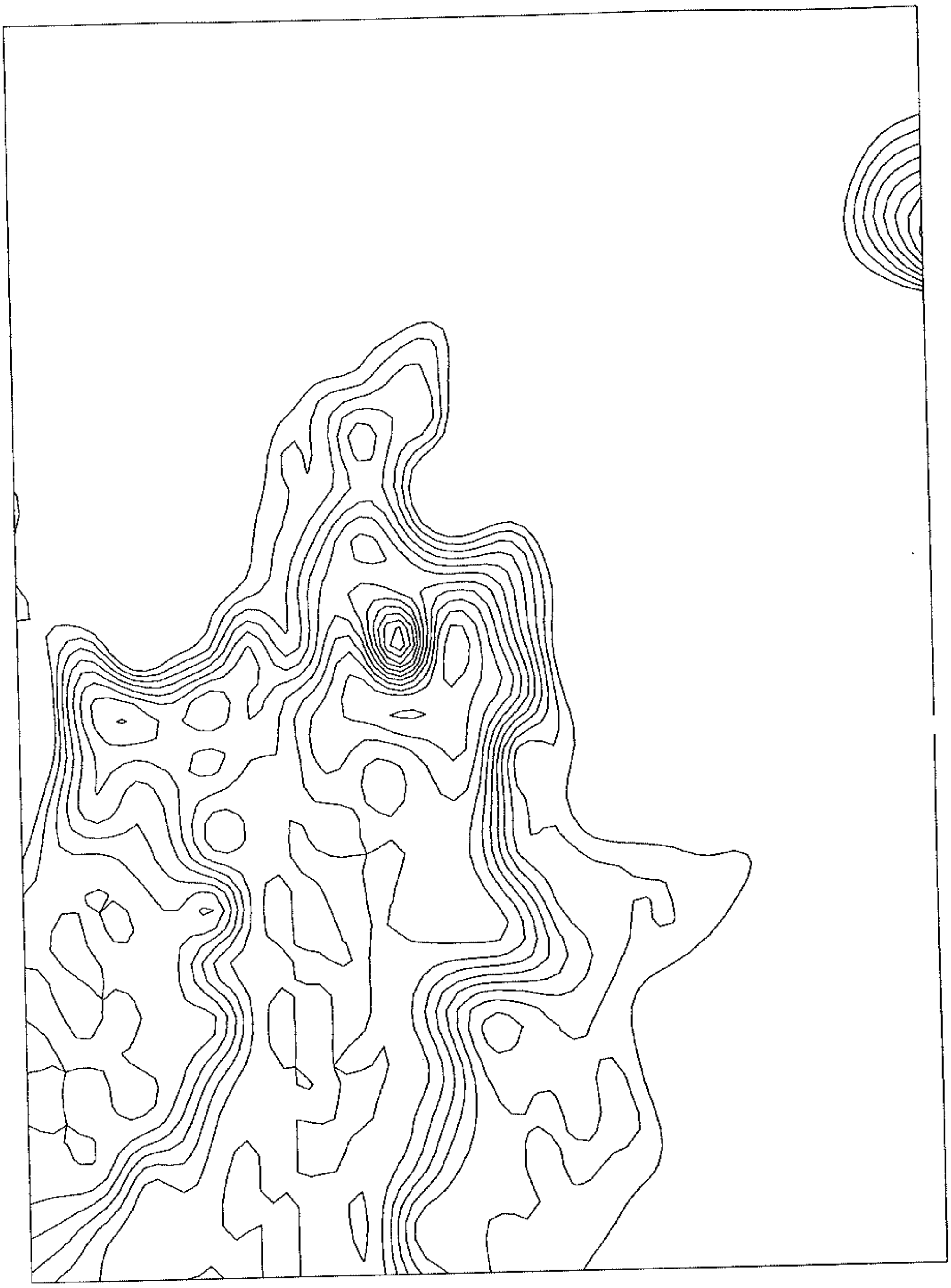
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 47. LRT Full Network 2010 NO_x 100% Ridership



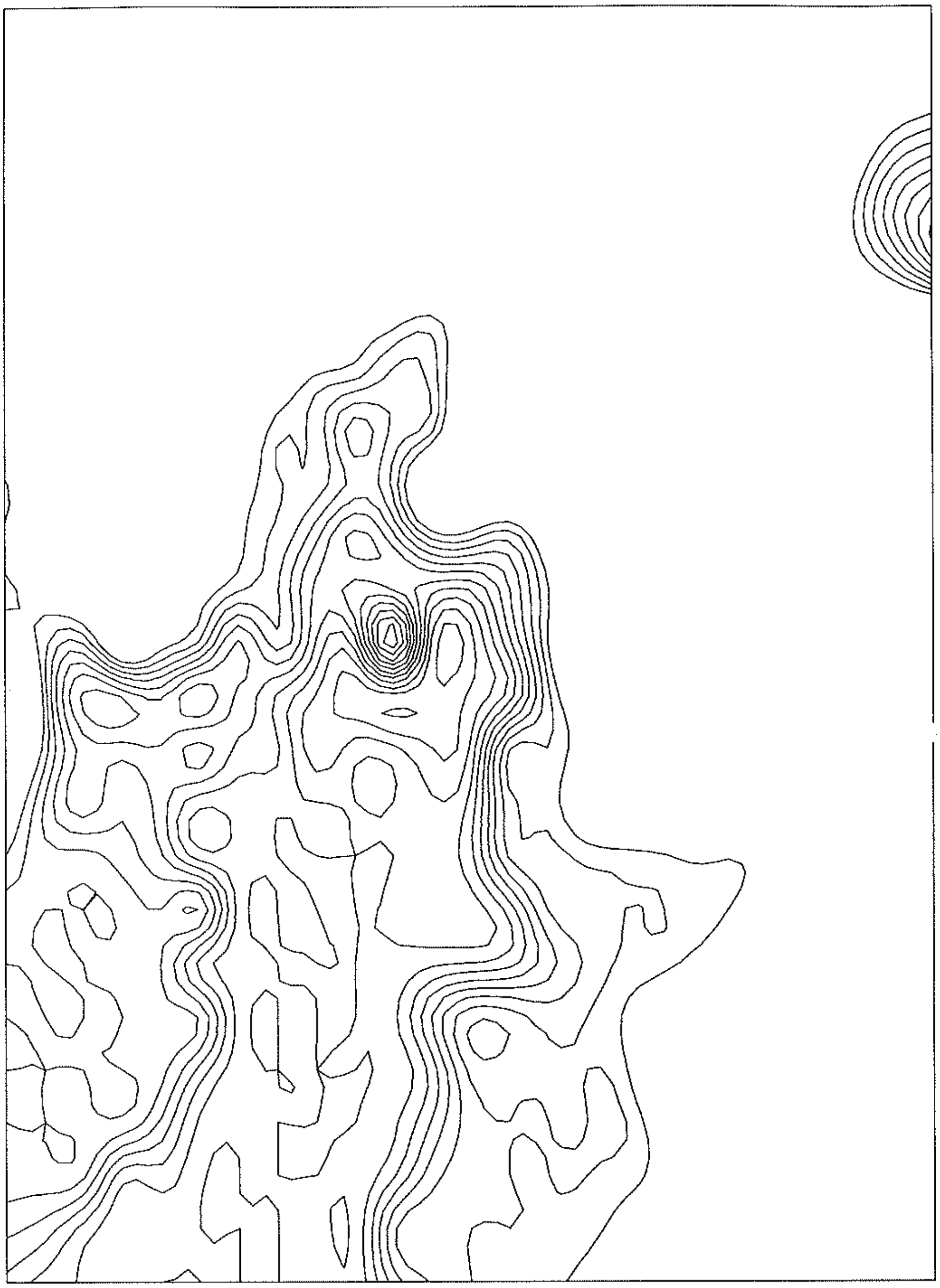
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 0.5 % of that standard.

Figure 48. LRT Full Network 2010 PM 25% Ridership



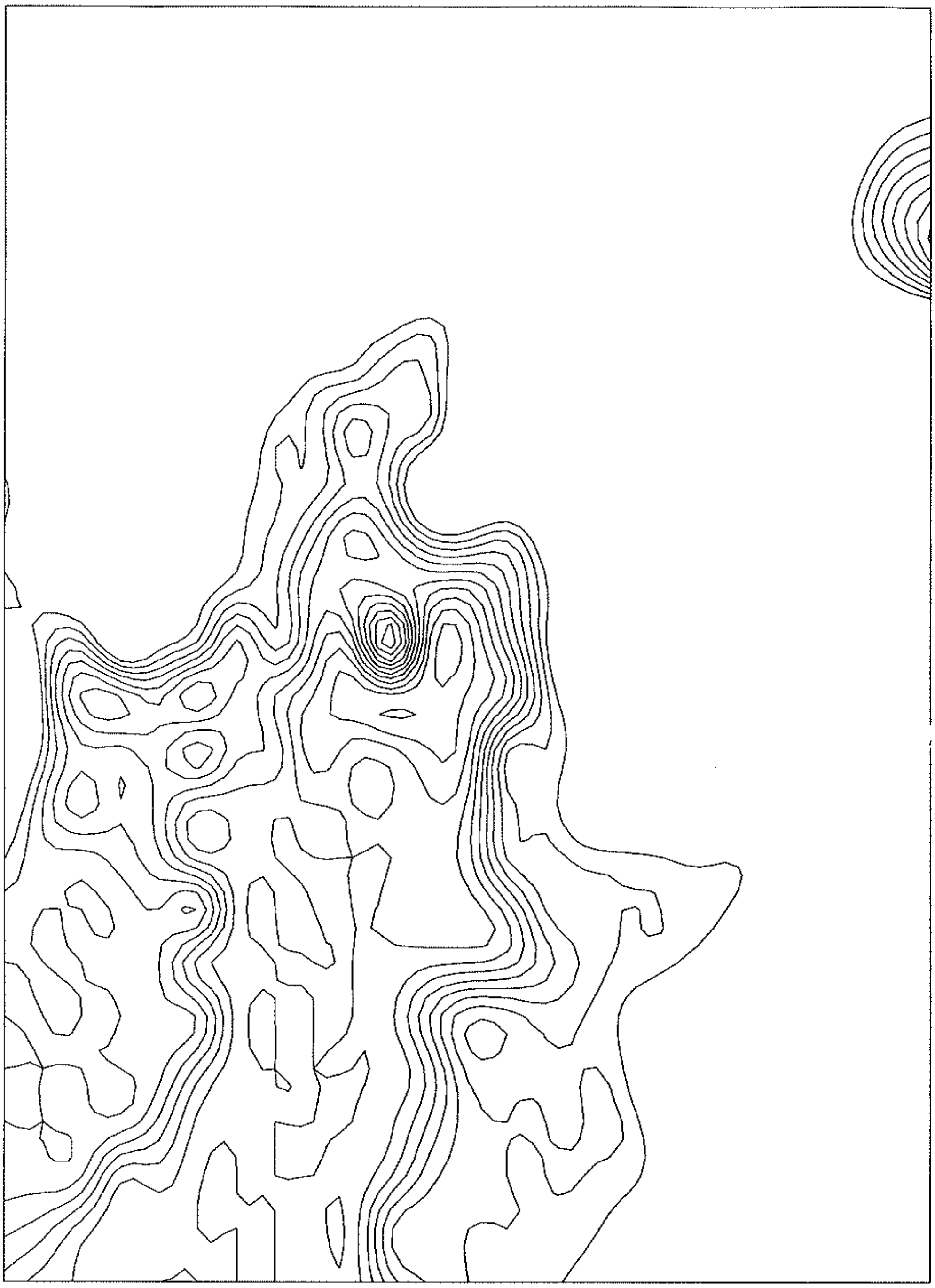
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 0.5 % of that standard.

Figure 49. LRT Full Network 2010 PM 50% Ridership



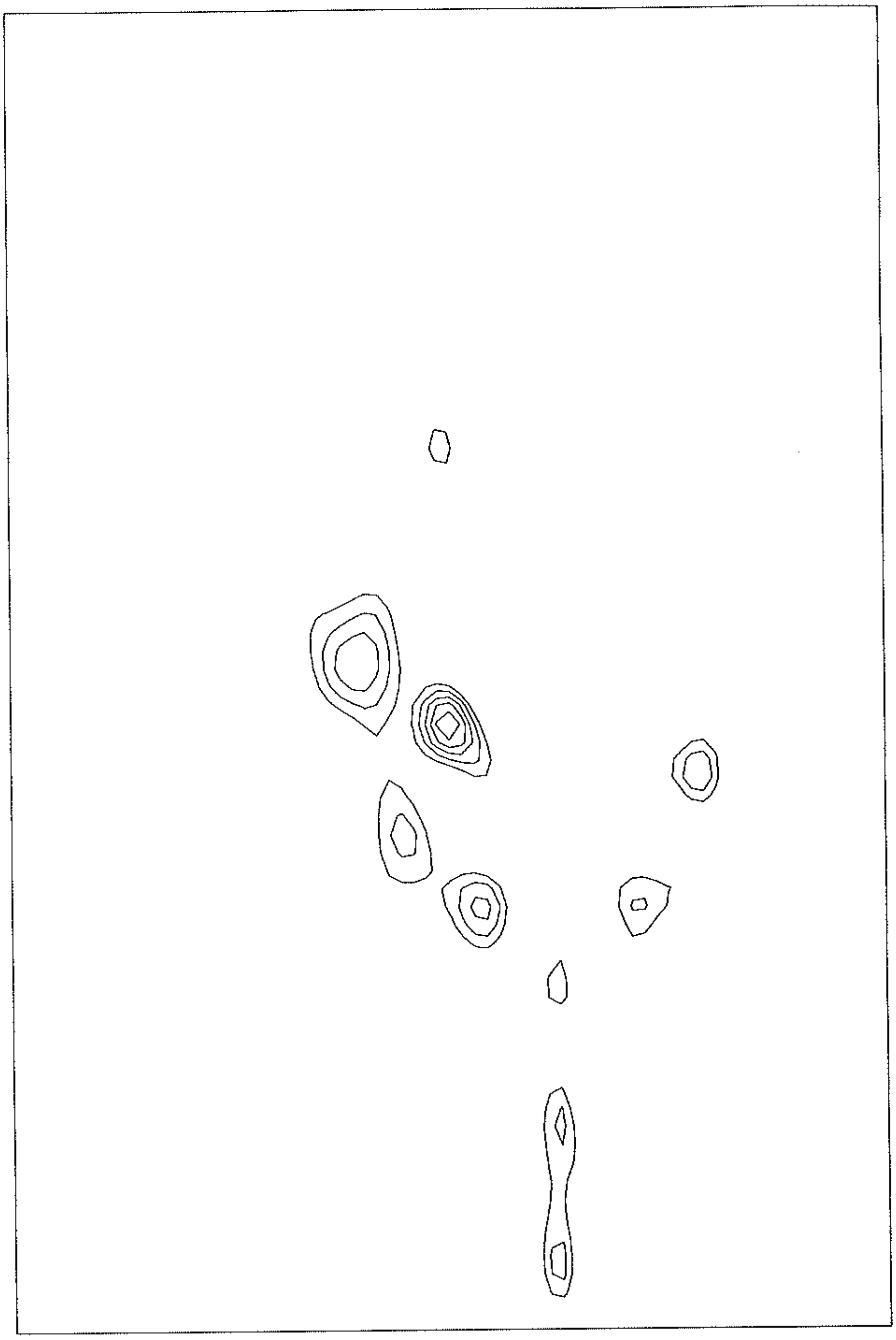
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 0.5 % of that standard.

Figure 50. LRT Full Network 2010 PM 75% Ridership



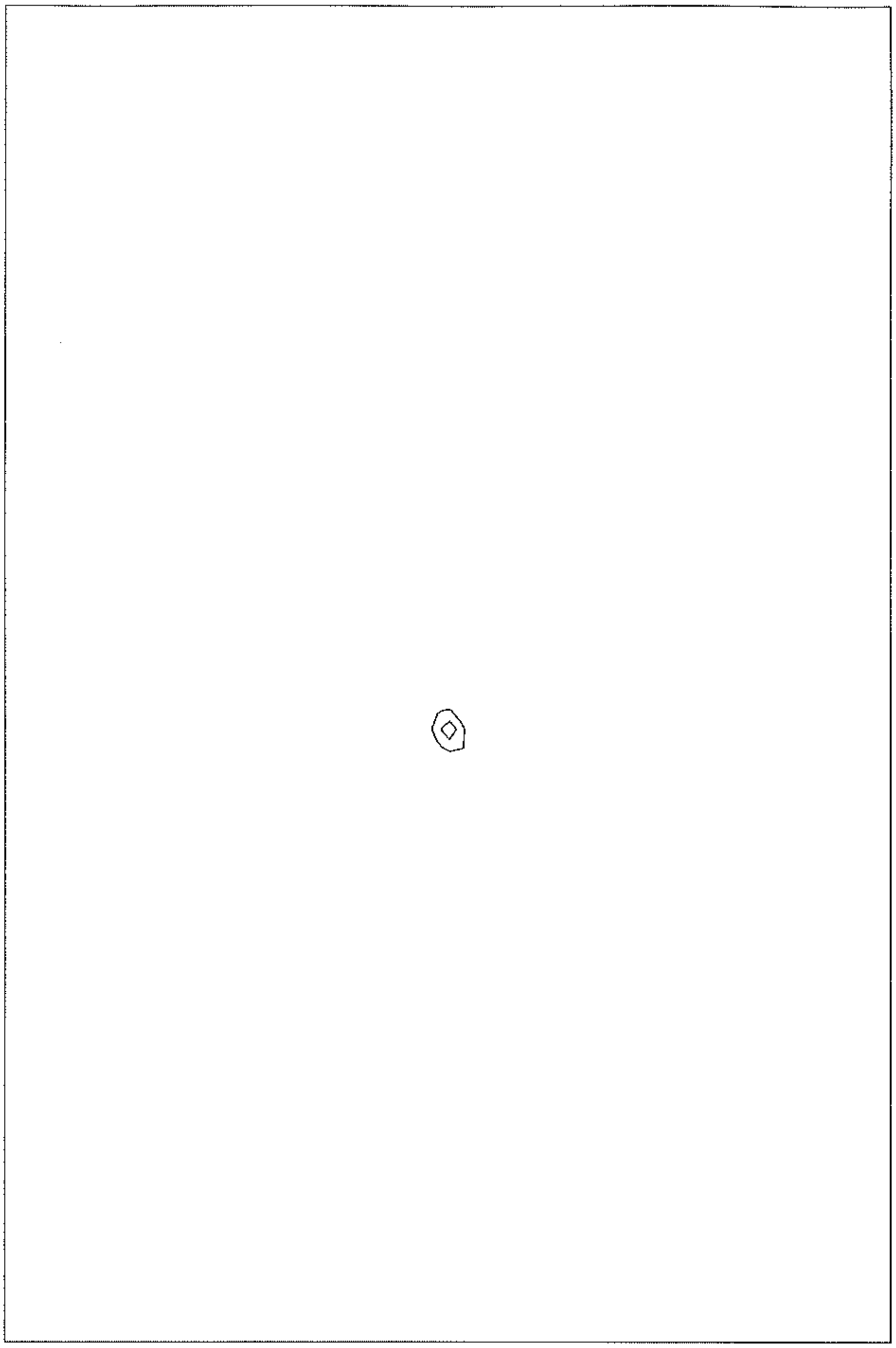
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 0.5 % of that standard.

