N-96-01
II-A-180

HUSH PROGRAM
(BARRIER COMPONENT)
GUIDANCE MATERIAL

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Noise Abatement and Control

August 1981

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SECTION I

HUSH PROGRAM (BARRIER COMPONENT) GUIDANCE MATERIAL

SECTION I

HUSH PROGRAM (BARRIER COMPONENT) GUIDANCE MATERIAL

INTRODUCTION

One of the U.S. Environmental Protection Agency's operational goals is to contribute toward the immediate reduction of environmental noise exposure of L_{dn}* larger than 75 dB. EPA has assisted people exposed to those levels from highway noise under its authority to regulate new products, to label products, and to assist States and localities to control and abate noise.

Computer simulations indicate that significant noise exposure reductions can be achieved through source controls, including Federal noise regulations of new vehicles, State and local government vehicle regulations, and enforcement of vehicle-specific noise regulations and codes. These simulations also indicate that despite all of these measures to quiet noisy road vehicles a great number of people will remain exposed to noise exceeding L_{dn} 75 dB. Moreover, many people in noise-sensitive institutions like schools, hospitals, and old age homes, who deserve or desire extra quiet are likely to suffer from noise exposure greater than L_{dn} 65 dB. These two conditions are referred to as noise "hot spots."

EPA's position is that since hot spots cannot be eliminated with new product emission regulations, path and receiver controls must be considered.

Except for the common characteristic of people suffering from high noise levels, every hot spot is unique. Consequently one cannot present a universal fine-tuned solution for each individual situation. Rule of thumb solutions applying to certain situations (see Exhibit I-1) are, nevertheless, helpful to sift control options and arrive at a set of reasonable controls.

Rather than addressing all possible solutions to hot spot programs, the purpose of this paper is to examine the noise barrier (including berms) solution for highway noise hot spot problems. Exhibit I-1 demonstrates that noise barriers are most appropriate when

*L_{dn} *is the 24-hour average-energy sound level expressed in decibels, with a 10-decibel penalty added to sound levels between 10 p.m. and 7 a.m.*

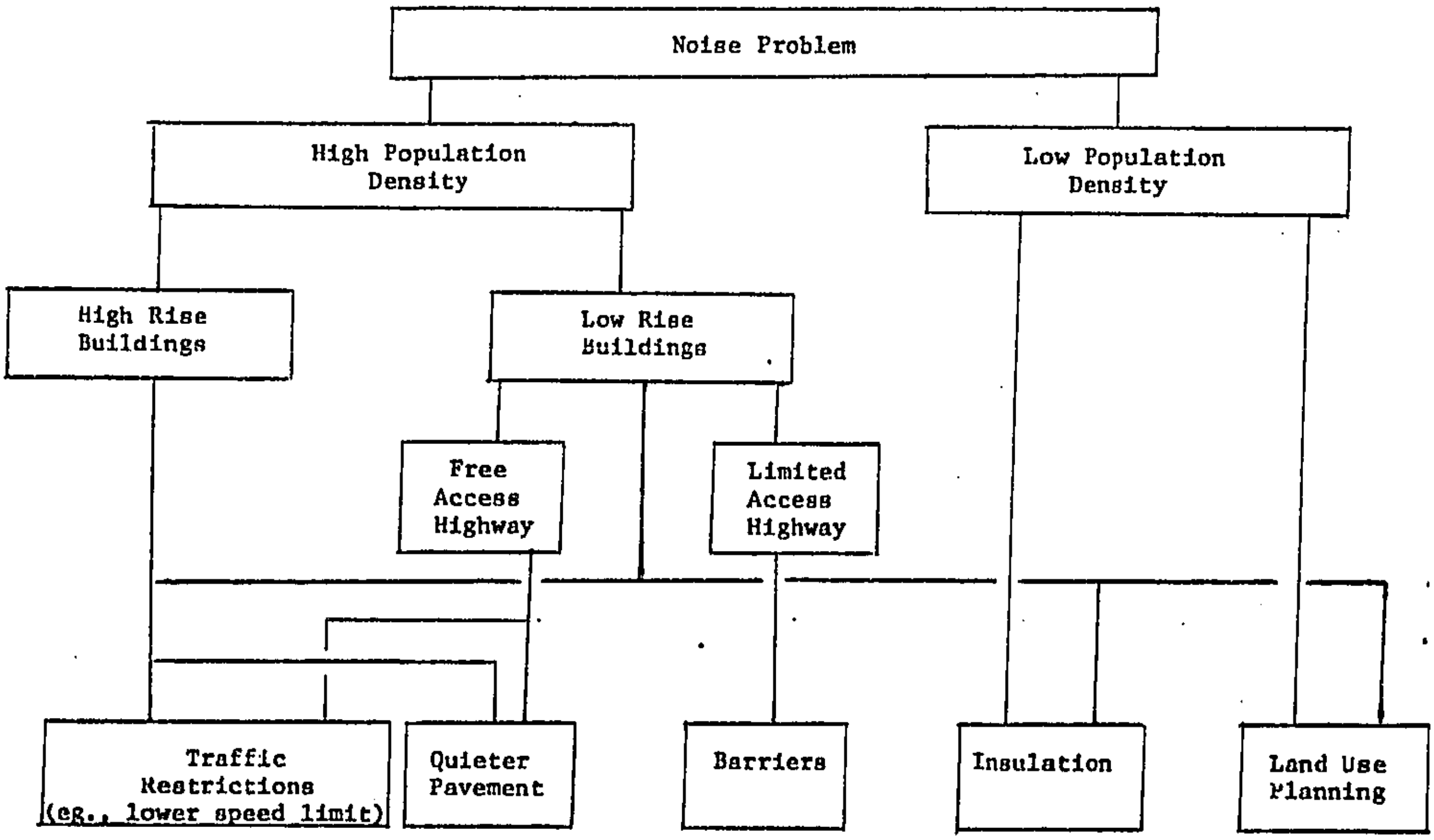

EXHIBIT I-1: ALTERNATIVES FOR HIGHWAY NOISE REDUCTION

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dealing with hot spots in densely populated areas, where people are living in low-rise buildings in the proximity of limited access highways.

The primary focus of this paper is to help individuals living in hot spot areas to understand the relationship between noise and their well being, and, at the same time to give them and those who are willing to help them, the tools to motivate those individuals and government agencies who can be instrumental in providing relief.

Section II (Noise and Health) is designed to explain briefly what is currently known about the relationship between noise and health. Such information should (1) help those people currently living behind barriers to appreciate their noise protection, even though there may be some aspects of barriers not desirable to them, (2) make others without any protection aware that noise is a health problem and prompt them to investigate the problem and seek avenues for relief.

Section III, "An Introduction for Potential Participants in Hot Spot (Barrier) Programs," is designed to help people who suspect that they are living in a hot spot area to assess the problem and to give them specific guidance toward a solution. This section defines a hot spot, and gives the reader a set of simple tools to ascertain whether or not the area of concern to them is a hot spot and if barriers are a likely solution. In addition, it advises the interested parties how to proceed to put the machinery in motion to attain barriers. Consequently, this section contains case studies so that potential participants in the hot spot (barrier) programs can benefit from others' experiences.

Section IV entitled, "Evaluation and Documentation," presents various technical materials to people who need them, like individuals or groups who become involved in motivating others to plan barrier construction or even those who actually become involved in the barrier construction process. The material is composed of discussions related to: (1) the noise evaluation process; (2) economic cost and benefits of barriers; (3) acoustical and non-acoustical considerations of barrier selection and construction; and (4) financial details of barrier construction.

Section V entitled, "Hot Spot Program Evaluation," stresses that a report card-type of record should be established and brought to the attention of the public and elected and appointed officials. This record should include: (a) stretches of highways identified as "hot spots"; (b) the number of problems that can be addressed effectively by barriers; (c) those areas properly treated at various times; and (d) an attitudinal and physical before-and-after survey.

Section VI entitled, "Hot Spot Identification and Aerial Photographs," identifies likely hot spots along major highways in Standard Metropolitan Statistical Areas (SMSA's) with populations greater than one million. This list was computed from existing traffic data and is therefore only an indication of the magnitude of the noise problem. It can be used in the report-card type of exercise described in Section V and should be augmented when additional data become available.

The aerial photographs for some of the noisier hot spots indicate that there are residences along these stretches of the highways that need attention immediately. Other stretches need to be protected against encroachment by residences; while still others appear to be compatably zoned or used.

SECTION II

NOISE AND HEALTH

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SECTION II

NOISE AND HEALTH

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SECTION II

NOISE AND HEALTH

A. THE NATION'S NOISE PROBLEM

What Is Noise?

Unpleasant or annoying sound is defined as noise.

Whether a sound is considered noise or not is a subjective decision depending on individual perception and taste. A sound that is loud, and harsh, inharmonious, and painful to one person's ears may be music to another's. For example, the sounds of a powerful automobile engine may evoke a sense of well being or pride in some people. However, to most people trying to relax, talk or sleep, that same sound is noise.

How Is Noise Measured?

The noise exposure measure recommended by EPA for all community noise studies and planning is the Day-Night Average Sound Level (L_{dn}). L_{dn} is the 24-hour energy average sound level expressed in decibels, with a 10 decibel penalty applied to noise occuring between 10 p.m. to 7 a.m. "L" in the expression stands for energy average noise level, "d" for day and "n" for night.

A similar, commonly used noise measure is the Equivalent Sound Level ($L_{eq(24)}$). This measure represents the sound energy averaged over a 24-hour period with no penalty for nighttime noise.

How Much Noise Is Considered Damaging?

In general, when the noise exceeds an $L_{eq\,(24)}$ of 70 dB, listeners will experience severe annoyance and a potential hearing loss. Noises of L_{dn} 55 dB or greater outdoors, or 45 dB or greater indoors usually produce activity interference and moderate annoyance.

How Extensive Is the U.S. Noise Problem?

Well over 100 million people, nearly half the U.S. population, live in areas where noise exceeds 55 dB, a level that may produce activity interference and annoyance. People who are exposed to significantly higher levels are likely to experience severe annoyance and hearing loss.

Urban traffic is by far the most pervasive outdoor residential noise source. It should be noted that the figures contained in the table for each source represent the number of people exposed at or above a given level for the source in question and do not take into consideration that an individual may be simultaneously exposed to more than one source, culminating in a higher total exposure.

B. THE EFFECTS OF NOISE ON HEALTH AND WELFARE

Noise endangers health and well-being in many ways. Most obvious to everyone is hearing loss caused by exposure to loud noise. Noise loud enough to cause hearing loss is everywhere — in our jobs, our recreation, and our homes. More than 20 million Americans are estimated to be exposed daily to noise that is permanently damaging to their hearing. Most hearing loss is gradual, becoming worse with time. It is irreversible, and can be handicapping. Associated with hearing loss can be discomfort, pain, and tinnitus (irritating ringing or roaring in the head.) As hearing loss worsens, severe feelings of isolation set in. The person with hearing loss feels cut off from the rest of the world.

Noise-induced hearing loss is not just the result of industrial or occupational noise. Noise levels in many urban settings, homes, recreational areas, and many transportation vehicles exceed the levels which can cause hearing damage over prolonged periods, especially in combination with other occupational and environmental noise. For example, researchers have discovered that hearing difficulties in children are likely by-products of noisy schools, play areas, and homes. High frequency hearing impairment has been measured in college-age persons, some of it attributable to recreational activities. Indeed, environmentally-induced hearing loss affects people of all ages in a wide spectrum of activities in countless settings.

The prevalence of community annoyance or response due to noise exposure throughout American society is known in considerable detail. General relationships of overall community response to noise (the central tendency of large numbers of groups of individuals) have been derived and accepted scientifically. Scales of varying complexity, some directly readable from simple instrumentation, others requiring complex computations, are commonly used to predict the annoyance of a great many noise sources. The combined effects of pure tones and duration of sounds, among other factors, are known to influence annoyance reactions to noise. Nonacoustic factors, such as attitudes toward noise sources, or the particular activities disturbed, can affect both individual and community reactions to sound. Annoyance due to noise exposure is not only restricted to neighborhoods near airports, highways, and other major noise sources, but that exposure to levels typical of many urban environments also produces widespread annoyance. Noises associated with automotive sources (e.g., street traffic noise) are the most universal sources of annoying noise exposure in urban America.

As a stressor, noise initiates automatic and unconscious physiological reactions known as the classic "stress response." Blood pressure rises, heart rate and breathing speed up, muscles tense, hormones are released into the bloodstream, and perspiration increases. People do not stop responding physically to noise. Regardless of a person's consciousness of the noise, these biological responses occur.

Noise levels below those necessary for hearing damage can cause these effects. Studies suggest that regular exposure to noise could lead to diseases of stress such as ulcers and high blood pressure, although sufficiently conclusive field studies have yet to be conducted. Noise may even lower people's resistence to disease and infection, or aggravate existing disease by disrupting restorative rest and relaxation.

A number of epidemiological studies of noise in the workplace link the presence of noise with the incidence of cardiovascular disease. These results are mirrored in the preliminary findings of a study on Rhesus monkeys now being conducted jointly by the National Institute of Environmental Health Sciences (DHHS, formerly HEW) and EPA. Heart disease and strokes cause 48 percent of the deaths in the United States each year, and to the extent that noise is linked to an increased incidence of these diseases, the public health implications could be very serious. The quantitative relationships between noise and cardiovascular disease await more definitive research.

Noise interferes with sleep. For many people, this is not an occasional event but rather one which happens night after night. By causing either awakenings or shifts from deeper to lighter stages of sleep, noise effects the quality and quantity of sleep. The health and performance implications of such disruptions in sleep are not yet known, but survey results do show that interruption of rest, relaxation, and sleep is the underlying cause for many complaints in noisy communities.

Even the unborn are not immune to the effects of noise. Loud noises have been known to cause changes in fetal heart rate and may pose a threat to fetal development. In particular, some studies have shown a high proportion of low birth weight babies in noisy areas. Of increasing concern is how noise and other associated environmental agents affect the growth and development of children. The primary activity of developing children is, of course, learning. If children are required to speak and listen in a noisy environment, they may have difficulty acquiring essential communication skills. In the schools, reading ability may be seriously impaired by noise, and the impairment becomes more pronounced with increasing exposure. Aircraft, traffic, and railway noise cause severe educational disruption in many schools in this country, interfering with learning, attention, and performance.

Disruptions in job or work performance are oftentimes attributed to noise. Changes in noise level, either increases or decreases, may have adverse effects on performance. Tasks requiring simple repetitive operations may actually be unaffected or even enhanced by the presence of noise. On the other hand, most performance decrements have been found on complex tasks that require activity, prolonged attention, or the accomplishment of two or more simultaneous operations. The presence of noise has also been found to reduce the accuracy of performance, and tends also to increase the variability of work rate.

Whether in the schools, home, or workplace, indoors or out, one of the most bothersome aspects of noise is its interference with conversation. We must frequently speak up to be heard or ask others to do so. People are forced to stop talking or to change the content of their communications, and usually must repeat themselves. For millions of Americans in noisy urban environments, the use of outdoor areas for various forms of work or relaxation is virtually impossible because of difficulties in communication. Because of frustrated efforts to communicate, lifestyles deficient in expressions and social interaction are not uncommon.

A booklet, "Noise: A Health Problem," provides more detail on the effects of noise on health and well being.*

**Copies can be obtained from the Environmental Protection Agency, Office of Noise Abatement and Control (ANR-471), 401 "M" Street, S.W., Washington, D.C. 20460.*

C. PREVENTION OF NOISE INDUCED HEALTH PROBLEMS

Noise problems can be reduced or eliminated through any combination of the three basic elements of the problem:

- By modifying the source to reduce its noise output

- By altering the transmission path to reduce the noise level reaching the listener

- By altering the receiver's exposure either through limiting the exposure time or by providing personal protective equipment.

The first of these methods is preferred since it results in a real reduction in the noise emitted. Mufflers and silencers are the most common devices for accomplishing this type of reduction with highway noise. However, even after motor vehicles are effectively muffled and are equipped with well designed tires that are safe and relatively quiet, their noise emissions are still high, particularly at high speeds and on wet pavements.

The second form of noise control is interruption or attenuation of the sound in its path to the listener. Noise barriers and berms are in this class of controls. Moving people away from the source of noise or preventing their building homes near the source is another way of interrupting or lengthening the path of the noise.