Figure 51. LRT Full Network 2010 PM 100% Ridership



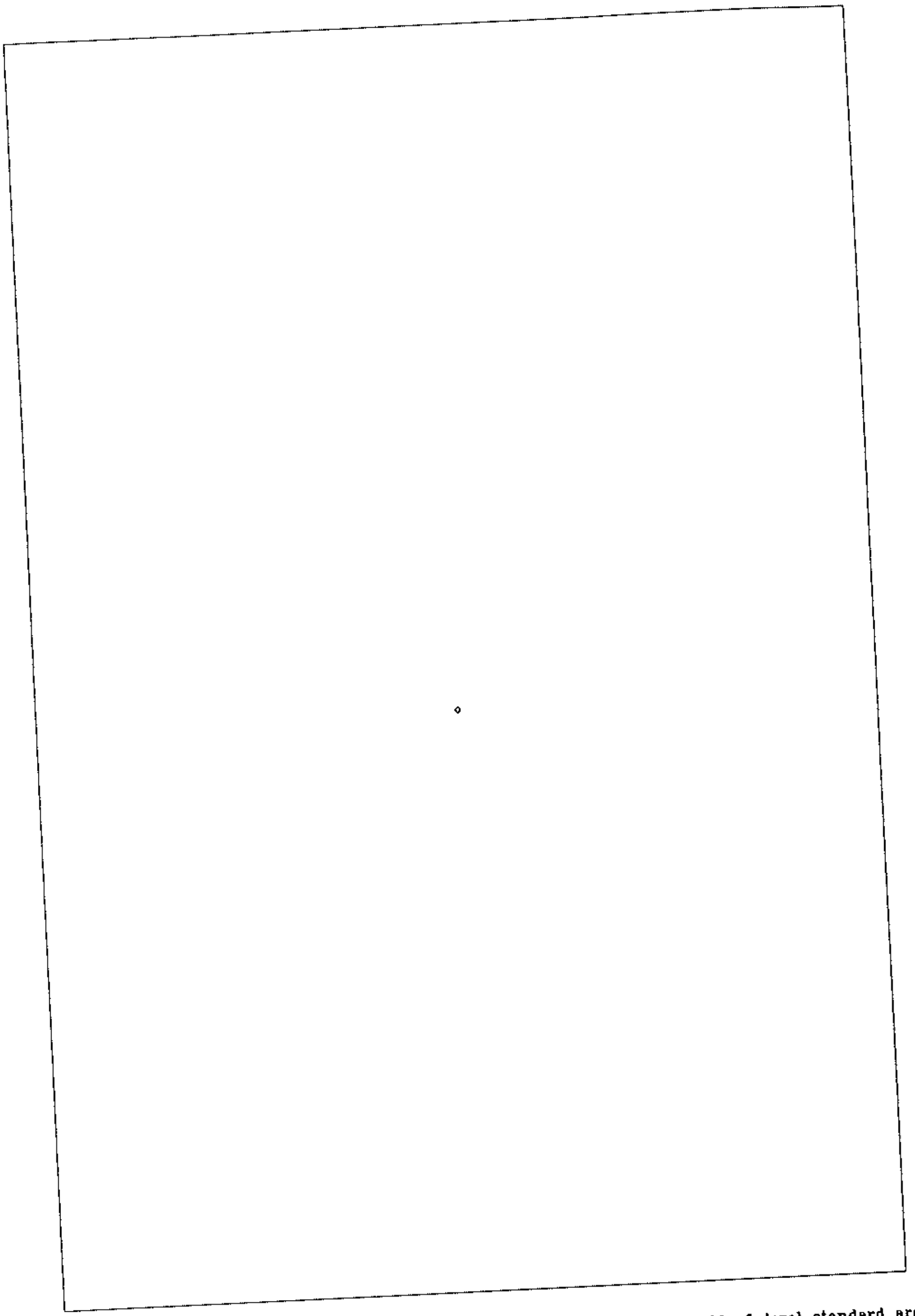
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

Figure 52. RPEV 1995 CO 25% Implementation



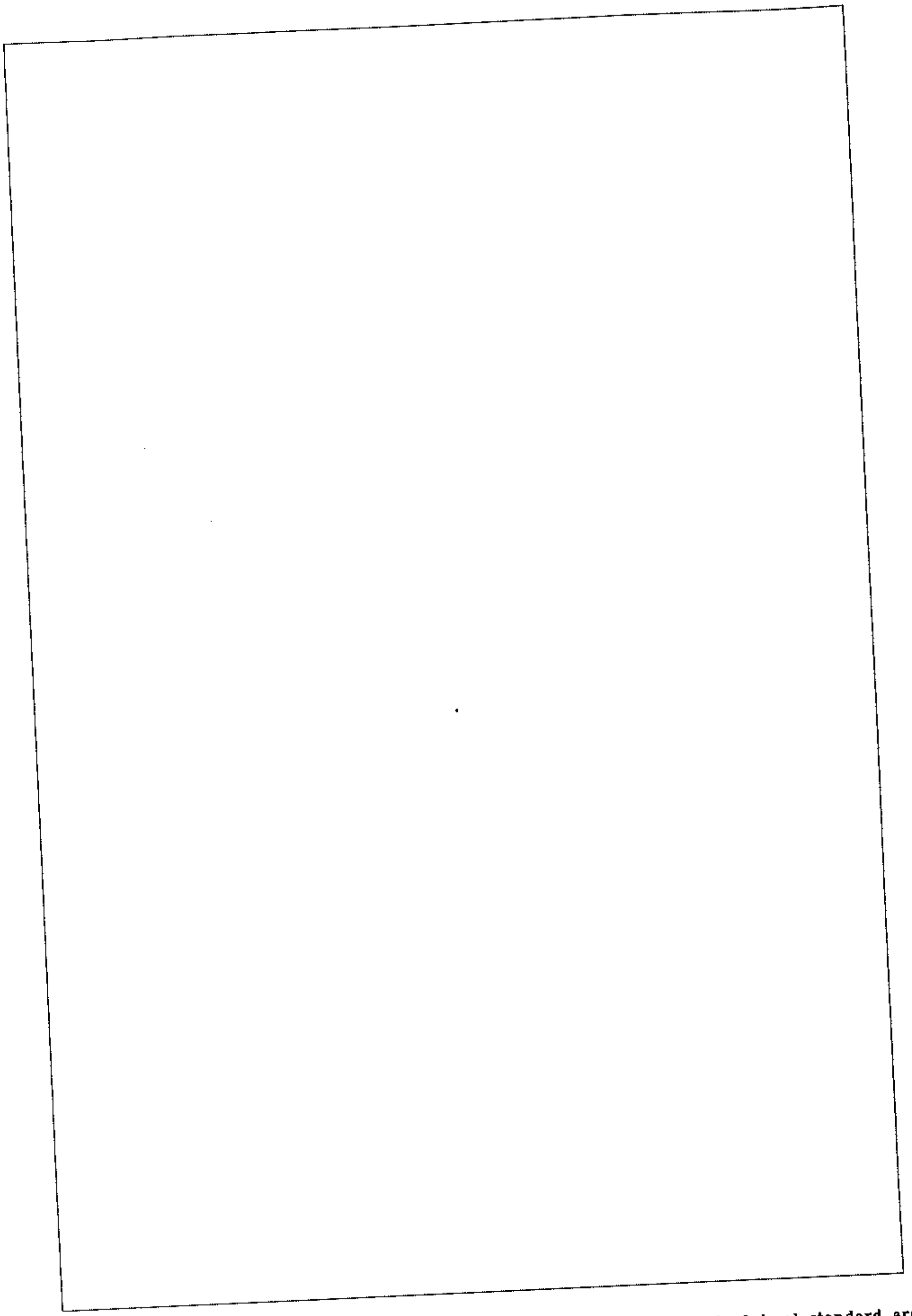
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 2 % of that standard.

Figure 53. RPEV 1995 CO 50% Implementation



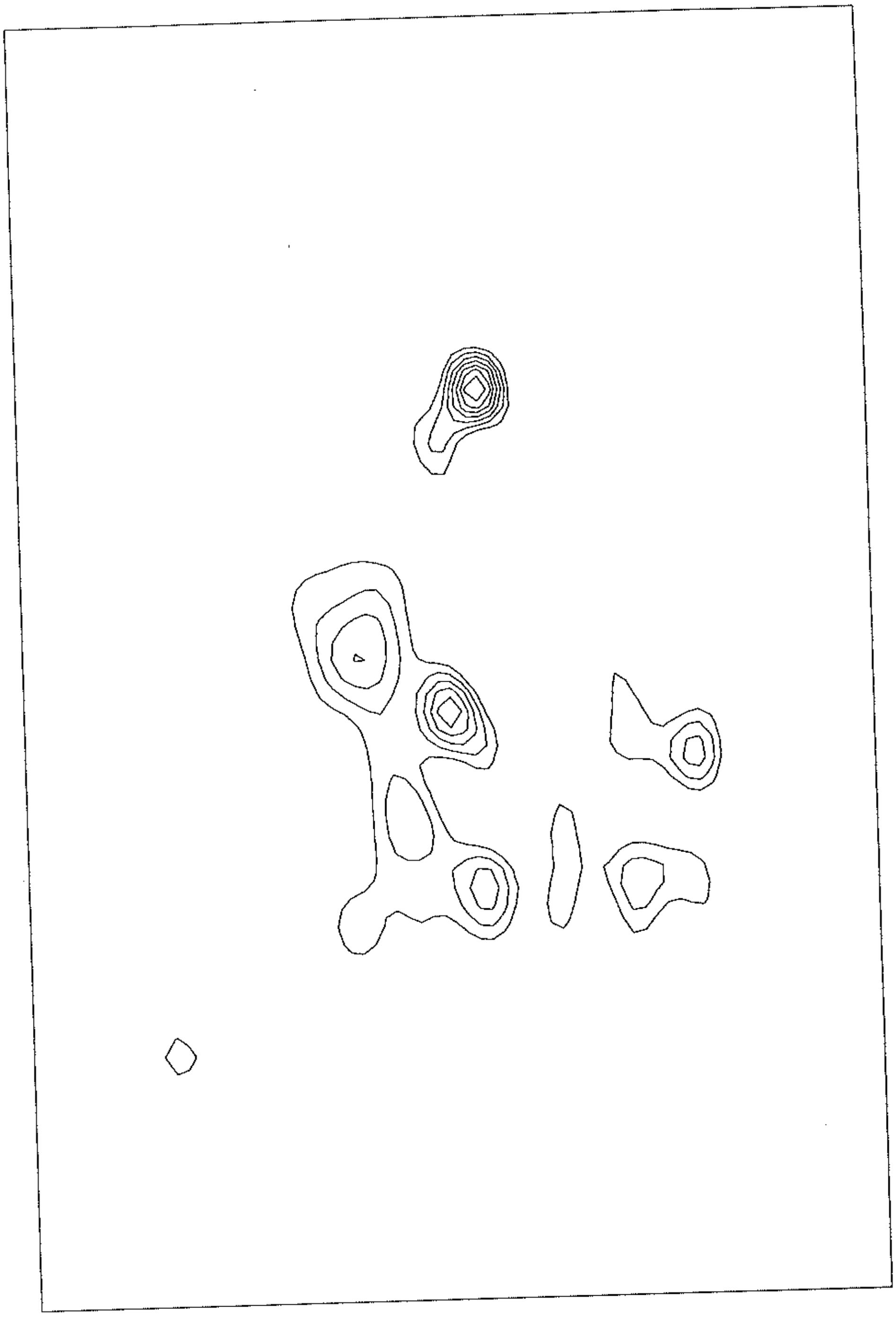
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 2 % of that standard.

Figure 54. RPEV 1995 CO 75% Implementation



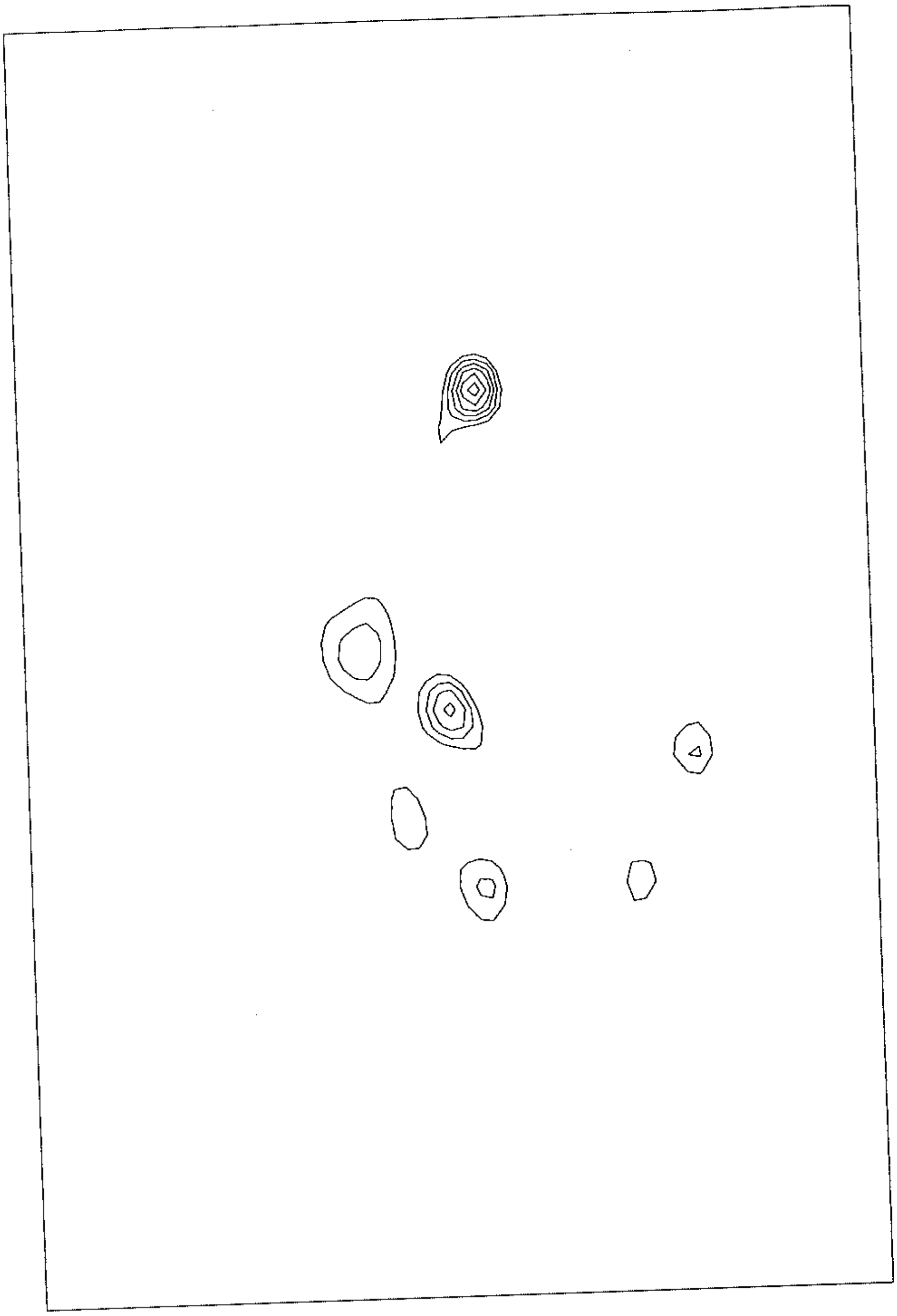
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 2 % of that standard.

Figure 55. RPEV 1995 CO 100% Implementation



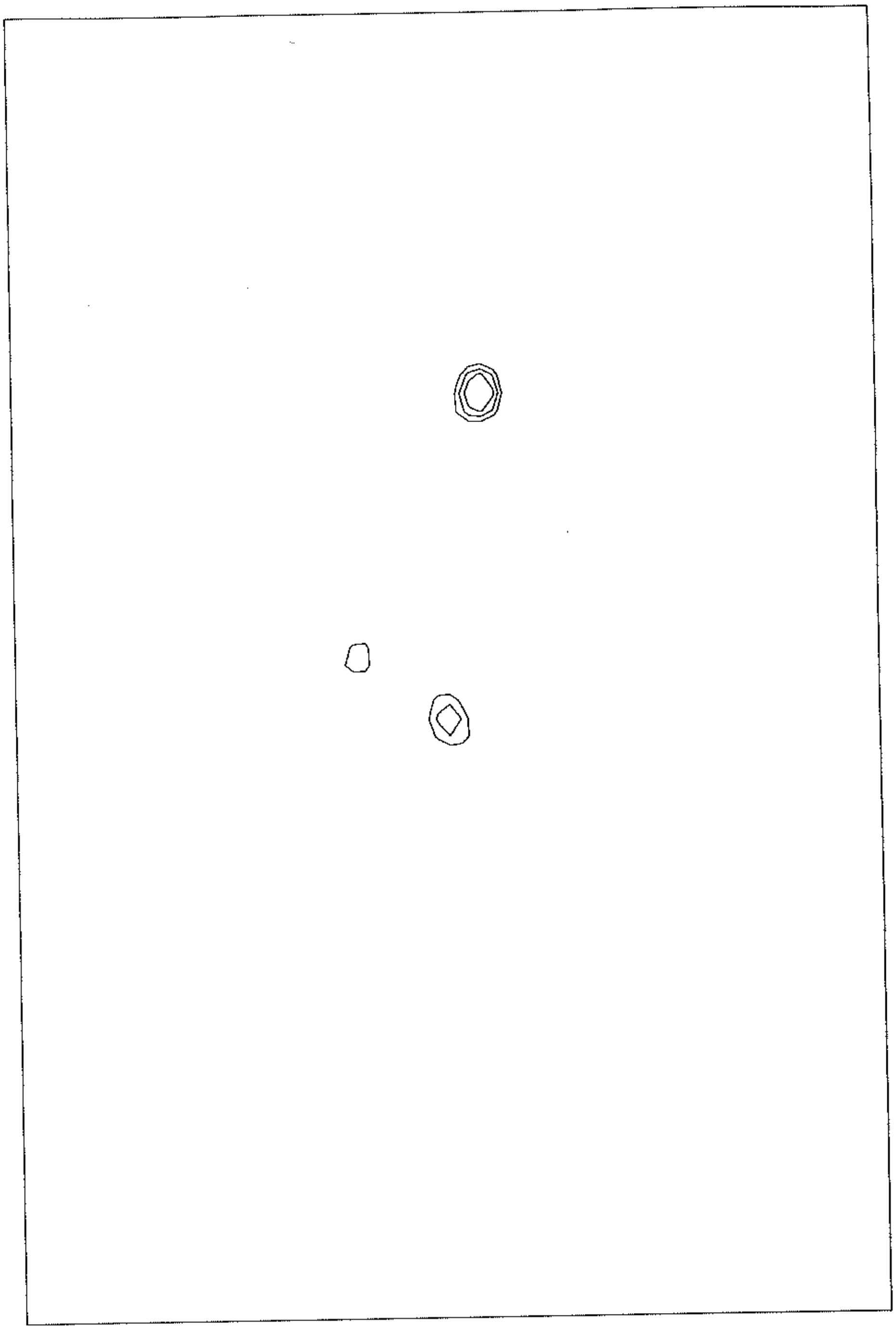
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2.5 % of that standard.

Figure 56. RPEV 1995 HC 25% Implementation



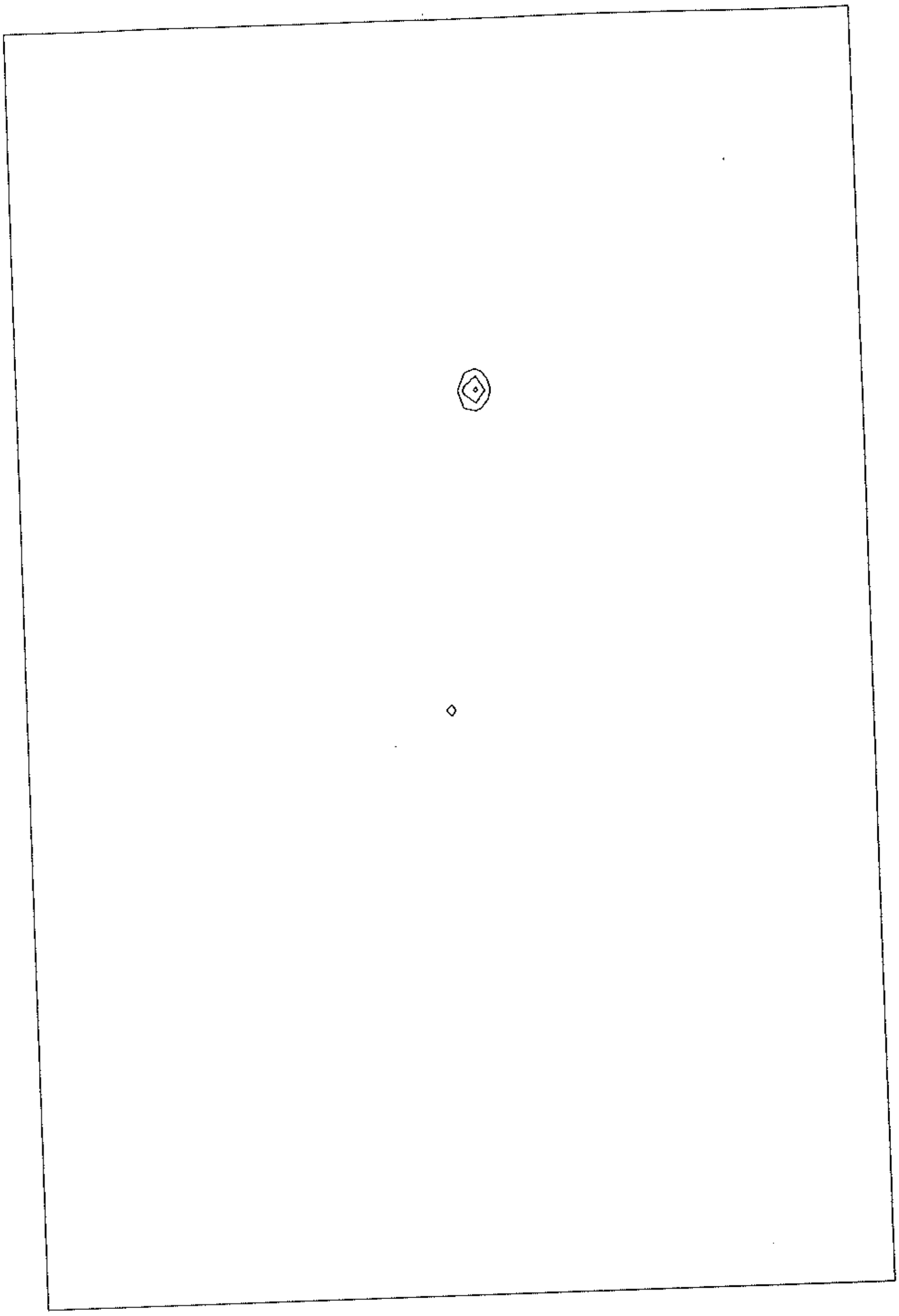
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 2.5 % of that standard.

Figure 57. RPEV 1995 HC 50% Implementation



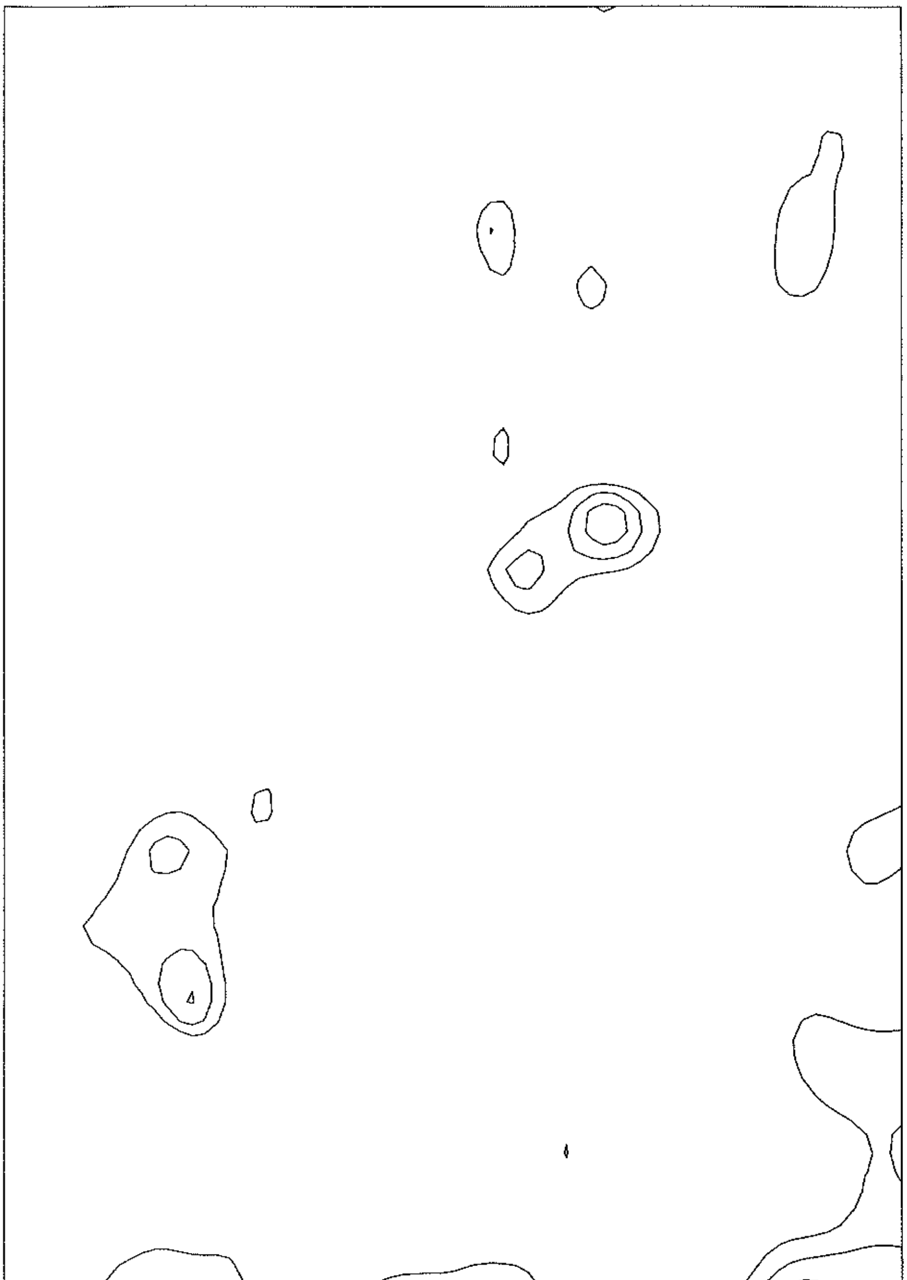
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 2.5 % of that standard.

Figure 58. RPEV 1995 HC 75% Implementation



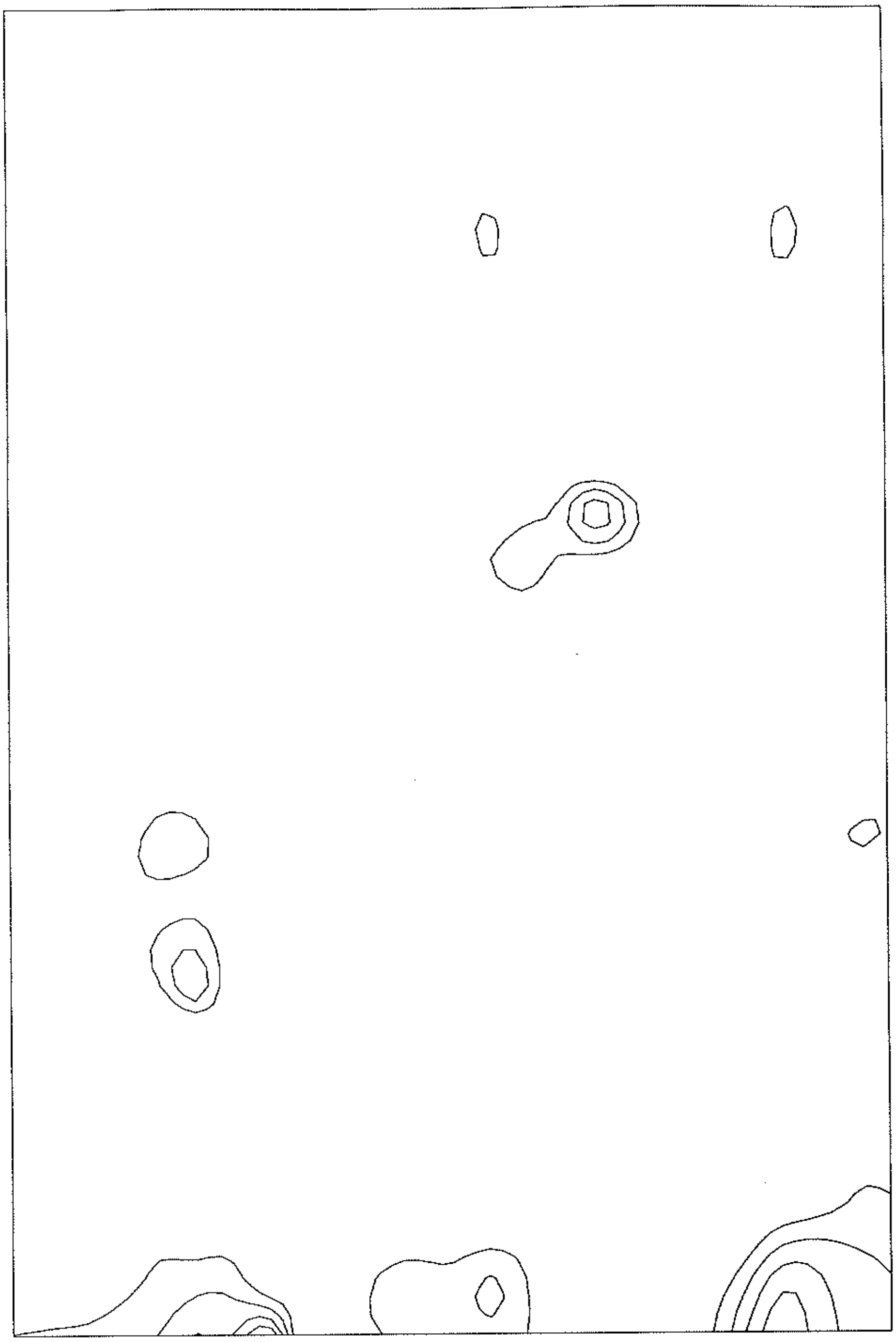
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 2.5 % of that standard.

Figure 59. RPEV 1995 HC 100% Implementation



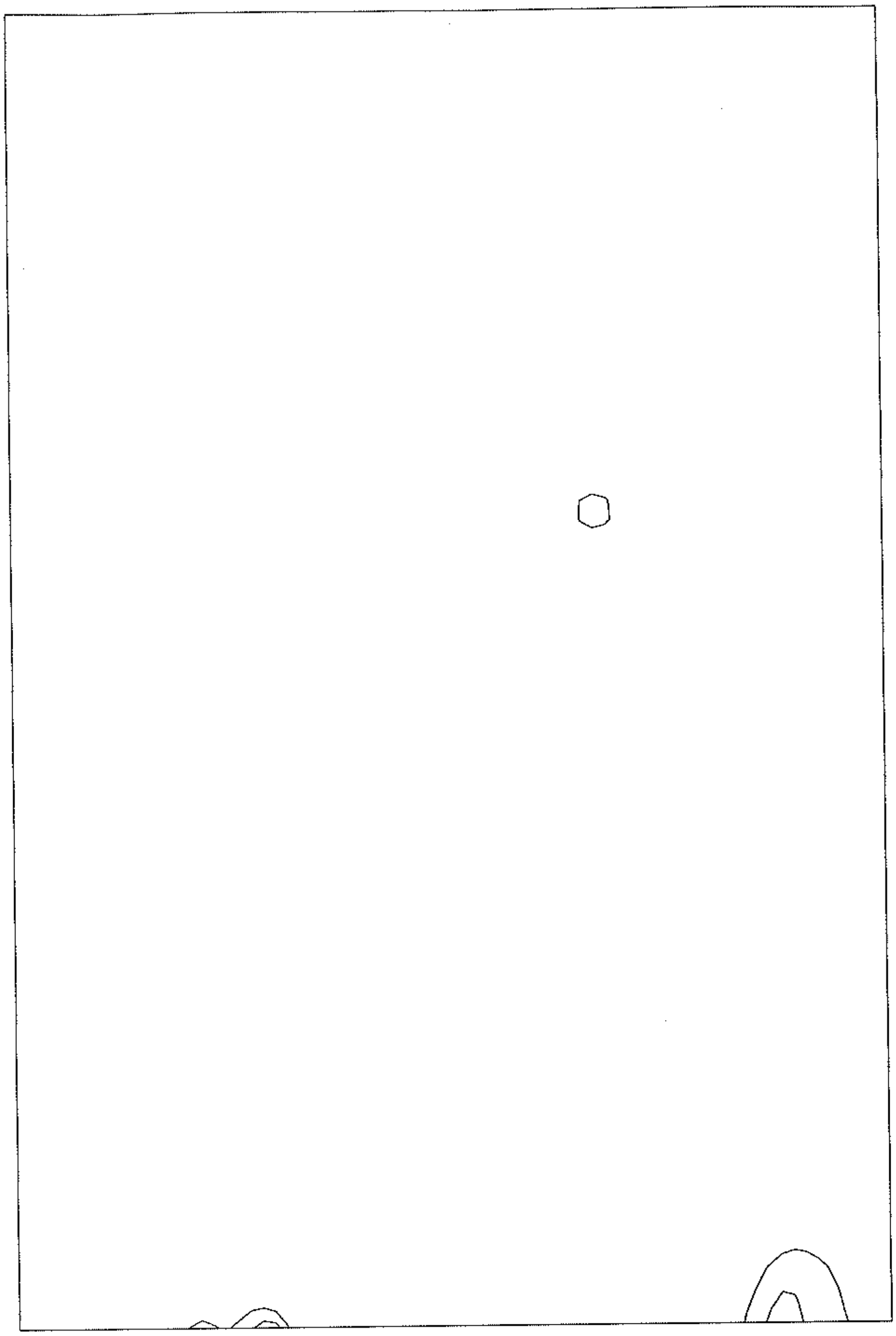
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 60. RPEV 1995 NO_x 25% Implementation