It may be technologically impossible or economically unfeasible to solve a noise problem by modifying the source or altering the transmission path. If so, exposure to noise can be reduced at the receiver, either by limiting the amount of continuous exposure to high noise levels or by using personal hearing protectors.

Hearing protectors may be either earplugs or muffs. Earplugs can be made of soft flexible plastic, wax, paper, glasswool, cotton, or mixtures of these materials. To be effective they must provide a snug, airtight and comfortable seal. Muff-type protectors cover the entire external ear and generally provide greater protection than do earplugs.

Hearing protectors should be used only as a last resort. They do not solve the problem; they only treat its symptoms, and may be a safety hazard in themselves.

References

Office of Noise Abatement and Control, U.S. Environmental Protection Agency, Noise Effects Handbook, 1979.

SECTION III

AN INTRODUCTION FOR POTENTIAL PARTICIPANTS IN HOT SPOT (BARRIER) PROGRAMS

SECTION III

AN INTRODUCTION FOR POTENTIAL PARTICIPANTS IN HOT SPOT (BARRIER) PROGRAMS

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SECTION III

AN INTRODUCTION FOR POTENTIAL PARTICIPANTS IN HOT SPOT (BARRIER) PROGRAMS

A. IDENTIFICATION OF A HOT SPOT

Many people live close to busy highways and are bothered by noise. Resources available to reduce their noise exposure are limited, so criteria have been established to choose the most serious situations that may qualify for assistance by Federal, State, and local governments. The primary criteria are sound levels as measured with special instruments manufactured for this purpose.

This section describes sound level measurements and states the criteria that define a hot spot. It explains what citizens can do to determine if their highway noise situation is a hot spot and what they can do to reduce the noise if it is. The situations to which noise barriers are applicable is described. Case histories of barrier programs in Maryland, Minnesota, Virginia, Wisconsin, and Pennsylvania are included as background information.

Noise Measurement Terminology

The dB's of Noise Measurement

How do we measure sound? Sound is a form of energy which is transmitted through the air and received by our ears.

Technicians have found it convenient to use a logarithmic scale to describe the extremely wide range of energy levels which we perceive as sound. The logarithmic unit is expressed in decibels (dB).

Since decibels are logarithmic units, sound levels cannot be added by ordinary arithmetic. For example, if one jet produces a sound level of 90 dB when it passes overhead, two simultaneous jet flyovers would not produce 180 dB. Two jets, each with a sound level of 90 dB, would have a combined level of 93 dB. Other sound levels combine similarly as shown on the chart below.

Decibel Addition Rules for Combining Sound Levels
(approximate only)

When Two Decibel Values Differ By:	Add the Following Amount to the Higher Value:
0 or 1 dB	3 dB
2 or 3 dB	2 dB
4 to 9 dB	1 dB
10 dB or more	0 dB

"A" Weighting for the Human Ear

The human ear responds more sensitively to some frequencies than to others. Sound measurement devices have been designed to account for the characteristics of the ear through the use of special electrical weighting networks. The most commonly used network — the A-weighted one — approximates the manner in which the human ear responds to sound. This unit of measurement is commonly referred to as decibels measured on the A-scale or dB(A), or simply sound level.

The sound levels of common noises are:

Sound Levels dB(A)	Sound Sources
130	Air raid siren at 50 feet
110	Live rock music indoors
100	727 on takeoff, at 1/4 statute mile
90	Busy street corner
80	Garbage disposal
70	Vacuum Cleaner
60	Ordinary conversation at 5 feet
30	Watch ticking
10	Rustle of leaves

The above examples all reflect sound levels generated by specific single noise events. In reality, one's noise exposure during any day is a composite of many different exposures.

The cumulative exposure measure recommended by EPA for all community noise studies and planning is the Day-Night Average Sound Level (L_{dn}).

L_{dn} is the 24-hour average sound level expressed in dB(A), with a 10 decibel penalty applied to noise events from 10 p.m. to 7 a.m. The penalty for nighttime noise events accounts for the increased sensitivity of most people to noise in the quiet nighttime hours. "L" in the expression stands for average noise level, "d" for day, and "n" for night with a 10 dB penalty added.

What is a Hot Spot?*

Definition

EPA established a goal to reduce to zero the number of people exposed to outdoor levels of L_{dn} equal to or greater than 75 dB before the year 2000. Therefore, the noise level criteria for hot spots are L_{dn} equal to or greater than 75 dB in ordinary residential areas and L_{dn} equal to or greater than 65 dB in noise sensitive areas such as those around nursing homes, hospitals, schools, or places of worship, if the windows are likely to be open.

The two most important factors in determining whether a highway noise situation will meet the criteria for a hot spot are the volume of traffic and the distance of the residents from the highway's edge. Information concerning the fraction of the traffic volume that is composed of heavy trucks and the average vehicle speed on the highway also are important.

State and local governments maintain records on traffic volume for most highways within their boundaries. The traffic volume is usually measured with a counting device connected to a pneumatic tape or tube that is laid across the roadway for a few days and is stated as the average daily traffic (ADT). The hourly distribution throughout the day is not ordinarily known.

**Some of the material in this section is repeated in Section IV so that the two can be read independently.*

Information on the fraction of traffic composed of heavy trucks and buses is valuable. If the fraction is not known, average figures for like roads can be used. Unless the highway is a designated truck route, the fraction of heavy trucks will rarely exceed 10 percent. The national average figure for heavily travelled highways is 8.5 percent.

If the ADT is less than 10,000 vehicles and the heavy vehicle fraction is 8.5 percent, it is very unlikely that the noise level at an abutting residence will exceed $L_{dn} = 75$ dB.

The nomograph[1] in Exhibit IV-1 provides a handy method for estimating the L_{dn} from easily obtainable data and is sufficiently accurate for use as a screening device. The nomograph is used as follows:

1) Draw a line from the annual average daily traffic on the left (for example, 10,000 vehicles) through the percentage of the traffic that is heavy trucks and buses (say, 10 percent). This is line 1 in the example. Mark the intersection of this line with the pivot line on the left.

2) Draw a line from this intersection to the speed limit on the stretch of highway under consideration (50 mph in the example). This gives line 2.

3) Draw a line from the intersection of line 2 with the pivot line on the right to the distance scale on the right. This gives line 3.

4) The intersection of line 3 with the sound level scale will give the estimated L_{dn}.

In the example line 3 intersects the sound level scale at between 66 and 67 dB, clearly less than 75 dB. Therefore, the case which this example represents probably would not qualify for a hot spot project, except possibly in noise sensitive areas such as hospitals and school zones.

If the planner experiments with the nomograph he will find that a large traffic volume, a high speed, and a short distance from the highway to the residence are usually required to achieve a 75 dB noise level. Special cases such as heavily travelled truck routes with 30 to 40 percent heavy vehicles, highways extraordinarily close to residences, and highways with heavy volumes of nighttime traffic are the best

[1] *From J.J. Hajed, "L_{eq} Traffic Noise Prediction Method," Transportation Research Record 648, National Academy of Sciences, Washington, D. C. 1977.*

candidates for a hot spot. The first two special cases are unlikely. Planners rarely construct truck routes close to residential areas, and homes are rarely located extremely close to heavily travelled highways. The last special case is more common. The nomograph above assumes that nighttime traffic amounts to 10 percent of the daily traffic. Some formulas assume a 16 percent figure. Actual nighttime volumes may vary considerably from these norms.

Not all hot spots are good candidates for barriers as a means of noise abatement. Exhibit I-1 shows a decision tree of likely solutions to highway noise problems. The term "access" in this exhibit refers to the ability of vehicles to get on the highway through intersecting roads, streets, or driveways.

At $100 - $200 per linear foot, noise barriers are too expensive for use in low population density areas. In high density areas, if the housing is high-rise or if it is located on a free access highway, a barrier will not be very effective. *The best candidates for hot spot barriers are high density areas containing one and two story housing adjacent to a limited access highway.*

<u>How Effective are Noise Barriers?</u>

In most situations of relatively open highway through one- and two-story residential neighborhoods, barriers can provide 5 dB to 15 dB of noise reduction for nearby residents. The exact amount of noise reduction that will be obtained at a particular location from a particular barrier can be calculated using special computer programs available to highway engineers. A good average figure widely attainable in practice is 10 dB. This amount is easily perceived by the receivers as a significant and worthwhile improvement in their quality of life, and, if the neighborhood leaders have been invited to participate in the barrier program, will be an aesthetic, environmental, and economic success.

<u>Advantages of Hot Spot (Barrier) Programs</u>

In addition to reducing noise levels, a hot spot (barrier) program may provide several benefits to the community. It is compatible with and complementary to other community noise reduction programs. Barriers may ultimately save the local area money since in some cases they are less expensive than other alternatives such as insulation of residences, relocation of highways or residents, or payment of damage compensation to residents of properties adversely affected by the noise. Finally, barriers may actually increase the value of the property and permit the community to recover part of its installation and maintenance costs.

Limitations on the Applicability of Noise Barriers

Barriers are unacceptably hazardous on portions of a highway that are either very confined or that have very limited visibility. Occasionally, scenic or other considerations will outweigh the pollution control aspects of the situation.

Developing the Highway Noise Abatement Plan

Who Will Lead?

We all have a shared responsibility to participate in the efforts which are needed to reduce the impact of highway noise on our communities and to insure the maintenance of a valuable highway transportation system.

The technical lead in developing highway noise abatement plans should, however, logically be taken by the State office of transportation or highway department since these are the agencies responsible for highway construction and maintenance plans. Also the State transportation and highway departments are in a good position for bringing together and consulting with all public and private interests involved in noise abatement. Successful solutions to a noise problem require participation by all interested parties.

The Citizen's Need and Right to Participate

Individual citizens or citizen groups who want to take part in highway noise abatement planning - or want to get the process started where none exists - may contact their elected officials or persons in the State Department of Transportation. These individuals are sensitive to citizen concern about highway noise.

However, experience with barrier programs (see the case histories at the end of this section) clearly shows that the communities in which the citizens have been most active and vigorous in requesting noise abatement measures have been the communities which have received the most attention and the most barrier projects. Such communities have made their concern known to officials in their State and local departments of health, public safety, highways, and environment. Frequently they also have obtained the support of the regional representatives of the U.S. Federal Highway Administration and the Environmental Protection Agency. The regional EPA offices have very limited resources with which to assist communities, but may be a source of information. A list of the regional offices is given in Exhibit III-1.

Affected citizens have the right to participate in the process of finding solutions to the highway noise impact problem. Decisions about how highways and communities can best coexist are not matters of technical judgment alone. They involve value judgments about the quality of life a community wants. Of course, it helps to research a problem before speaking out.

<u>Where to Begin?</u>

If a State or local government, private citizen, or private citizens' group suspects that certain areas of a community are suffering from high noise levels, the first step to take is to determine the location and severity of the problem. This may include reviewing complaints received by government agencies, contacting complainants, and mapping out the neighborhoods that appear to warrant further investigation. The investigator might then obtain highway traffic, speed, and population figures and use the nomograph in Exhibit IV-1 to screen candidates for hot spots. The decision tree in Exhibit I-1 then may be used to identify the hot spots for which barriers seem to feasible solutions. The next step is to read the case histories in this Section and Section IV - Evaluation and Documentation.

EPA Region	States	Address	Telephone
I	ME, NH, VT, MA, RI, and CT	JFK Building Room 2113 Boston, MA 02203	(617) 223-7210
II	NY, NJ, PR, VI	26 Federal Plaza Room 970G New York, NY 10007	(212) 264-2525
III	PA, MD, DE, WV, VA, and DC	Curtis Building Room 225 6th & Walnut Streets Philadelphia, PA 19106	(215) 597-9814
IV	NC, SC, TN, KY, MS, GA, FL, and AL	354 Courtland, St., NE Atlanta, GA 30308	(404) 881-4727
V	WI, IL, MI, OH, IN, and MN	230 S. Dearborn Chicago, IL 60604	(312) 353-2000
VI	NM, OK, AK, LA, and TX	1600 Patterson St. Room 1107 Dallas, TX 75201	(214) 767-2600
VII	NB, KS, IA, and MO	1735 Baltimore St. Kansas City, MO 64108	(816) 374-5493
VIII	MT, ND, SD, WY, UT, and CO	1860 Lincoln St. Suite 900 Denver, CO 80203	(303) 837-3895
IX	CA, NV, AZ, and HI	100 California St. San Francisco, CA 94111	(415) 556-2320
X	WA, OR, ID, and AK	1200 Sixth Avenue Room 11C Seattle, WA 98101	(206) 442-1220

EXHIBIT III-1: EPA REGIONAL OFFICES

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B. LEGAL RECOURSES FOR CONCERNED CITIZENS

Introduction

Local and State authorities are usually responsive to the suggestions, demands, and complaints of public interest groups and individual citizens. However, these groups and individuals should be aware that when their demands are ignored or considered only superficially, they have a right to legal recourse.

Legal Obligations of the State

Federal legislation and Federal Highway Administration regulations require states to study the effects of new federally-funded highway construction or highway improvements on noise levels, as part of an overall environmental impact assessment. Applying FHWA standards, noise reduction measures may be required if the new construction will cause either 1) a "substantial increase" in noise levels, where "substantial increase" is usually defined as 10 to 15 dBA, or 2) an exceeding of "design noise levels," defined for outdoor activities in residential areas as an L_{10} of 70 dBA (L_{10} is the level that is exceeded 10 percent of the time) or an L_{eq} of 65 dBA. States are not required to use these standards. However, more lenient rules are subject to FHWA approval.

Once a significant noise impact has been established, states must investigate the feasibility of taking steps to mitigate the noise. All options should be considered, not just noise barriers. At this stage, the state highway authority will probably hold public meetings to determine public sentiment on the issue. In most cases, the state will then act according to the demands of the majority of the affected individuals.

States are not required either by Federal legislation or by regulations to study the noise effects of highways other than those undergoing new construction.

Options for Citizens

Citizens have a right to contest the decisions of state highway authorities in the courts, whether those decisions be made in favor of or against noise barriers and whether or not the citizen be in the majority of all those affected by the highway.

A major case involving this right was that surrounding the construction of a portion of I-95 in Philadelphia, Pennsylvania. A three mile section of the highway in Philadelphia Center City was completed in the Spring of 1979, but its opening to traffic was delayed until late August 1979 by conditions of a consent decree signed in December 1975.

The 1975 consent decree was an agreement between the Pennsylvania Department of Transportation, the Federal Highway Administration, the City of Philadelphia, and a community organization called the Neighborhood Preservation Coalition (NPC) requiring that noise barriers be constructed, where possible, before the Center City part of I-95 began to be used and that NPC have final approval of all barrier designs.

> Before the signing of the consent decree, the Pennsylvania DOT had performed noise-monitoring and preliminary noise-prediction analyses. Under the terms of the consent decree, the DOT was required to obtain the services of an independent noise consultant to verify the preliminary analyses and to determine recommendations regarding feasible types and locations of noise barriers. A consultant was retained and, after considerable delays, a final reort was published in December 1977. The report verified previous analyses performed by the Pennsylvania DOT and recommended various noise-abatement treatments. In a review of the report by the NPC and the DOT, the suggested solutions were found to be generally unacceptable. Many of the barriers suggested would have obstructed the adjacent communities' view of the Delaware River waterfront, and other recommendations -- such as those involving building insulation and air conditioning — presented legal and long-term complications and were contrary to the terms of the consent decree.
>
> After the rejection of the consultant's recommendations, the DOT and the NPC initiated a series of meetings with the intention of arriving at an acceptable solution that would provide the optimum in terms of both noise reduction and view. It was through approximately 30 such meetings, and 2 large, formal public meetings, that final noise-barrier location, size, and type were determined.[1]

[1] *Harvey S. Knauer, "Noise Barriers Adjacent to I-95 in Philadelphia," Highway Noise Abatement, Transportation Research Record 740, National Academy of Sciences, Washington, D.C., 1980.*

As this example shows, private citizens are able to have a large effect on noise barrier designs, and can even obtain noise reduction objectives in the face of oppsition from government authorities.

References

Mr. Bob Armstrong
Highway Engineer
Noise and Air Quality Branch
Federal Highway Administration
Washington, D.C.

Knauer, Harvey S., "Noise Barriers Adjacent to I-95 in Philadelphia," Highway Noise Abatement, Transportation Research Record 740, National Academy of Sciences, Washington, D.C., 1980.