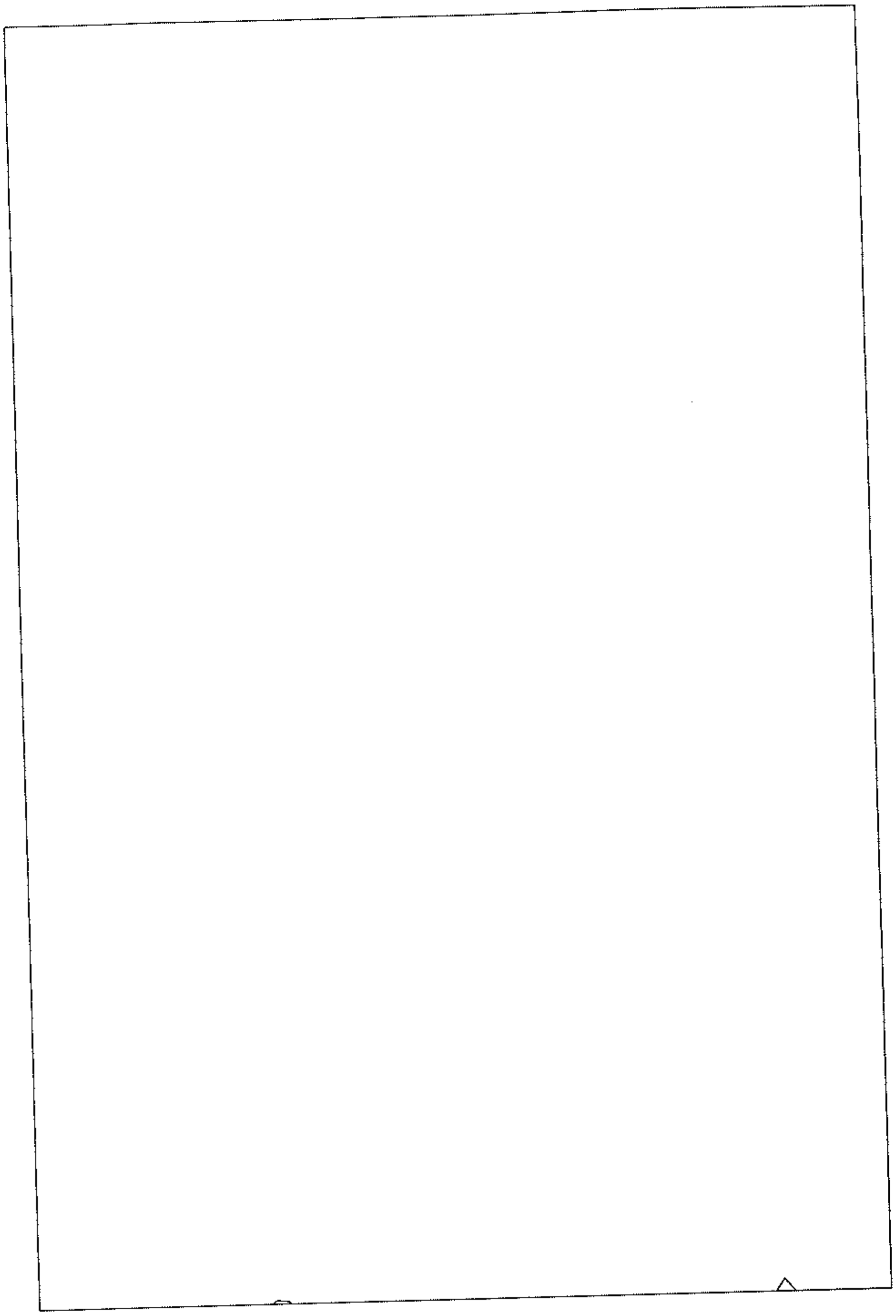
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 61. RPEV 1995 NO_x 50% Implementation



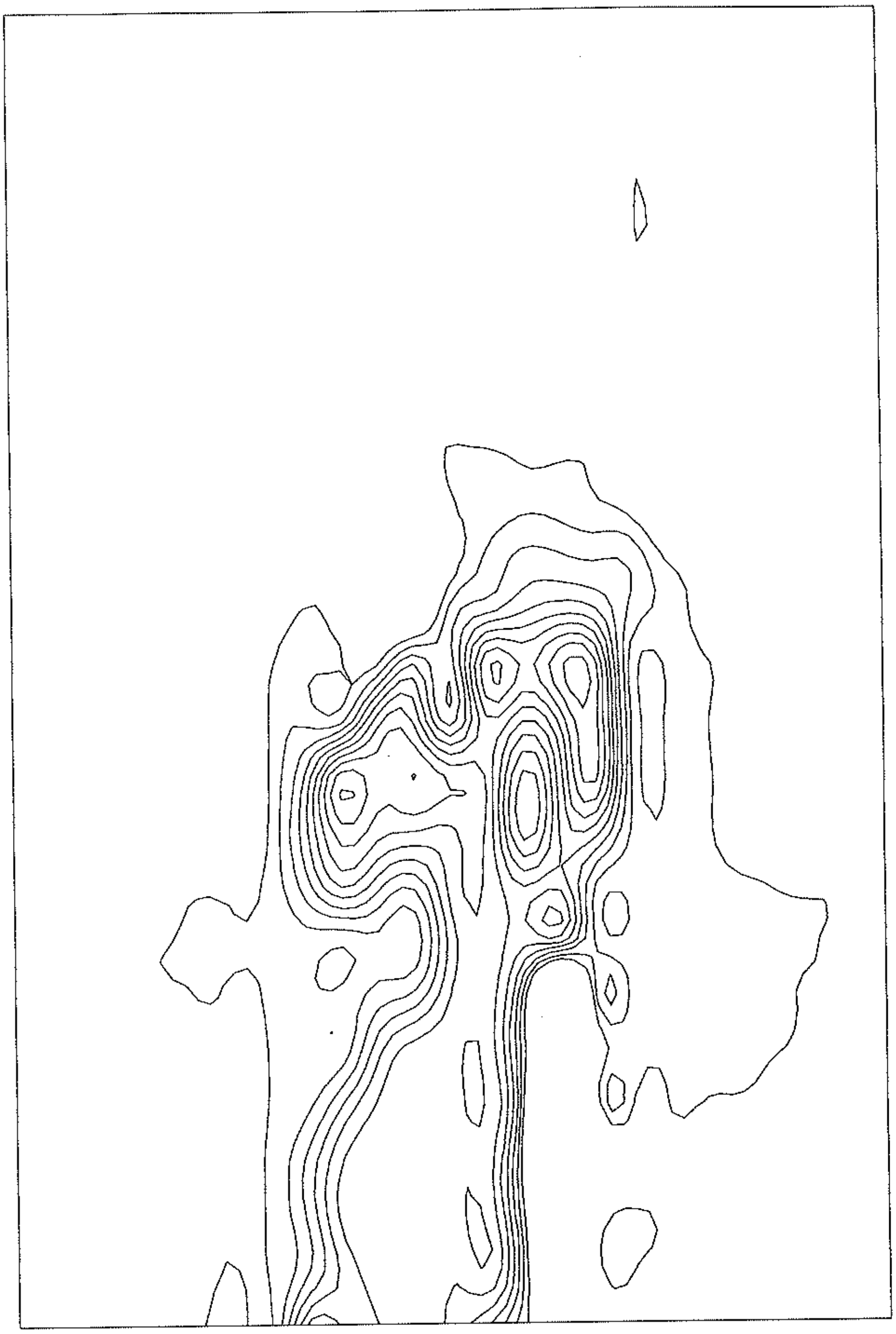
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 1.5 % of that standard.

Figure 62. RPEV 1995 NO_x 75% Implementation



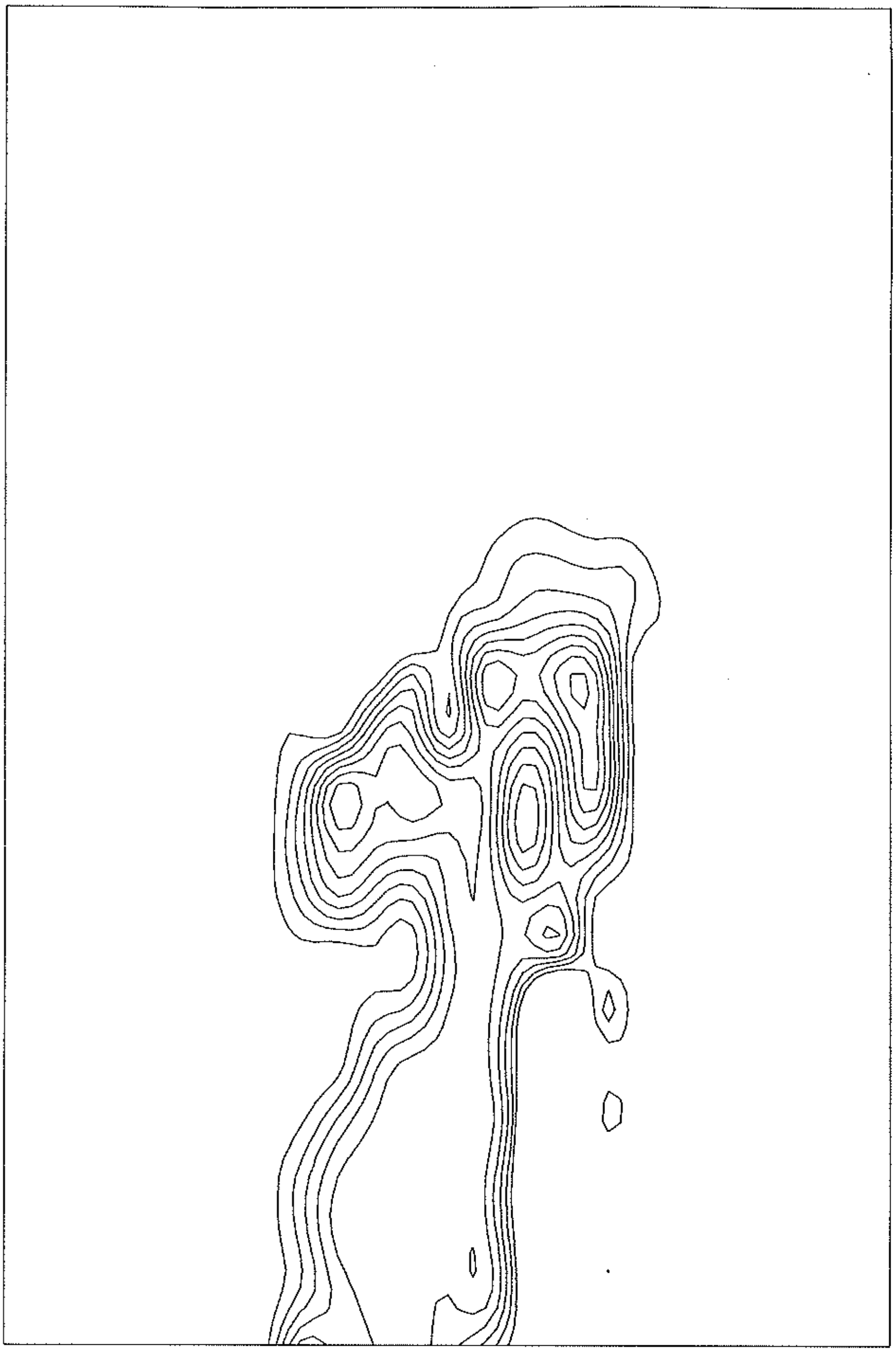
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 63. RPEV 1995 NO_x 100% Implementation



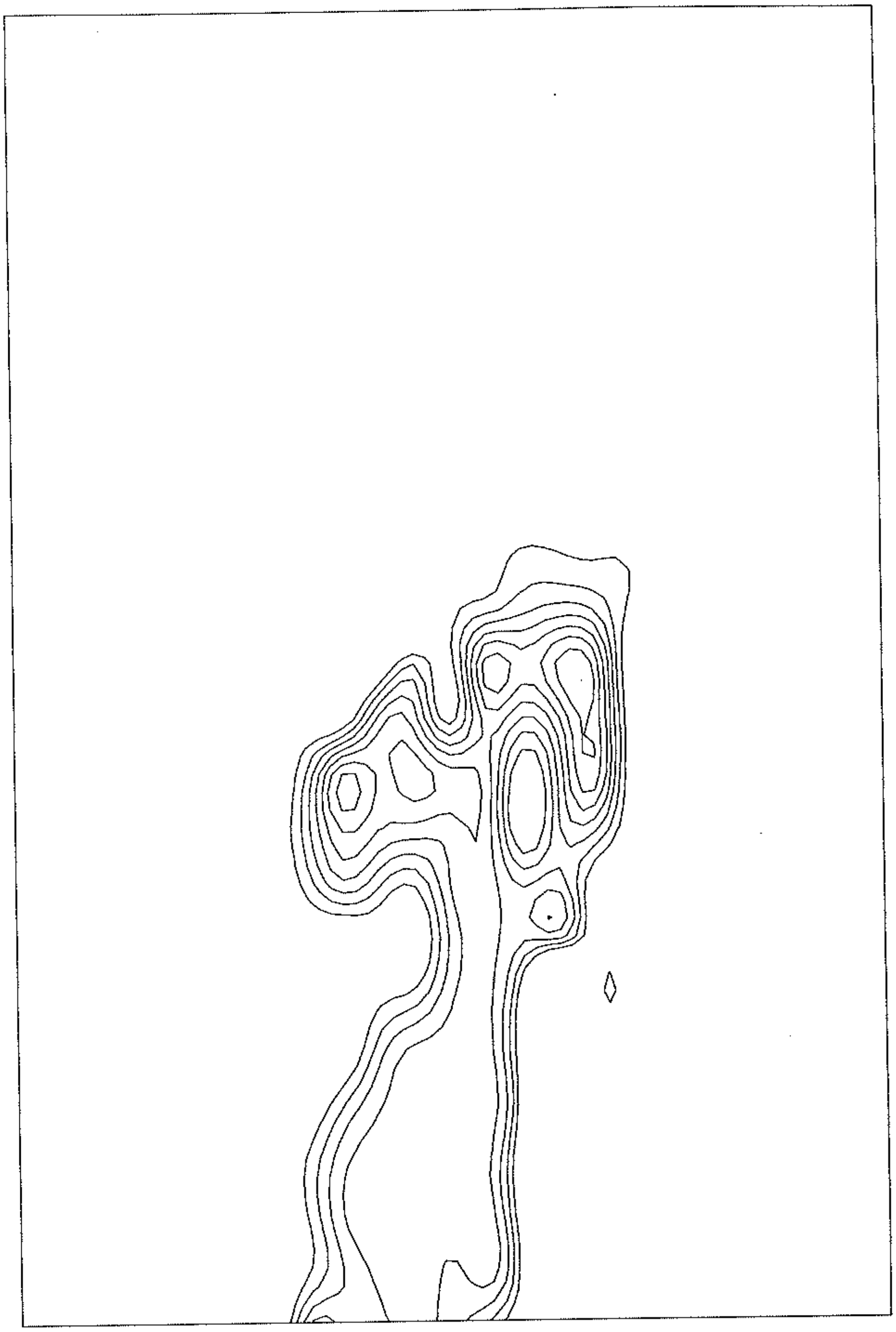
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 0.5 % of that standard.

Figure 64. RPEV 1995 PM 25% Implementation



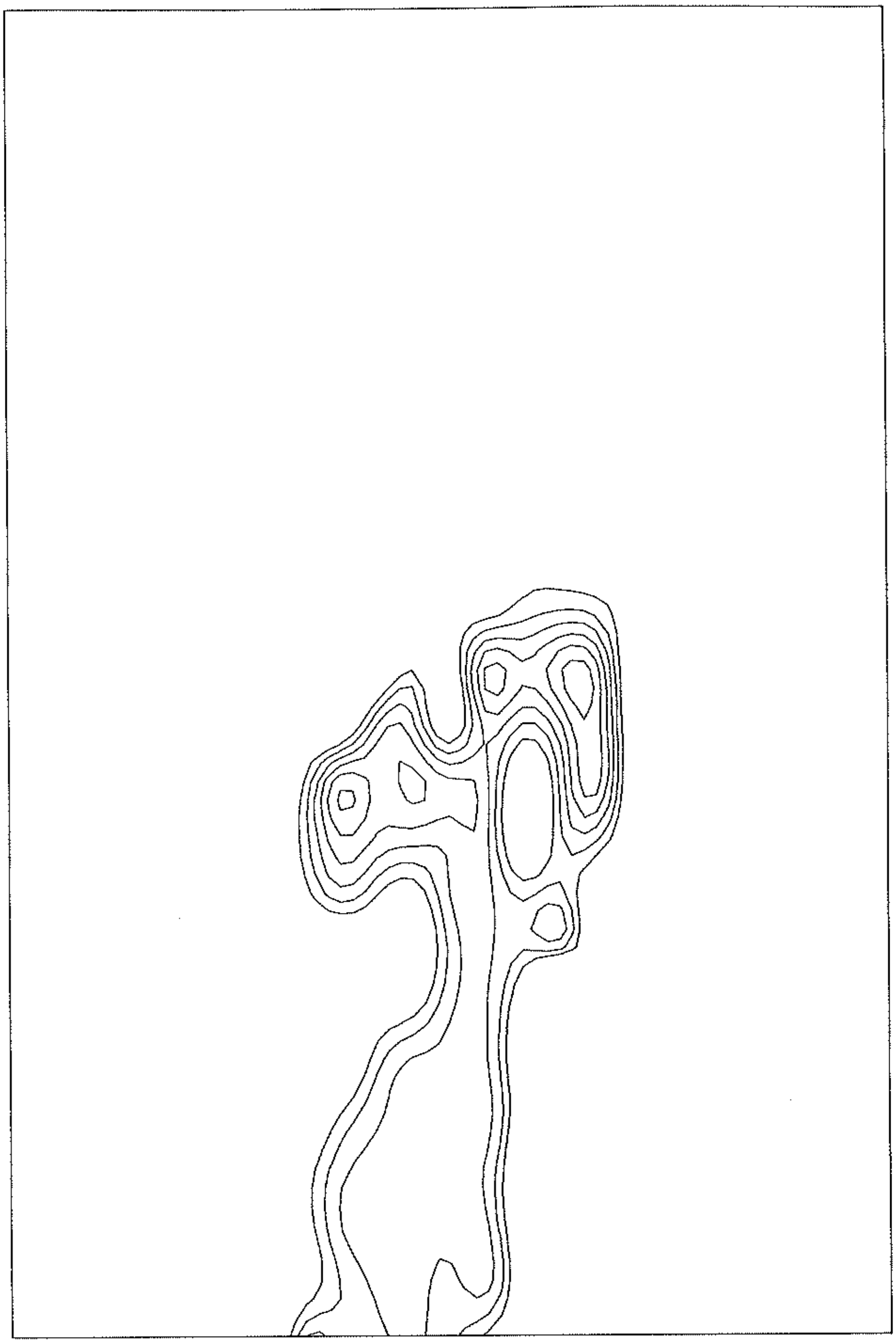
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 0.5 % of that standard.