C. DISSEMINATION OF BARRIER PROGRAM INFORMATION

Alternatives for Disseminating Information

Even the best-intended and most carefully investigated hot spot (barrier) project will be meaningless unless the people who will benefit from it and the people who must carry it out are aware of it. Therefore, getting information about hot spots and barriers to the people who must support the project is a critical part of project planning.

Targets for information on hot spot projects may be one of several types. Local citizenry with no technical expertise and no bureaucratic authority will be most interested in general motivational materials and in their abilities and rights to demand noise barriers and to participate in their design. Local government authorities also will be interested in this information and may also wish to know more about the costs and benefits of noise barriers; the experience other places have had with the barriers; and details on the safety and maintenance aspects of the barriers. At the State level, where highway authorities will usually be acquainted with noise barrier programs, the informational needs are centered on the technical aspects of selecting barrier candidates, barrier design, financing, and reviewing the solutions other States have found to particular problems. Two alternatives for reaching each of these groups are discussed below.

Media

Private citizens who may need to know about hot spot projects usually reside in major urban areas. One of the best methods to reach these individuals with information about the program is through the media: public service programs on radio and TV stations and newspaper articles. Information dissemination through the media will reach the largest audiences, but should be repeated occasionally as the residents and conditions in the area change. Also, any media program should direct the audience to sources from which to obtain additional information.

Club Meetings and Other Group Gatherings

A second alternative for reaching a large number of people at the local level is to have knowledgeable individuals make presentations on noise pollution and abatement at club or public interest group meetings, churches, and schools. Specific audiences who would be most likely to become involved in noise abatement can be targeted in this way. Again, it is important for the speaker to make sure his listeners know where they can go for more information or help in starting a program.

D. CASE STUDIES IN HIGHWAY NOISE ABATEMENT

1. Minnesota

Overview

Minnesota has completed about 34 miles of barriers in the past five years. Of the total, about 26 miles are Type II barriers (for roads that were in existence before May 1976) and 8 miles are Type I barriers (new or reconstructed roads). The 1975 Type II barrier program is now nearly complete. Further Type II construction is not currently programmed.

All of the barriers were built in the Minneapolis-St. Paul area, the major urban area of the State. Construction priorities were assigned according to the highway noise levels to which residents of abutting properties were exposed. All barriers were designed to give at least 10 dB of noise reduction. Tests show that the predicted results were achieved.

Background

History

Although local jurisdictions regularly received complaints about highway noise, it was not until the early 1970's that the Minnesota Highway Department (now part of the Minnesota Department of Transportation) began to receive complaints about the noise associated with limited access highways. State and Federal noise laws were being enacted during this period and it is possible that some of the complaints were the results of public appreciation of the fact that noise pollution was going to be taken seriously.

The Minnesota Highway Department began experimenting with barriers in 1972 and found them effective and feasible. In 1974 the Minnesota Pollution Control Agency set noise standards, as required by the provisions of the Minnesota Environmental Policy Act of 1973. In 1975, the State legislature directed the Commissioner of Highways to abate noise along interstate highways* abutting residences in the area around Minneapolis and St. Paul (the Twin Cities) and required him to use part of the gasoline tax to fund the program. The Highway Department began an active program of barrier construction in the Twin Cities area in 1975. In 1978, the legislature placed a moratorium on Type II projects but passed legislation continuing Type I projects.

Project Planning Procedures

The first activity of the Highway Department after beginning the noise program was to conduct an inventory of interstate highways that had noise levels exceeding the FHWA and/or Minnesota Pollution Control Agency criteria. Preliminary plans were prepared for each of these projects, in order of the priorities assigned them. Meetings were held with local officials and the local general public. Originally, the Department offered local citizens a wide choice of materials for the barriers, but experience showed that some were much more expensive than others. Now if an earthen berm is not going to be used, the public is offered only barriers which the department is prepared to pay for, and which fit a visual design continuity plan for that highway. (The logic of this limited choice is presented below in <u>Technical Aspects of Minnesota Barriers</u>.) If local officials and the public approved of the Department's intentions, a project statement was prepared. This statement included maps, an environmental assessment, cost and noise

***Trunk highways were added in 1977.*

abatement projections, the results of design studies, and plans for public involvement. If the plan and statement were approved, the project was budgeted and assigned for execution just like other highway projects.

The project planning process used today is outlined in Exhibit III-3.

Acoustical Criteria for Eligibility

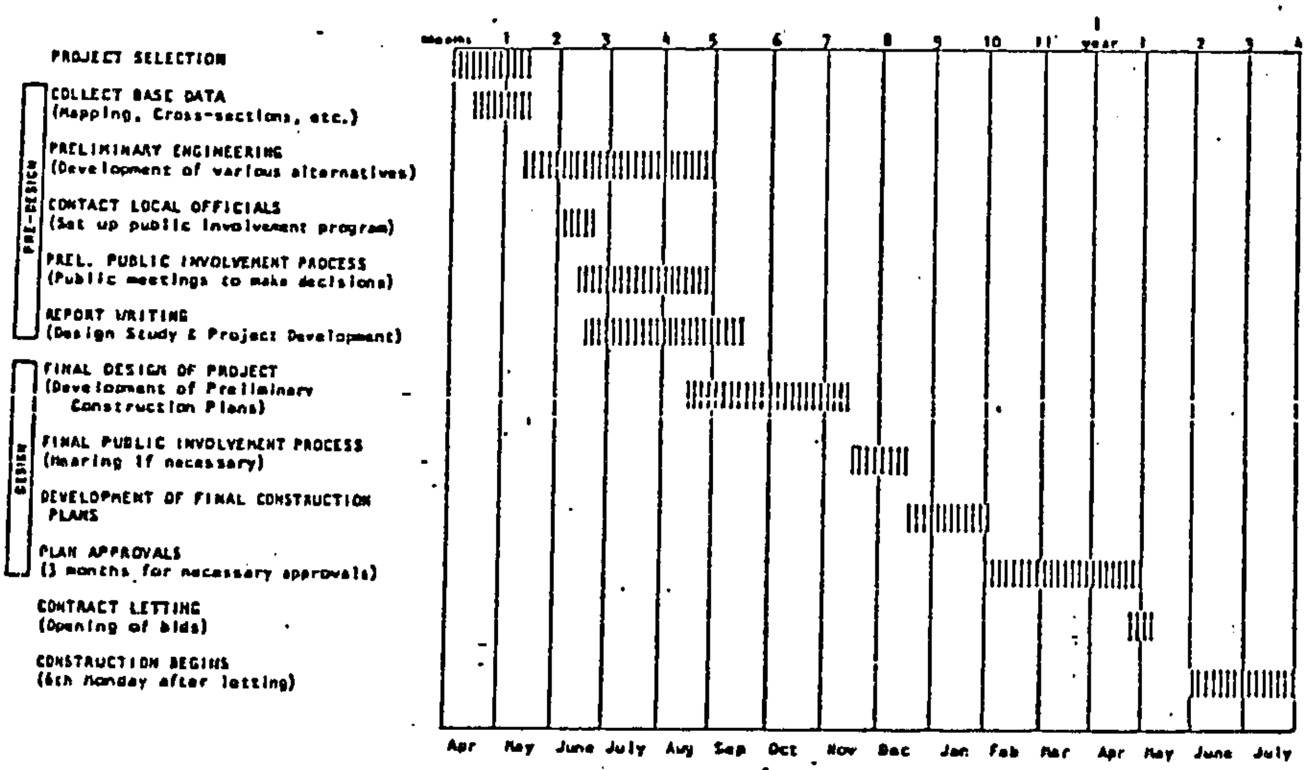
Most new community noise level criteria are written in terms of L_{dn}, but this measure has not been used as a criterion for selection of areas for noise barriers in Minnesota. Instead, the Minnesota Pollution Control Agency sets its criteria in terms of L_{10} and L_{50}, the levels that are exceeded 10 and 50 percent of the time. For example, if one measured the immediate sound level in every one of the 86,400 seconds in a day, L_{10} would be exceeded in 8640 seconds. Only residential areas have been considered. In that land use, as Exhibit III-4 shows, the Minnesota criteria are more stringent than the FHWA criteria.

The noise levels were measured in every residential neighborhood that abutted interstate and trunk highways in the Twin Cities area. Then, a noise level in decibels was assigned to each of 28 highway sections. Each highway section was then placed in one of five categories of noise impact. Category I, for example, had daytime L_{10} levels greater than 80 dB and/or nighttime levels greater than 77 dB. Each of the other categories covered the lower levels in steps of 5 dB.