Figure 65. RPEV 1995 PM 50% Implementation



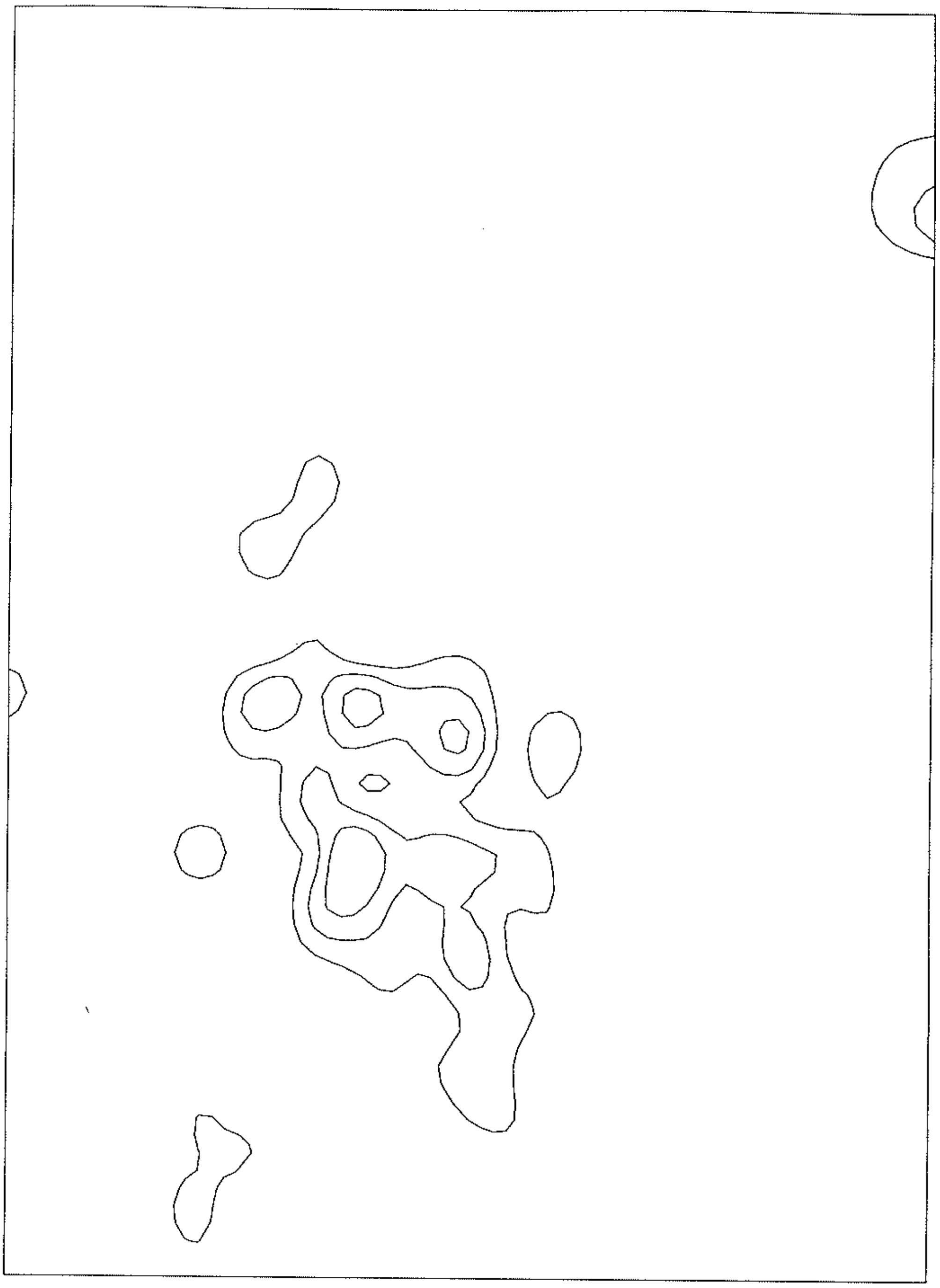
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 0.5 % of that standard.

Figure 66. RPEV 1995 PM 75% Implementation



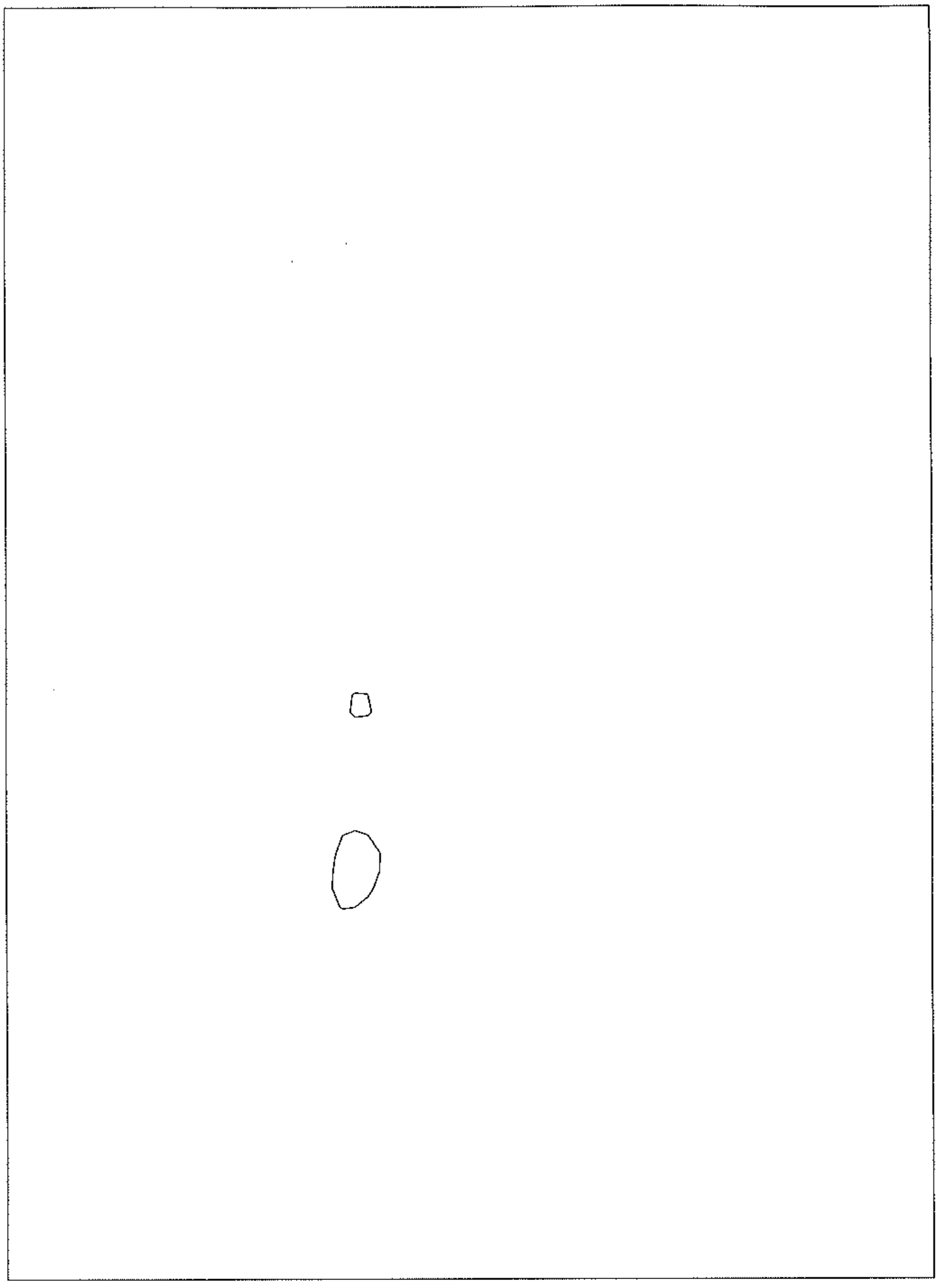
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 0.5 % of that standard.

Figure 67. RPEV 1995 PM 100% Implementation



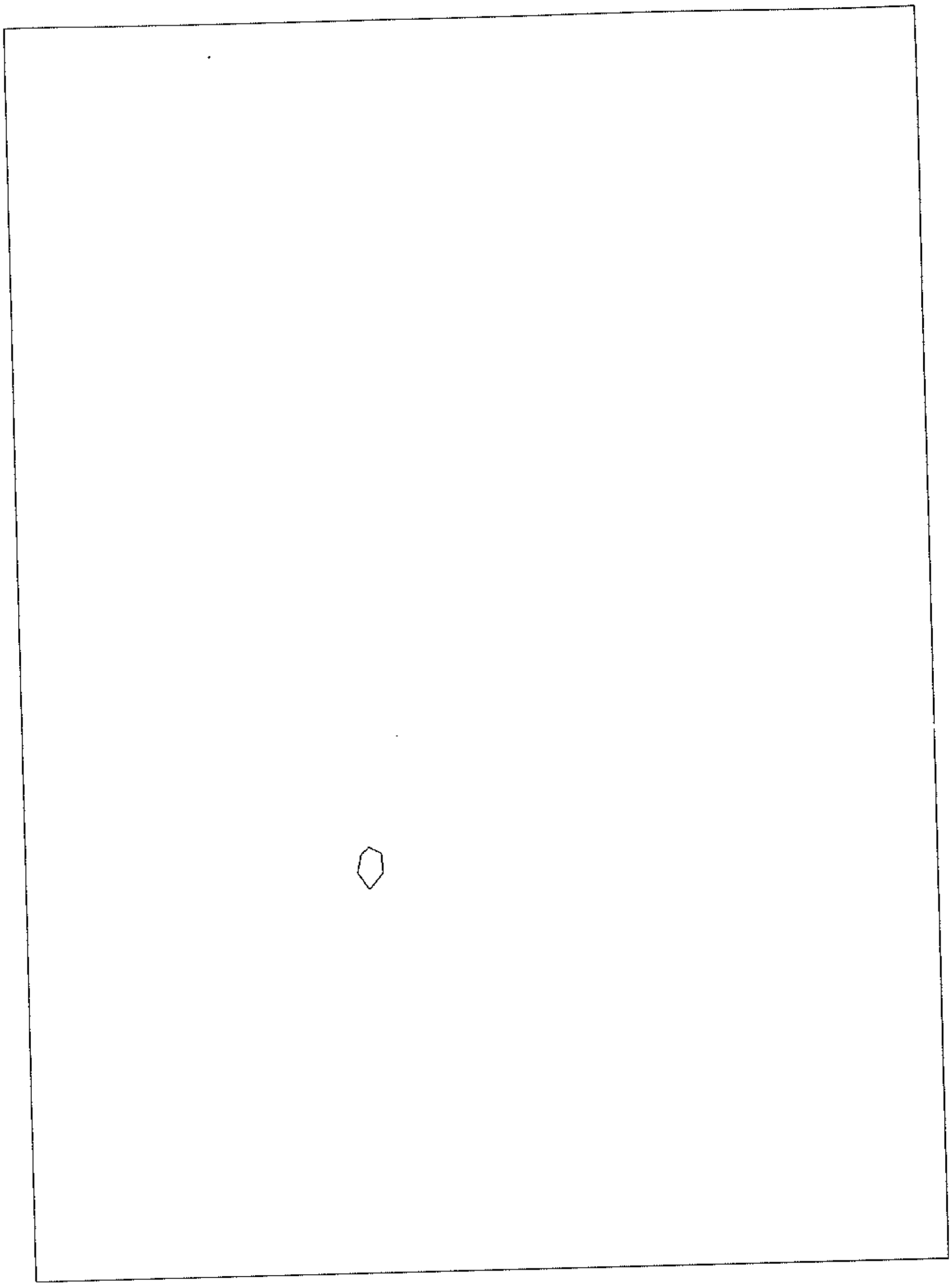
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

Figure 68. RPEV 2010 CO 25% Implementation



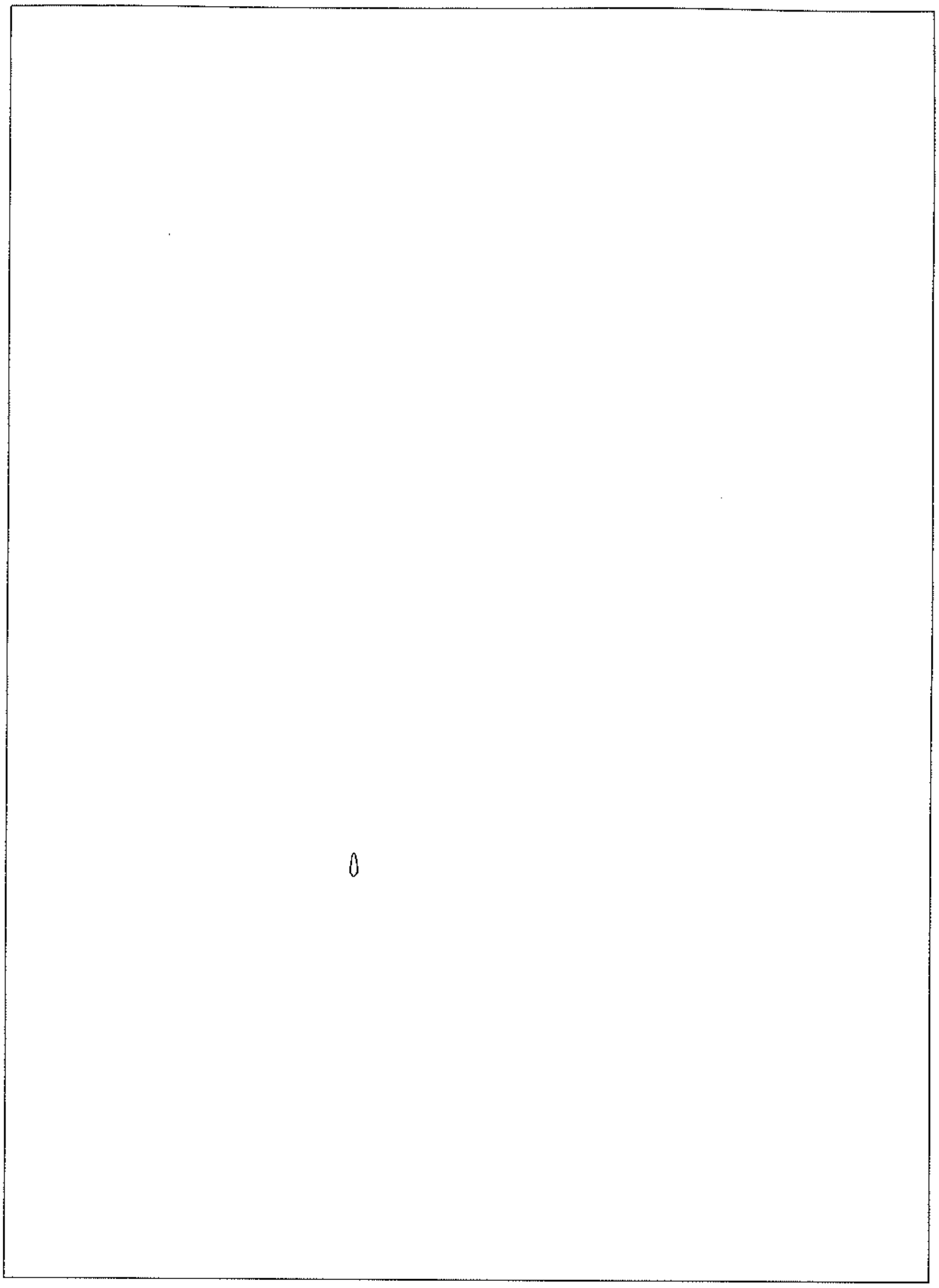
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