The highest construction priority was assigned to Category I. There were 8.5 miles of highway (counting both sides of the roadway) in this category and all have been furnished with barriers. Lower priorities were assigned in order of decreasing noise levels. There were 31.5 miles of highway in Category II. Barriers have been built along 23.5 miles, 5.0 miles of proposed barriers were rejected by communities, and 3 miles remain as candidates for future barriers. There were 46.0 miles of highways in Category III, of which 2.0 miles have been furnished with barriers, and 4.0 miles of barriers have been rejected. No mileage in Categories IV or V has been furnished with barriers.

Effectiveness

All Type II barriers constructed to date were designed to reduce noise levels by 10 dB or more and to meet the FHWA standard of L_{10}=70 dBA or less. Where it has been



<u>Source:</u> *Minnesota Department of Transportation, Interstate Noise Abatement Program Status Report, January 1977.*

EXHIBIT III-2: PROJECT DEVELOPMENT
(TYPICAL EXAMPLE OF A NOISE ABATEMENT PROJECT)

LAND USE	FHWA Category	Minnesota Pollution Control Agency* Day (7AM-10PM)		Minnesota Pollution Control Agency* Night (10PM-7AM)		Federal Highway Administration**	
		L_{10}	L_{50}	L_{10}	L_{50}	L_{10}	L_{eq}
Residential, outdoors	B	65	60	55	50	70	67
Commercial, outdoors	C	70	65	70	65	75	72
Industrial, outdoors	D	80	75	80	75	75	72
Special areas requiring serenity outdoors	A					60	57
Residences, hospitals, libraries, indoors						55	52

*Sound levels are made outdoors at the point of human activity within the land use that is closest to the sound source.

**Either the L_{10} or the L_{eq} may be used on any project, but not both.

EXHIBIT III-3: COMPARISON OF THE HIGHWAY NOISE CRITERIA OF THE FEDERAL HIGHWAY ADMINISTRATION AND OF THE MINNESOTA POLLUTION CONTROL AGENCY possible to do so without great extra cost or loss of visual appeal, the barriers have been designed to reach the Minnesota Pollution Control Agency daytime standard of L_{10}=65 dBA or less.

Actual reductions were measured in four locations and noise levels were shown to have dropped by 11, 12, 13 and 16 dBA.

Management

Though the Minnesota Pollution Control Agency sets the criteria for acceptable noise levels, the major responsibility for the barrier program has been held by the Highway Department and the Department of Transportation into which it was merged in 1976.

MDOT conducted the original research on noise barriers, chose the areas to receive highest priority, planned and designed the barriers, met with the community leaders and obtained their support, let contracts for the construction and landscaping, and followed up after the barriers were installed with surveys to determine the acoustical, economic, and social consequences of the barrier program. The Department also investigated alternatives methods of noise abatement including pavement resurfacing, building insulation, and land use planning.

The Federal Highway Administration furnishes technical assistance in the form of reports, analytical studies, computer models, and design guides for different types of barriers and barrier programs in general but not site specific designs.

Local Involvement

Community involvement in highway noise abatement planning starts about two months after the planning process. MDOT representatives first meet with local officials, then schedule a meeting with citizens living adjacent to the barrier and other interested persons to discuss noise abatement alternatives, the location and height of the barrier and the possible noise reduction. Reaction from this meeting is forwarded to the local officials with a request for a resolution containing their findings and recommendations. No barriers are built in areas where residents do not want them.

If the project is approved at the local level, the community will be contacted again before construction plans are finalized. A formal public hearing may be held at this time.

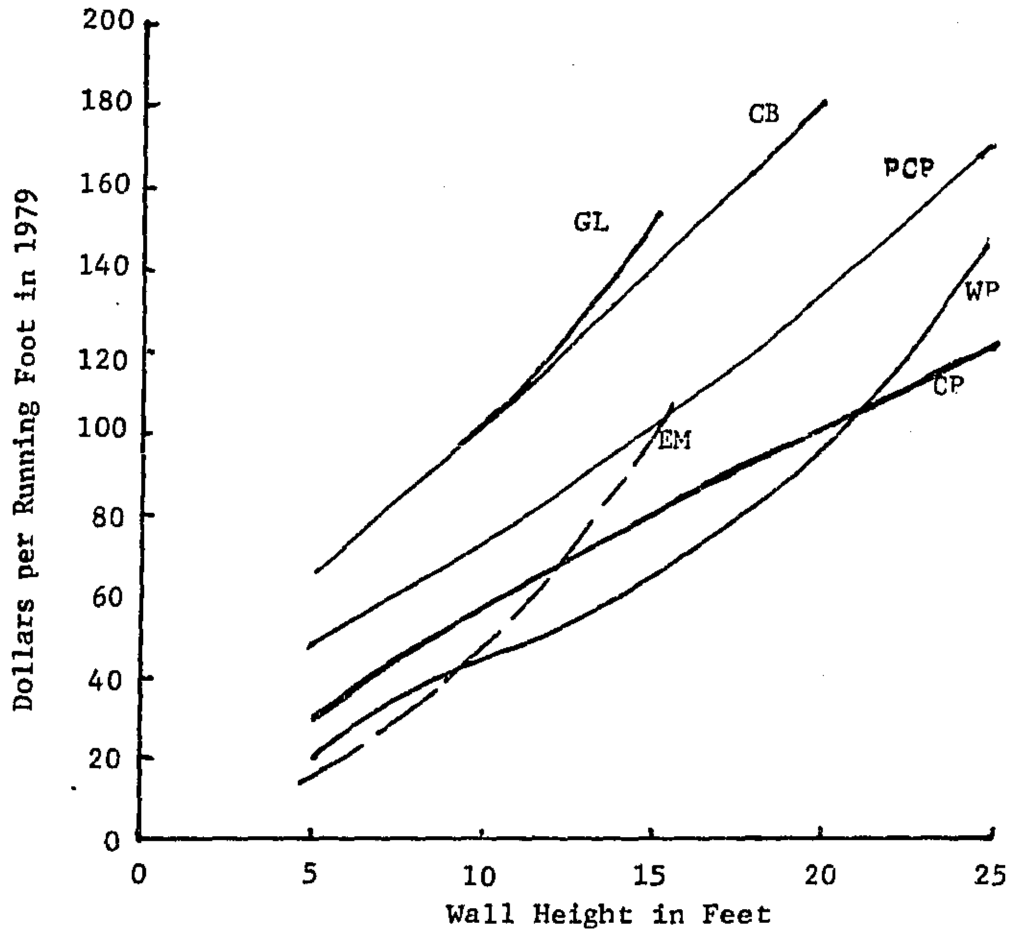
Acceptance by the public has always been an important part of the barrier program in Minnesota. One measure of public acceptance is the fraction of the communities that accept the barrier project when it is offered: Out of 43 miles of projects that were offered, communities accepted 34 miles, just under 80 percent. There was one rejection of part of a project in Category I, those in areas with the highest noise levels. The barrier mileage rejection rate was 17 percent (5 miles out of 28.5) for the Category II projects. Two-thirds of the barrier mileage, 4.0 out of 6.0, was rejected in the Category III projects.

A second measure of public acceptance of the barriers is the attitude of residents who are affected acoustically and visually by the projects. A limited survey of attitudes was conducted before some of the barrier projects were adopted, and a complete mail survey was made of residents living adjacent to noise barriers within two years after they were built. The answers to questions in the latter survey varied significantly from project to project, but residents generally approve of the barriers and believe that they increase real property values, though Minnesota's studies indicate that no real change in property values has occurred. There are definite exceptions to the general acceptance however. The owners of three residences brought suit against the Department of Transportation and won with compensation to be determined through eminent domain action on claims that the noise barrier blocked the view and air movement. This court decision has been appealed.

Technical Aspects of Minnesota Barriers

Minnesota has in use some of each of the four basic types of noise barriers: wood planks on posts, prestressed concrete panels, earth mounds, and glued laminated wood panels. Exhibit III-5 shows the cost of barriers of various construction materials. Barriers with sound absorptive materials have not been used. In cases where sound is reflected off a barrier and back across a highway, a higher barrier is installed on the opposite side of the highway to reduce the reflected noise.