Figure 69. RPEV 2010 CO 50% Implementation



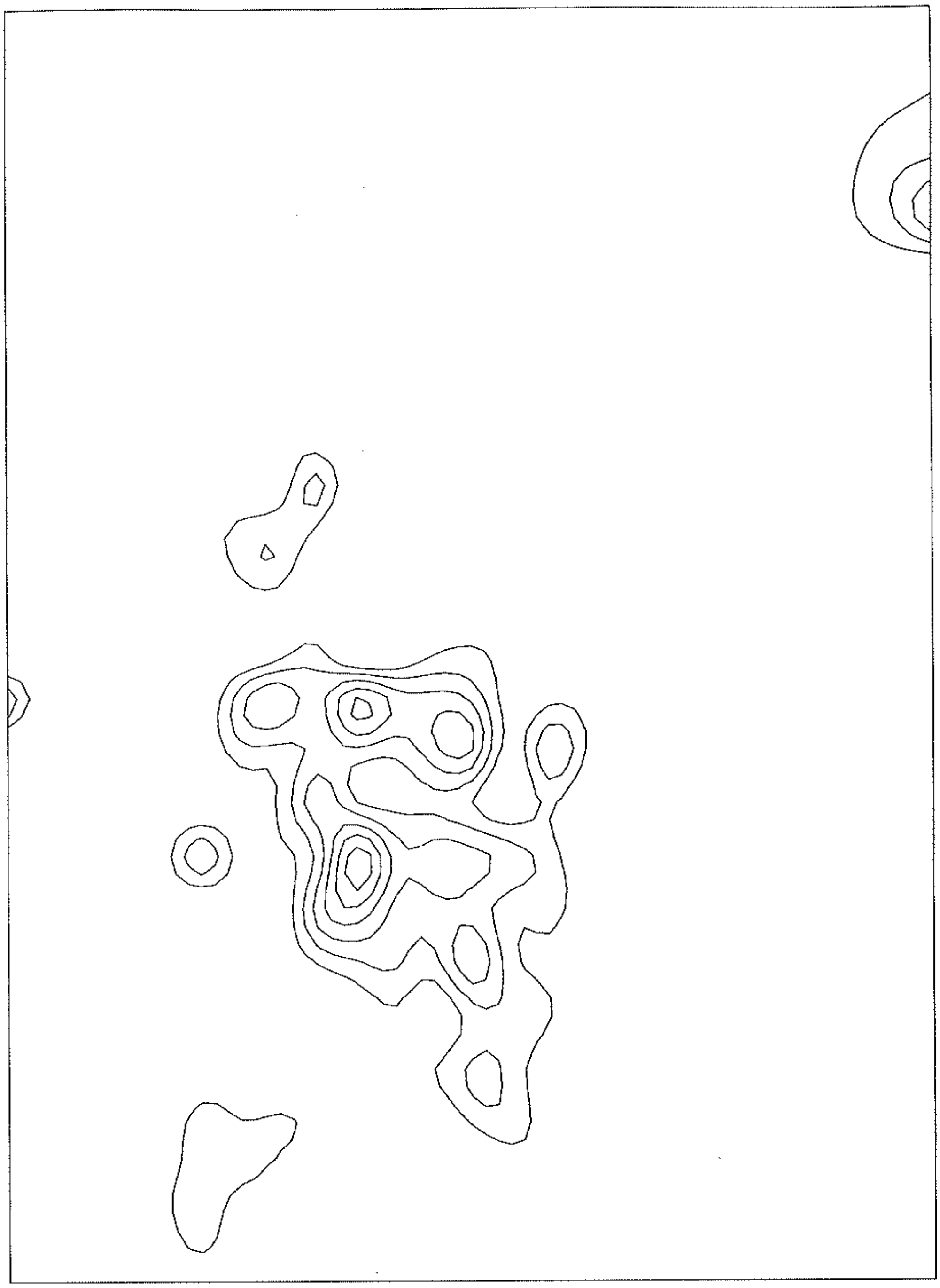
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

Figure 70. RPEV 2010 CO 75% Implementation



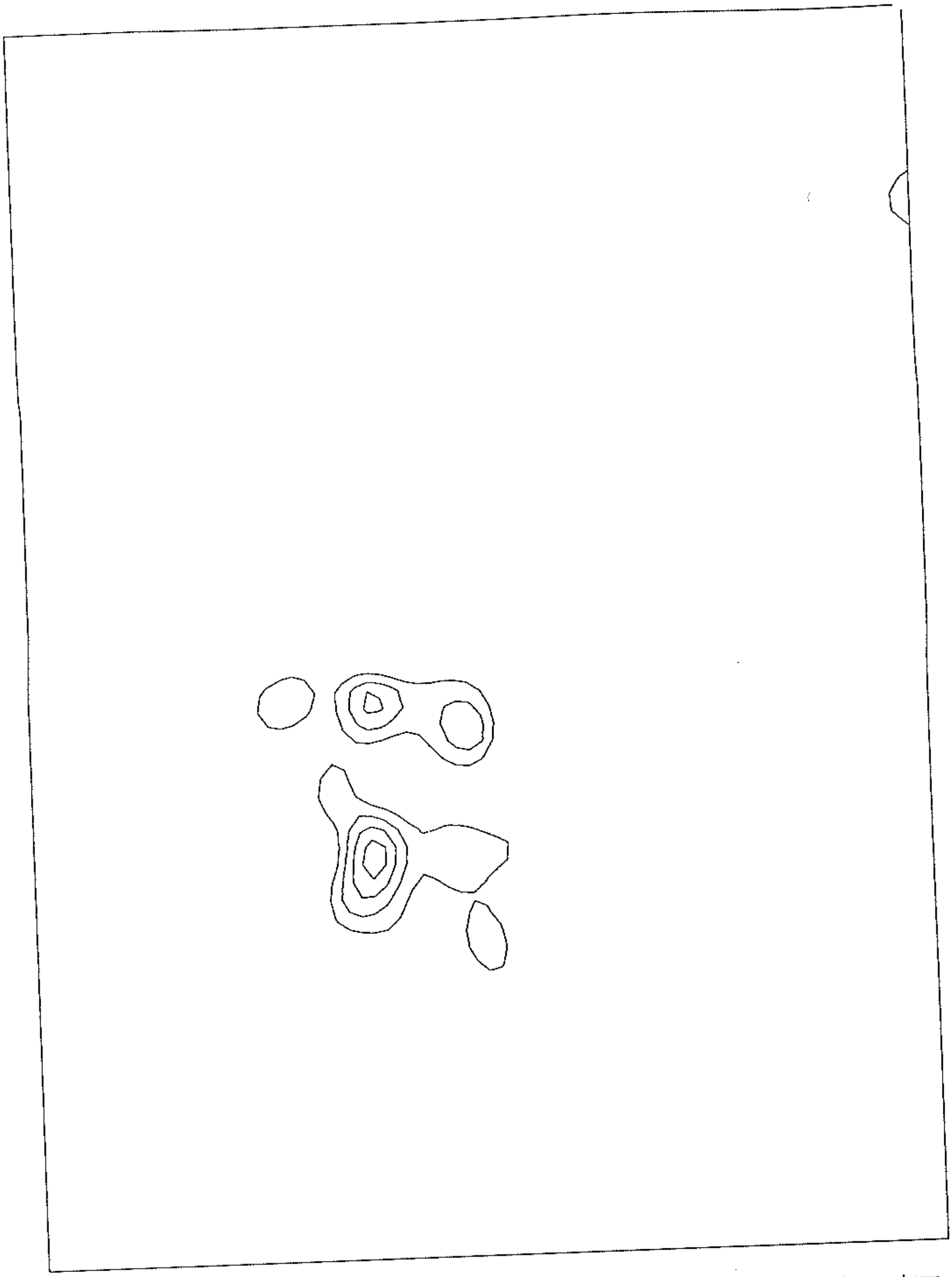
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2 % of that standard.

Figure 71. RPEV 2010 CO 100% Implementation



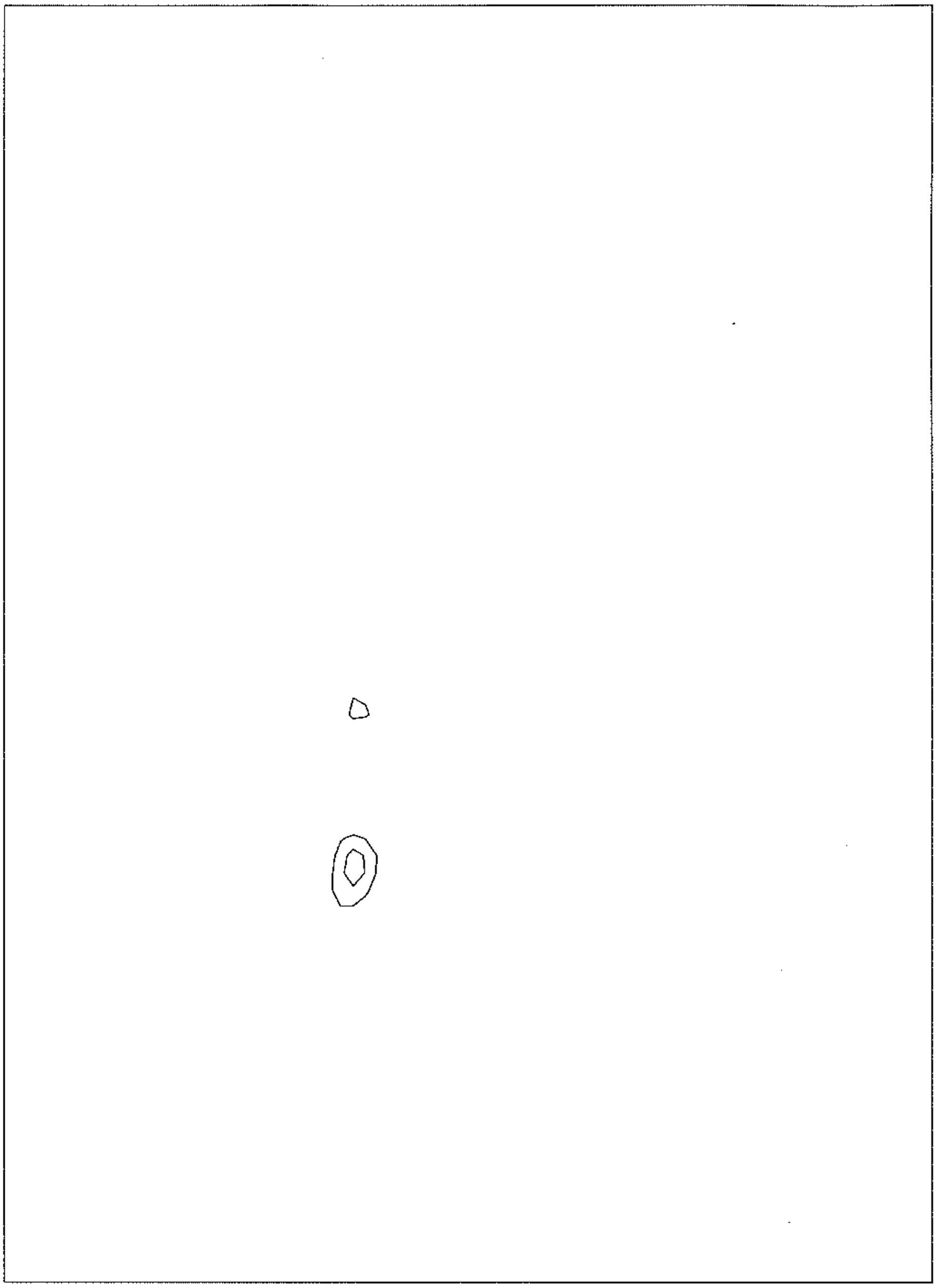
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2.5 % of that standard.

Figure 72. RPEV 2010 HC 25% Implementation



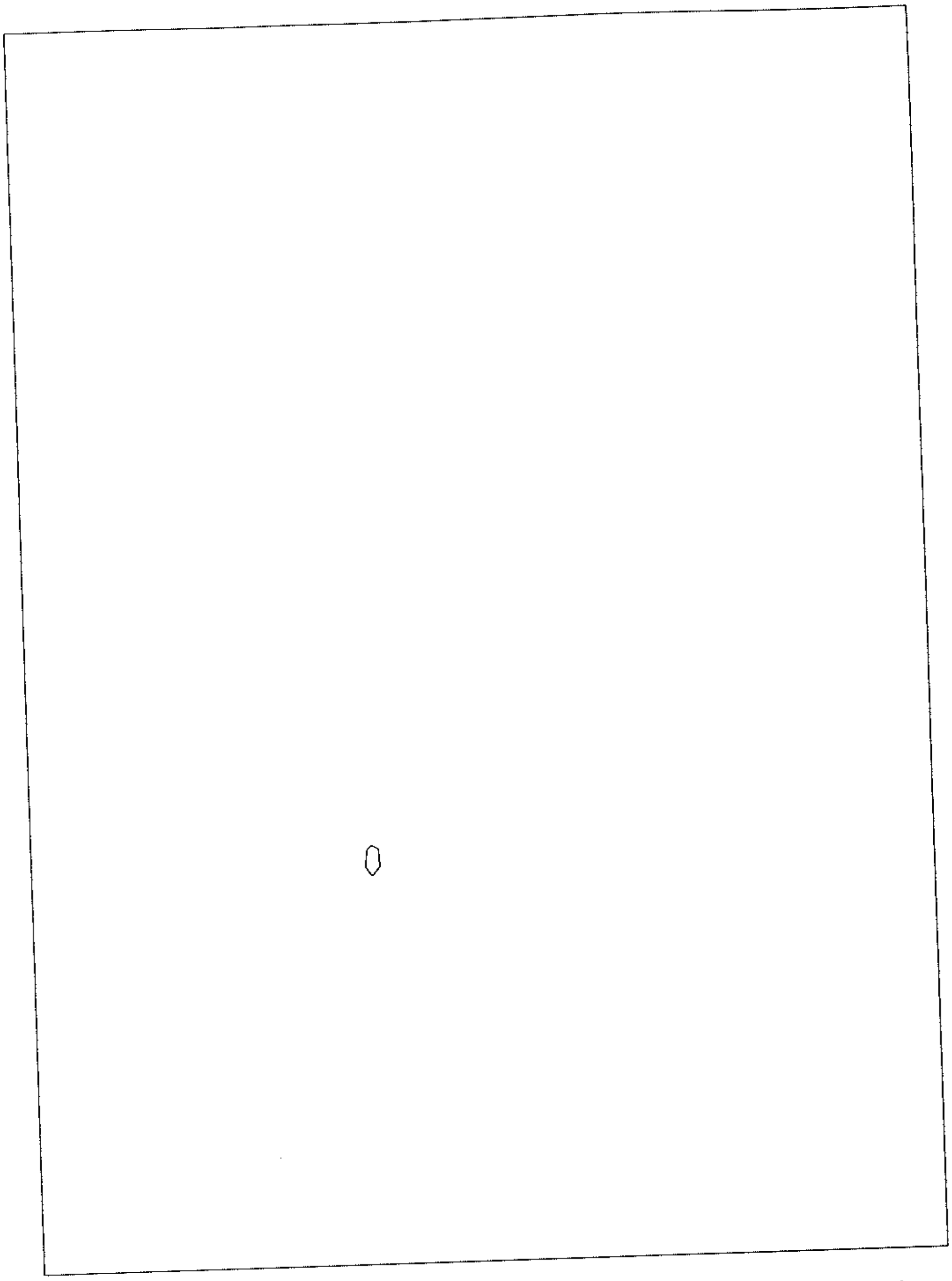
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 2.5 % of that standard.

Figure 73. RPEV 2010 HC 50% Implementation



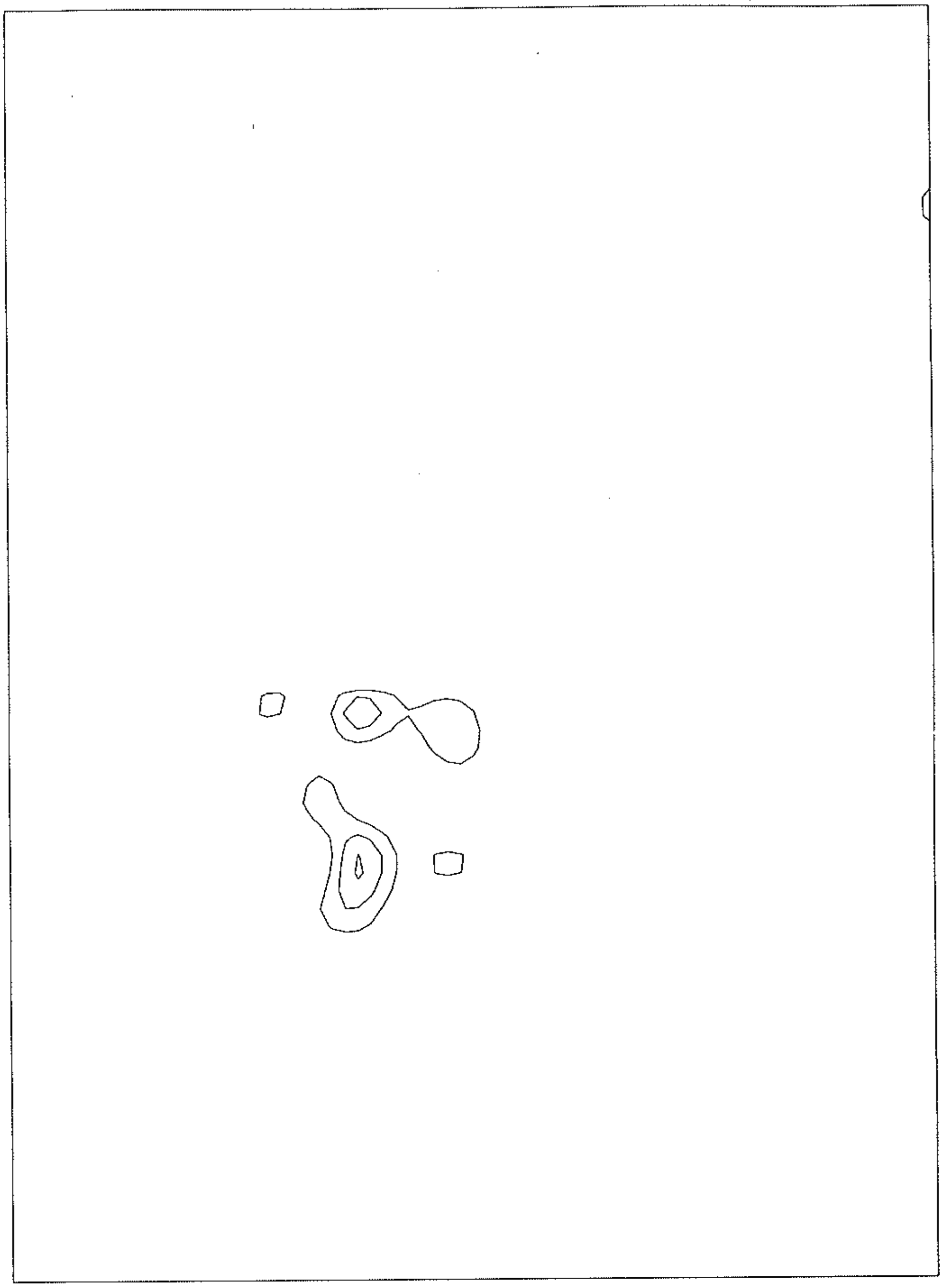
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 2.5 % of that standard.