Unless the Department of Transportation elects to use earth mounds, the public is allowed to participate in selecting the barrier material. The laminated wood panel construction, however, is restricted to walls less than 15 feet high. Selection is further restricted to designs visually compatible with others along that highway.



Estimated Average Costs of Noise Walls of
Different Types Erected on Level Ground

EM = Earth mound, CP = Concrete posts, wooden face
WP = Wood posts, wooden face, CB = Concrete block
PCP = Prestressed concrete panel,
GL = Glued laminated panel

EXHIBIT III-4

Costs and Financing

The average cost of the barriers over the five years of the program has been about $137 per foot. Ninety percent of the costs were paid with Federal funds obtained under the provisions of the Federal-Aid Highway Act of 1973. State funds for the barrier program were obtained from the gasoline tax, in accordance with a 1975 Minnesota law directing the Commissioner of Highways to spend 0.62 percent of the revenues on motor vehicle fuel on barriers along interstate and trunk highways.

2. Maryland

Overview

Maryland's Highway Noise Program began in 1967 when the first noise berm was constructed on I-495. Since 1970, traffic noise attenuation has been an integral part of all highway planning. Maryland's Highway Noise Barrier Program was instituted in response to a need for Type II barriers projects in residential neighborhoods that were in place before the highways were constructed. This barrier program concerns itself primarily with the two beltways around Washington and Baltimore, with I-95 (Washington-Baltimore-Wilmington), and to a lesser extent with I-83 (Baltimore-Harrisburg).

The program is in its infancy, with only two projects completed at this time. One, a 1300 foot barrier in a residential community on the Baltimore-Washington corridor, has reduced L_{10} noise levels by 7 to 9 dB. Another, a 2200 foot barrier in Baltimore City, is expected to reduce noise by 10 to 11 dB. Several projects are under construction.

Management

The Highway Noise Barrier Program in Maryland is unique in that it is administered by a landscape architect within the Bureau of Landscape Architecture of the State Highway Administration, rather than by an engineer within design division. This approach to noise problems has resulted in barrier solutions that are highly effective visually as well as acoustically.

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Local Involvement

The Maryland DOT approach to the installation of Type II barriers incorporates heavy community involvement. Projects are first discussed with local government officials and community leaders and then proposed to the community through newspapers and flyers. A public meeting is held to assess community opinion concerning the project. (A sample handout used at a citizen association/MDOT meeting follows in Exhibit III-5). If the community is opposed to the project, MDOT will not proceed.

After this initial contact with citizens' groups, MDOT conducts on-site acoustical monitoring and prepares preliminary barriers designs. Additional public meetings or meetings with a community task force may continue until final design is complete.

In the future, local citizens will also have the opportunity to participate in follow-up surveys after project completion. Follow-up surveys were not performed for the first two projects.

Technical Aspects of Maryland Barriers

Maryland has utilized a fiberglass reinforced cement post and panel system, concrete fan wall barrier, exposed aggregate post and panel system, and a metal barrier. Several current projects are investigating the use of a wooden barrier system. Each new project is approached as a new design problem attempting to select a system which fits the requirements of the site.

Each barrier project must be complete in all respects, including drainage, minor highway facility improvement and landscaping. MDOT avoids barrier plans that require a high degree of maintenance.

Cost and Financing

Maryland estimates that its barrier projects costs range from $14-20 per square foot including all the site work and landscaping. Most projects require drainage work, leveling or berm building, or some site work other than the erection of the barriers themselves. These costs are figured into the average quoted above. Design costs are not included.

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Ten highway noise projects were included in Maryland's capital improvement plans for 1979-85. All but one is funded 90 percent by Federal interstate funds with 10 percent state matching monies. The exception is a project near the Baltimore tunnel which is funded by the Toll Facilities Administrtion. About $300,000 is budgeted from the State treasury each year, with 3-5 projects active at one time.

(Text continues on page III-26)

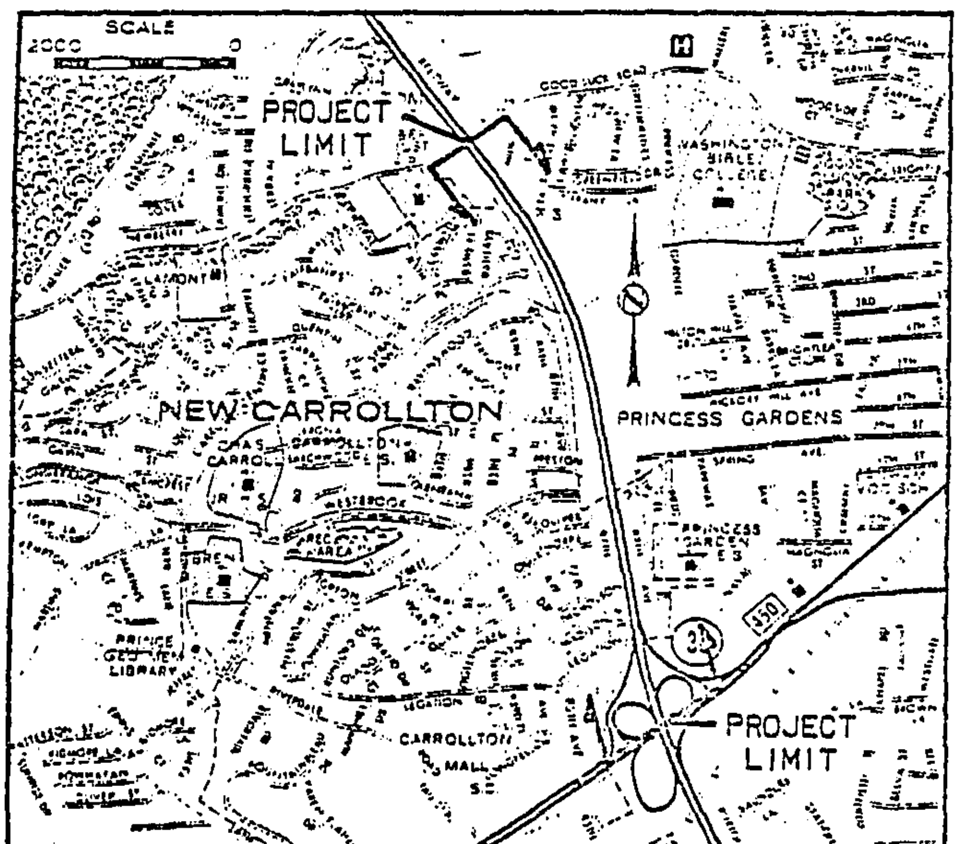
Maryland Department of Transportation
State Highway Administration

NOISE ABATEMENT STUDY AND DESIGN

for the

CAPITAL BELTWAY (I-95)

from Maryland Route 450 (Annapolis Road) to Good Luck Road



State Project No. P633-251-372

EXHIBIT III-6

CONTRACT NO. P 633-251-372
TYPE II NOISE ABATEMENT STUDY
I-95--MARYLAND ROUTE 450 TO GOOD LUCK ROAD

INTRODUCTION AND PURPOSE OF STUDY

Greiner Engineering Sciences, Inc. has been retained by the Maryland State Highway Administration to design noise abatement measures for a portion of the Capital Beltway (I-95) from Maryland Route 450 (Annapolis Road) to Good Luck Road. The purpose of this project will be to reduce the impact of traffic noise levels from I-95 upon residential communities adjacent to both sides of that highway in the described area. Of primary importance is the involvement of affected citizens and communities as an integral part of the overall design process.

In order that the communities involved might understand our goals, the following outline of the approach to this project is presented.

PROCEDURE

An initial meeting was held with the Mayor of New Carrollton and several community leaders in October, 1979 to introduce the design team and the purpose of the project. Since October, the following activities have been completed leading to this meeting:

+ Monitoring of existing noise levels along the project.
+ Site analysis with emphasis on vegetation, topography, views, etc.
+ Analysis of barrier length, height and attenuation, balancing attenuation with aesthetic compatibility.
+ Preparation of barrier material concepts for presentation to the community.

EXHIBIT III-5 (cont.)

This data has brought us to tonight's meeting. A presentation of the process to date and the barrier design concepts will be made, followed by a period for comments and questions from the community. Concerns raised by the community will be considered prior to proceeding further with the project.