Figure 74. RPEV 2010 HC 75% Implementation



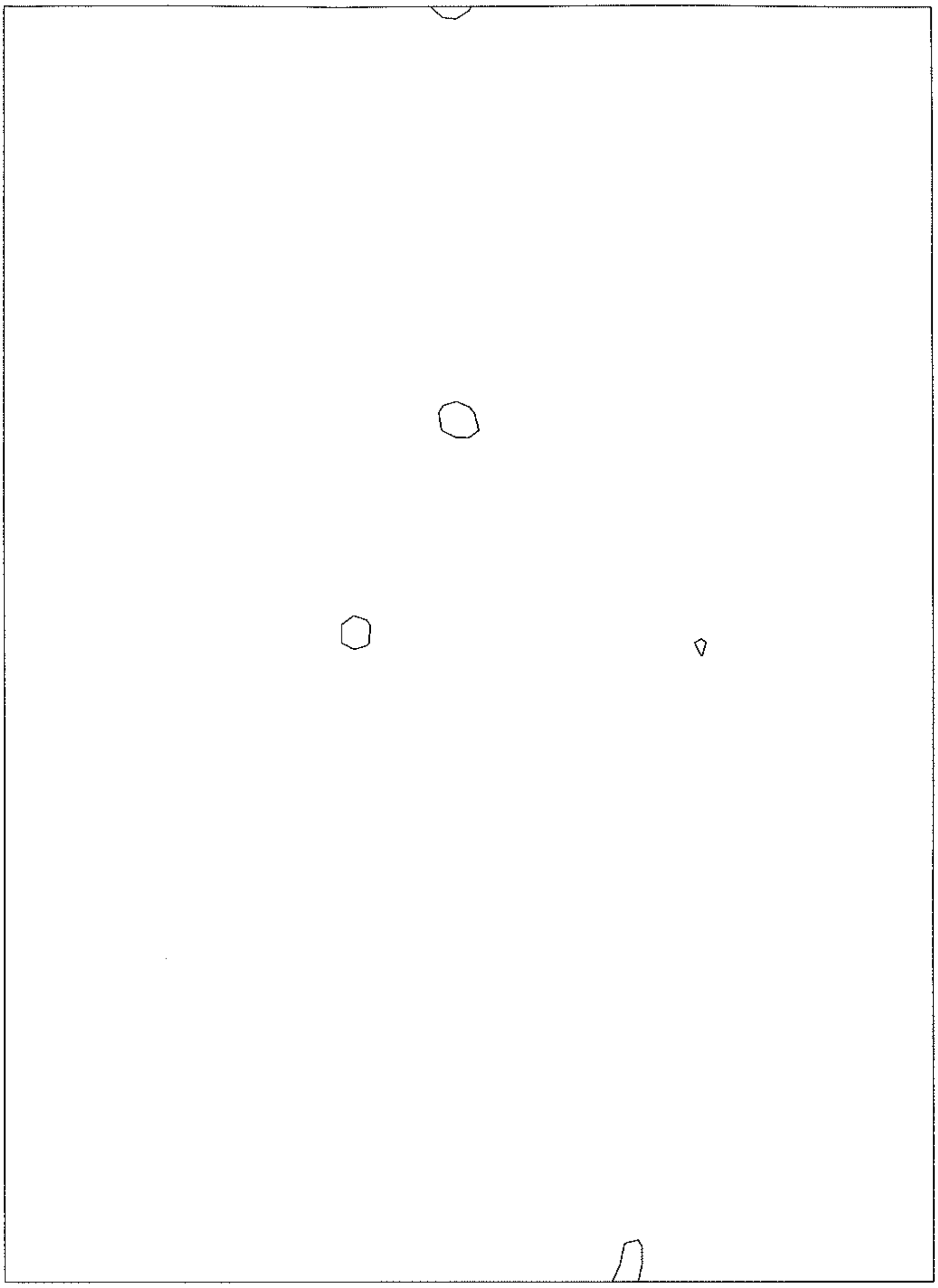
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 2.5 % of that standard.

Figure 75. RPEV 2010 HC 100% Implementation



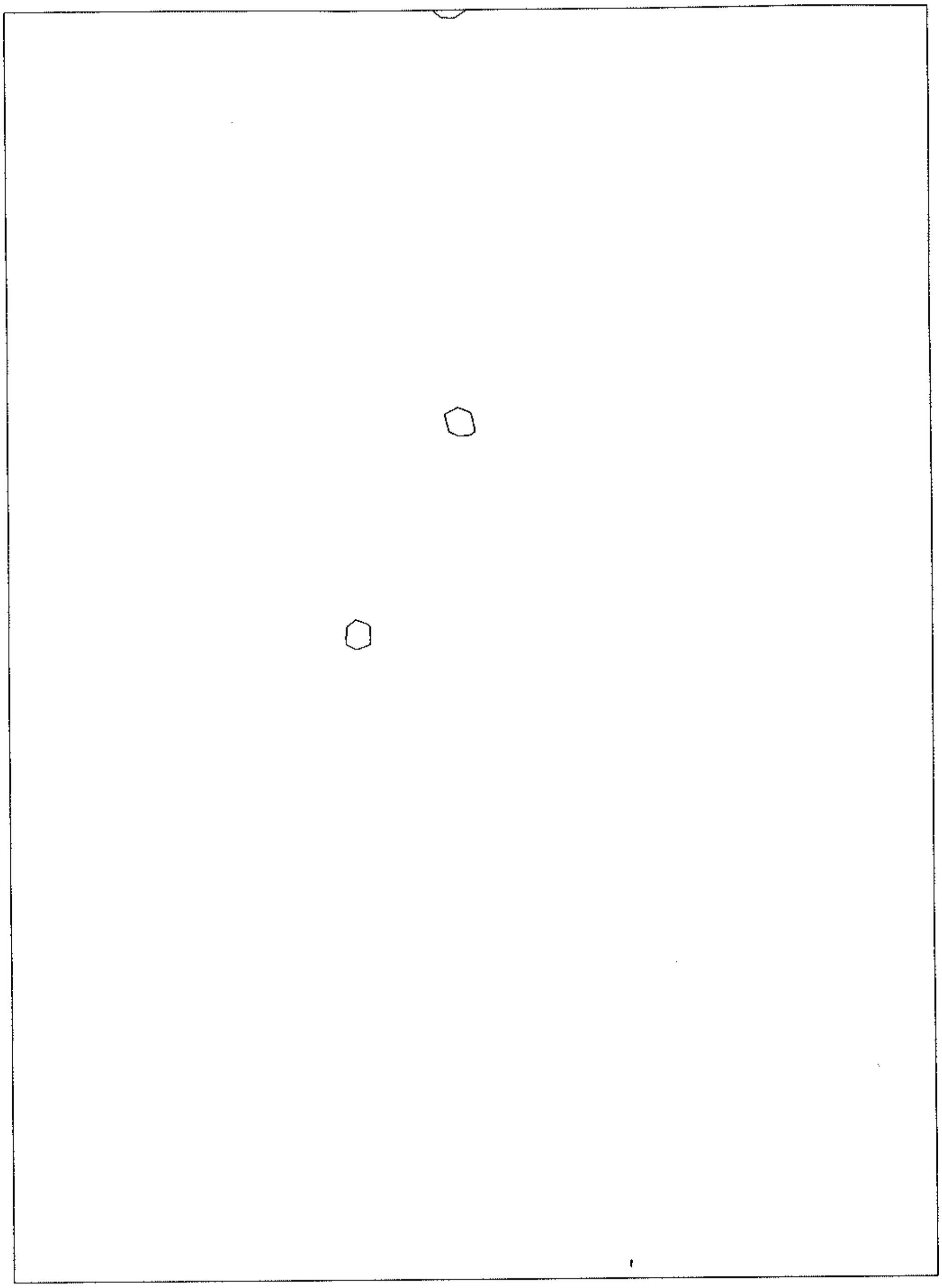
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 76. RPEV 2010 NO_X 25% Implementation



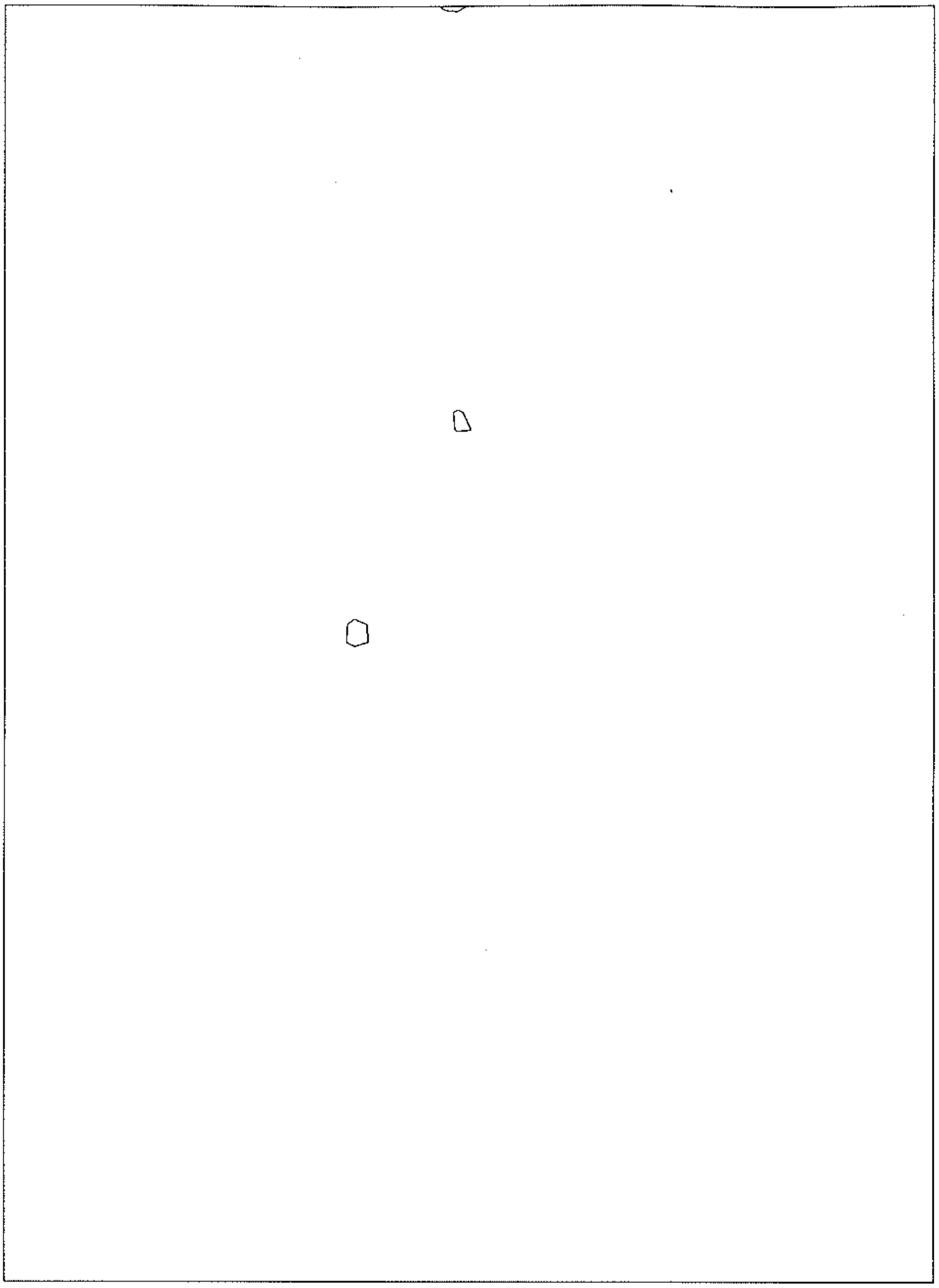
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 1.5 % of that standard.

Figure 77. RPEV 2010 NO_X 50% Implementation



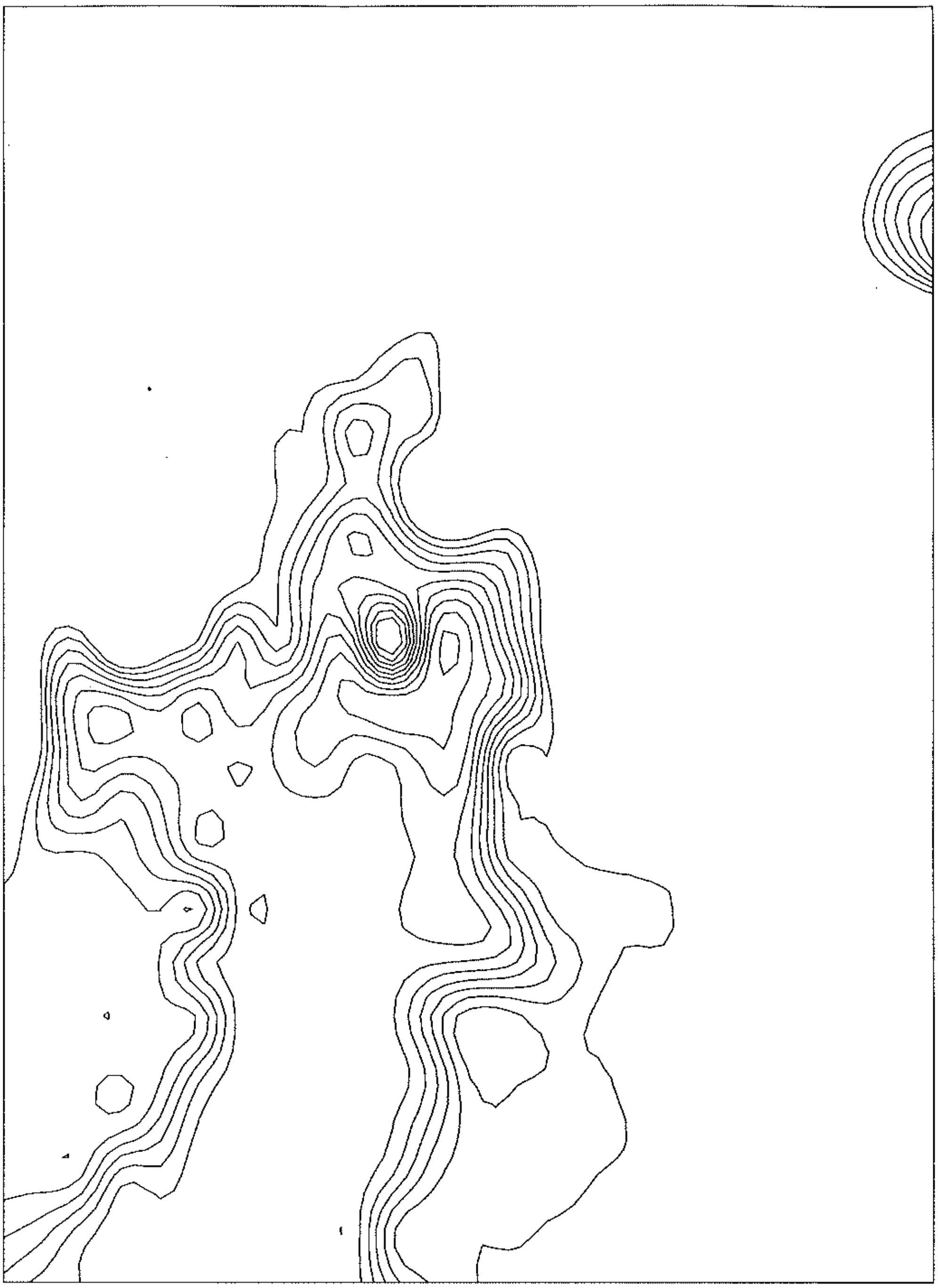
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 78. RPEV 2010 NO_x 75% Implementation



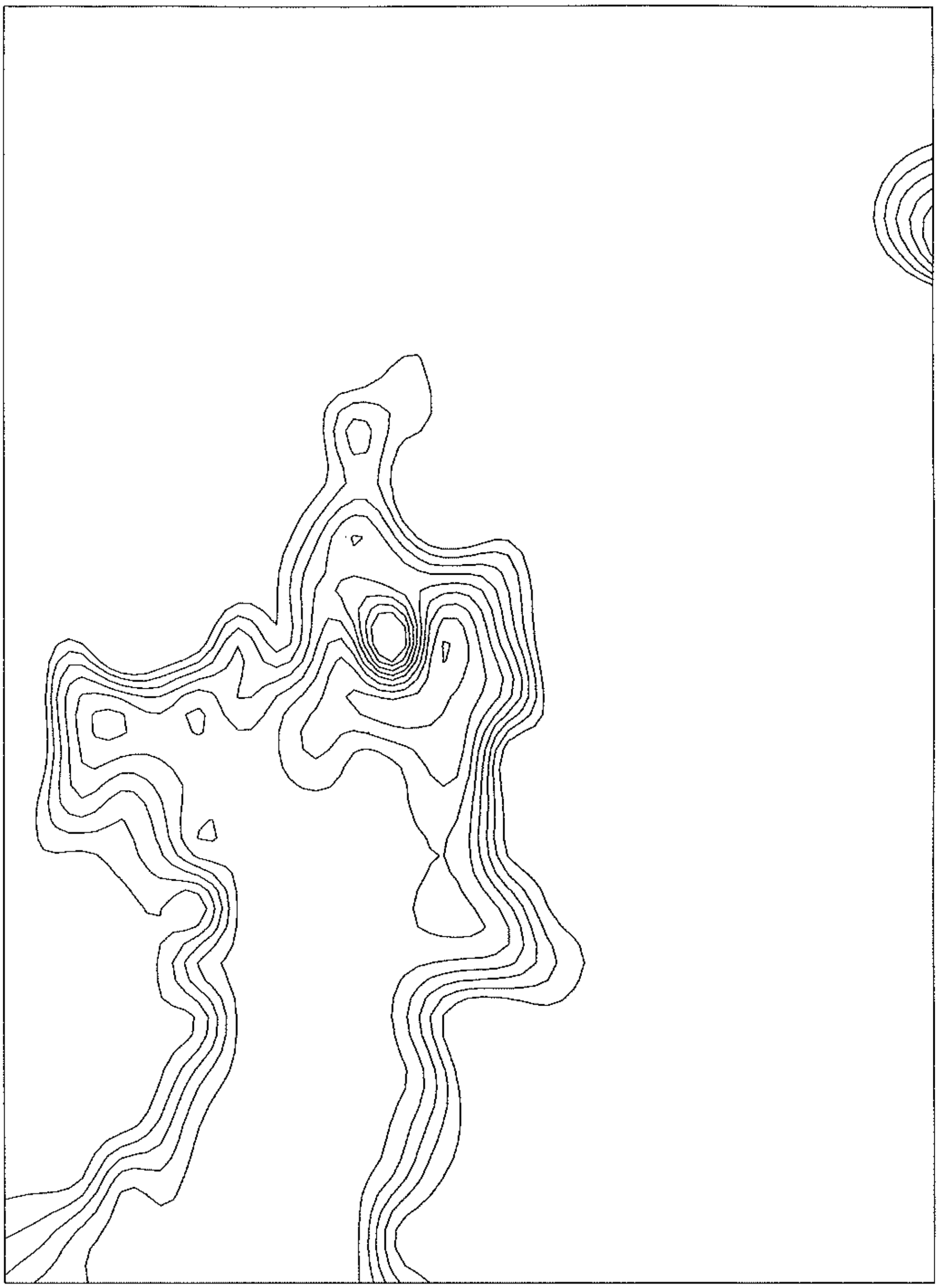
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 1.5 % of that standard.

Figure 79. RPEV 2010 NO_X 100% Implementation



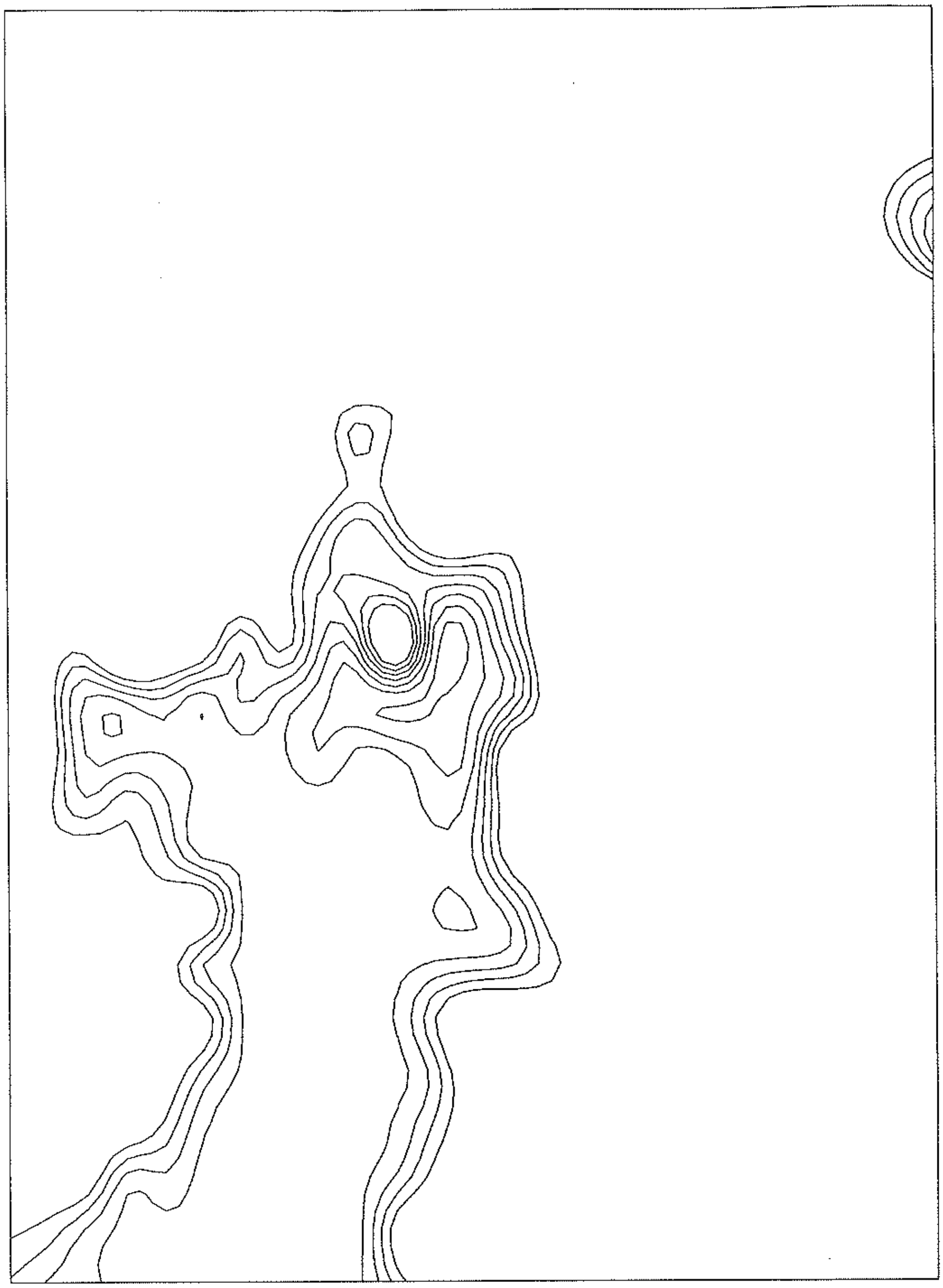
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 0.5 % of that standard.

Figure 80. RPEV 2010 PM 25% Implementation



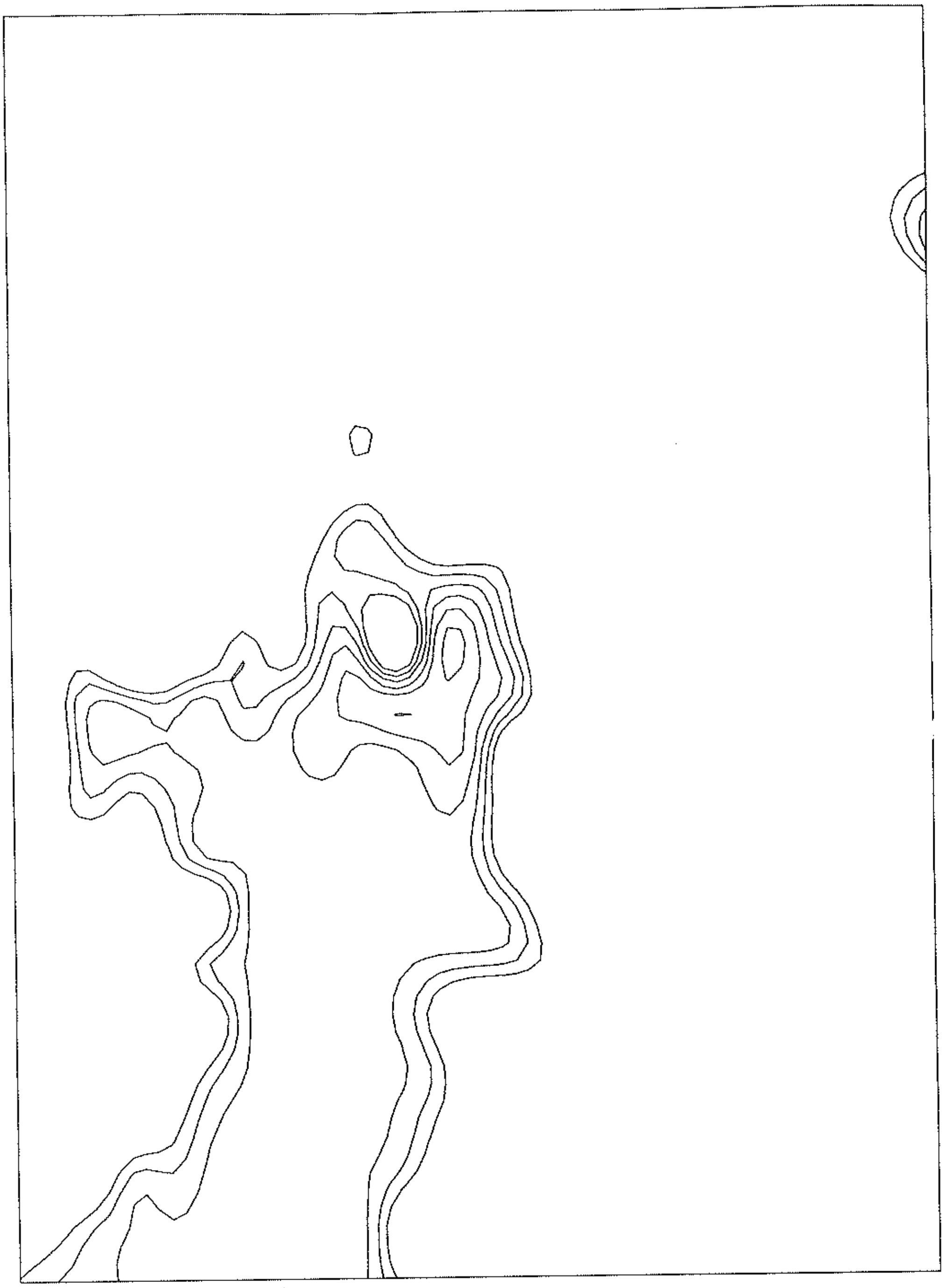
NOTES: Only those isolines that have values above the maximum allowable federal standard are shown. The value between consecutive isolines is 0.5 % of that standard.

Figure 81. RPEV 2010 PM 50% Implementation



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 0.5 % of that standard.

Figure 82. RPEV 2010 PM 75% Implementation



NOTES: Only those isolines that have values above the maximum allowable federal standard are shown.
The value between consecutive isolines is 0.5 % of that standard.

Figure 83. RPEV 2010 PM 100% Implementation

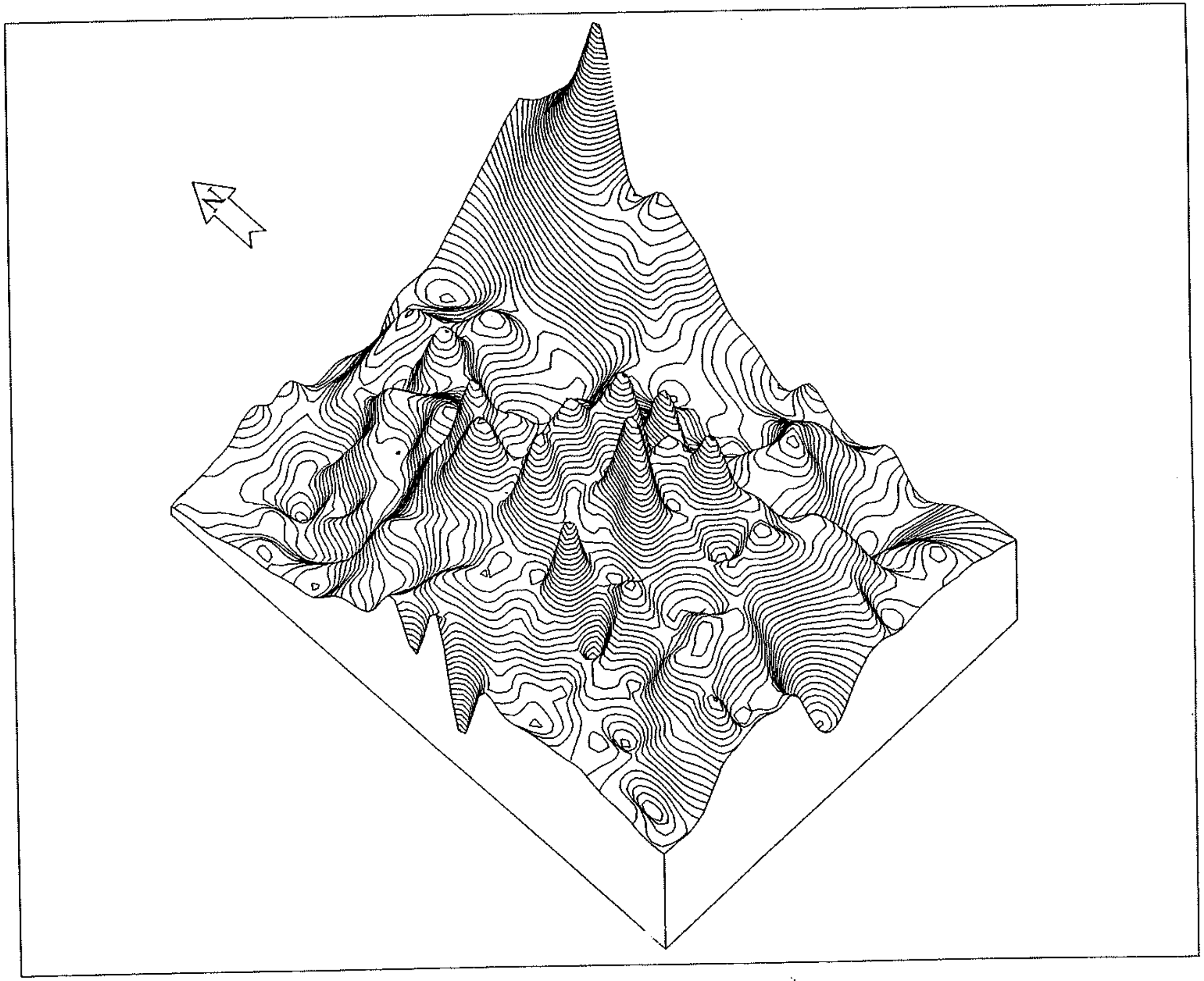


Figure 84. Weighted Average Combination 2010 2(HC)+NO_x+PM+EW V/C+NS V/C+CO

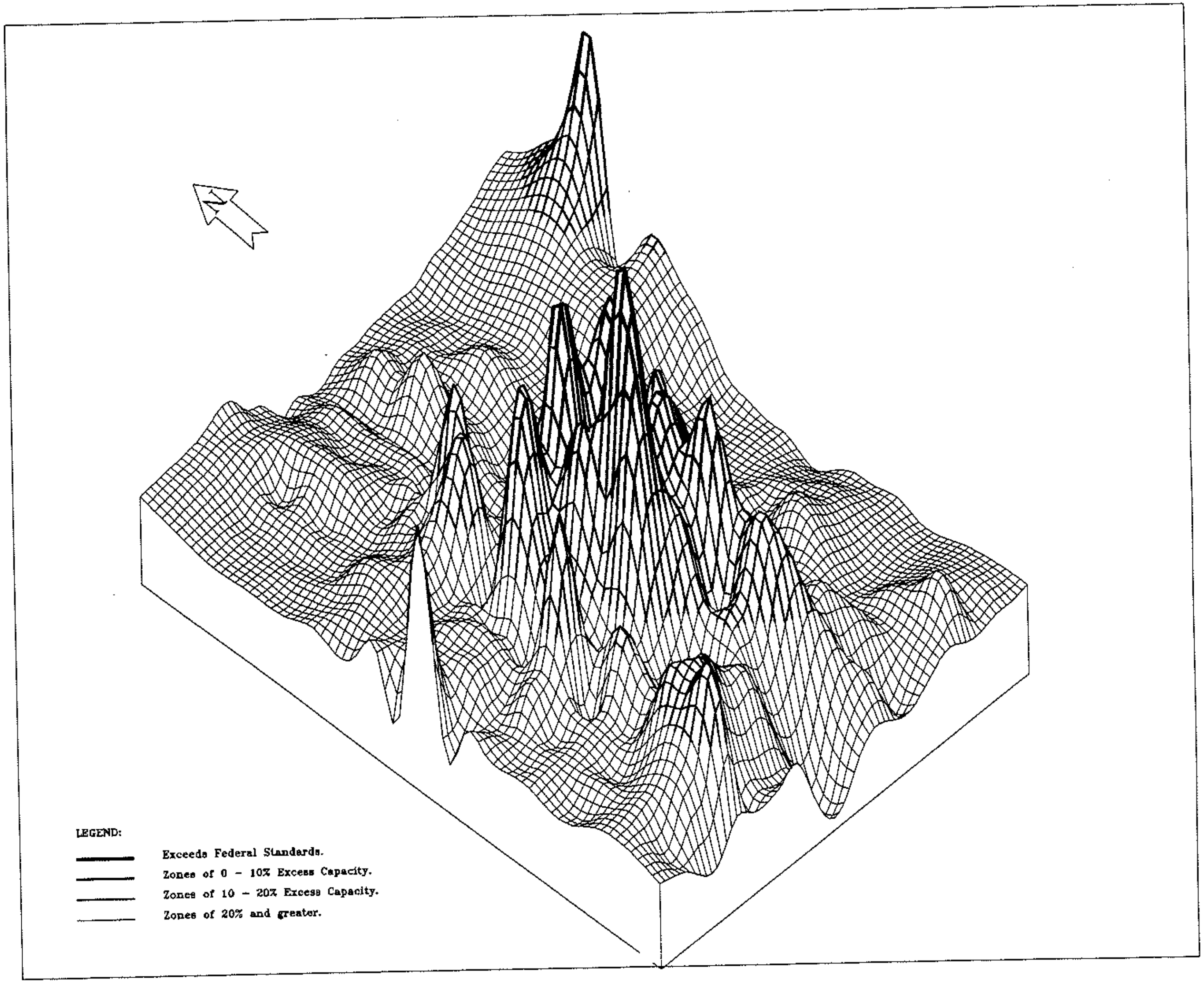


Figure 85. Excess Capacity RPEV 2010 CO 50% Implementation