The Highway Administration will make a decision as to which of the alternate configurations in each portion of the project corridor best meets the goals of the project from the standpoints of barrier effectiveness, engineering feasibility, aesthetic compatibility, construction cost, and public acceptance. The project will proceed to Final Design and development of plans, specifications, and cost estimates so that the project can be advertised for construction. It is anticipated that these plans and specifications will be completed by December 31, 1980. Construction is anticipated to take approximately nine months.

We hope that this has helped to explain the basic facet of this project and the role of public involvement. Should you have any questions, please feel free to contact one of the following individuals:

Mr. Charles R. Anderson, Chief
Bureau of Landscape Architecture
State Highway Administration
2323 West Joppa Road
Brooklandville, Maryland 21022
(301) 321-3521

Mr. William E. Kallas, P.E.
Chief Environmental Engineer
Greiner Engineering Sciences,
1 Village Square
Village of Cross Keys
Baltimore, Maryland 21210
(301) 323-8100

EXHIBIT III-5 (cont.)

PROPOSED AGENDA FOR PRESENTATION TO NEW CARROLLTON
AND DRESDEN GREEN COMMUNITY ASSOCIATIONS
I-95 NOISE BARRIER DESIGN STUDY
MAY, 1980

OPENING REMARKS AND INTRODUCTION OF CONSULTANT TEAM - BLA

HISTORY AND PURPOSE OF PROJECT PLANNING

DESCRIPTION OF STUDY CORRIDOR

NOISE CHARACTERISTICS AND FHWA DESIGN NOISE LEVELS

DESCRIPTION OF MONITORING PROGRAM

IDENTIFICATION OF NOISE IMPACT AREA

BASICS OF NOISE BARRIER DESIGN

MODELING PROCEDURE

DESCRIPTION OF PROPOSED NOISE BARRIER SYSTEM

RIGHT-OF-WAY REQUIREMENTS

AESTHETIC CONSIDERATIONS

PRESENTATION OF MATERIAL CONCEPTS

COMMENT PERIOD

EXHIBIT III-5 (cont.)

3. Virginia

Overview

Between 1975 and 1979, the Virginia Department of Highways and Transportation (VDOHT) erected approximately 11.7 miles of noise barriers. All but one of these were constructed in conjunction with highway improvement projects (Type I barriers). The State is now considering a Type II barrier program, one for existing highways that are not undergoing expansion or change. The Type I barrier program will be completed before Type II barrier construction begins.

The Virginia Noise Barrier Program is consistent with the Federal-Aid Highway Act of 1970 and subsequent Department of Transportation Regulations which require States to include noise abatement along with any new construction associated with highways.

Management

The Air, Noise and Energy Section of the Virginia Department of Highways and Transportation is responsible for the barrier program. The agency's duties include managing noise barrier research and development and design planning, primarily through a special Barrier Review Committee. This committee evaluates the sound barrier proposals received from contractors and others and, if the proposal is accepted, oversees the adoption of the design. The committee's decisions are based on:

1. Acoustical characteristics
2. Structural adequacy
3. Durability and maintenance requirements
4. Cost relative to other similar designs
5. Aesthetics
6. Citizen input.

The VDOHT is also completely responsible for barrier program implementation, supervising all phases of construction, and landscaping. Finally, the Department is required to conduct follow-up surveys to evalute the effectiveness and acceptability of the barriers.

Local Involvement

In one case community complaints rather than Federal requirements played a major role in the decision to construct a noise barrier in Virginia. In that case citizen complaints about noise near a State tollway brought the noise problem to the attention of VDOHT officials. The State then conducted a study to determine the validity of the complaints and once officials were satisifed that a problem existed, the barrier was constructed.

Plans and pertinent data for probable noise abatement activities are made available for review and comment at a public hearing, as an element of the overall highway project proposal.

Public opinion is incorporated into noise abatement planning in two ways. First, plans and pertinent data for noise abatement activities associated with a proposed highway construction project are presented for review and comment at a public meeting. Second, barrier construction projects may be followed-up with VDOHT surveys to ascertain which materials are the best noise attenuators, what modifications are needed, and how the community perceives the noise barrier. The results of this survey are taken into consideration in planning the design, color, and landscaping for future noise barriers.

Technical Aspects of Noise Barriers

Virginia has used five basic materials for sound barriers: earth berms, wood planks on posts, prestressed concrete, glued laminated wood, and steel posts and panel walls.

Earth berms have been used where there has been sufficient right-of-way available. Berms have also been used in conjunction with barriers made of other materials to provide necessary height. When berms alone are not feasible, the choice of materials has been left to the public. Favorable results have been obtained from all types of materials used.

Costs and Financing

The average cost of Virginia noise barriers is $863,000 per mile. The cost per foot has ranged between $100 and $250 depending on the material used for the barrier, the barrier's height, and other construction factors.

The Federal Highway Administration provides funding for noise barrier construction on interstate highways to the same extent to which it provides funds for construction of the highway (usually 90 percent), with the State providing the remainder from the general highway fund supported by the State gasoline tax. The State's portion of the funding for one project, a barrier on a non-interstate highway, was obtained from funds remaining from toll road construction bonds. There are no special taxes or funds specifically designated to support barrier construction, as there are in Minnesota.

4. Pennsylvania

Overview

The first major noise barrier project constructed in Pennsylvania is located in Philadelphia's Center City on a 3-mile stretch of the Delaware Expressway (I-95). The barriers were built in response to pressures by citizens' groups and involved a great deal of community participation throughout the design and planning stages. Barrier heights range from 8 to 27 feet and were sometimes compromised in favor of an unobstructed view of Philadelphia's historic waterfront.

Management

Primary responsibility for barrier construction was held by the Pennsylvania Department of Transportation. However, the citizens' groups that were active in obtaining the barriers also played a major role in design. Under the terms of a 1975 consent decree between the Pennsylvania Department of Transportation, the Federal Highway Administration, the City of Philadelphia, and an organization called the Neighborhood Preservation Coalition, an organization of about 20 constituent community groups in the vicinity of I-95 in Philadelphia, all barrier designs had to be approved by the Neighborhood Preservation Coalition.

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Local Involvement

The Pennsylvania noise barrier project illustrates the impact that concerned and active citizens can have on noise planning in their neighborhoods. Had citizens not banded together and taken the issue to the courts, the barriers probably would not have been built, and certainly would not have been designed in a way that would be as satisfying as they are. The following excerpt from an article by Harvey S. Knauer describes the citizen participation process.

> . . .The finalization of barrier locations, types, and sizes was considered a major accomplishment in itself in light of previous relations between the community and the state DOT. Agreements were reached in numerous meetings held in the area, usually in the homes of community leaders. Most of these meetings were held at night and were attended by two or three representatives of the Pennsylvania DOT and two or three community leaders. The early meetings involved informal discussions of noise models, noise theory, and noise effects. Alternative locations for noise barriers were discussed extensively, and major consideration was given to the issue of the view provided. In one area, temporary barriers were erected to aid the community in making its decisions about barrier height.
>
> Many samples of barrier materials were shown to the community representatives prior to their selections. Barrier materials, locations, and heights agreed to by the community leaders and the department were presented as joint recommendations at two large public meetings. These meetings consisted of an initial two hour informal display period in which individual questions were answered on a one-to-one basis. A short 30- to 45-minute formal joint presentation by a representative of the Pennsylvania DOT and a community leader followed. Slides of various barrier types were included in this presentation. After a short recess, a general question-and-answer period was held, and this was followed by another one-on-one question-and-answer period. To aid in citizens' understanding of noise levels, an audiovisual tape of traffic on a local expressway was played back in the presence of a sound meter. The volume was adjusted to varying noise levels, depending on the level a particular individual was interested in hearing. The noise meter made it possible to approximate L_{10} noise levels. The video portion of the demonstration enabled participants to experience the noise fluctuations caused by approaching and diverging truck and automobile traffic.
>
> Each participant in the meeting was asked to complete a questionnaire indicating his or her feelings about the barrier recommendations presented, barrier materials, associated improvements, and noise-view trade-offs. Results of the questionnaires were reviewed by the community leaders and Pennsylvania DOT personnel before formalization of the final barrier recommendations.[1]

[1] *Harvey S. Knauer, "Noise Barriers Adjacent to I-95 in Philadelphia," Transportation Research Record T40, National Academy of Sciences, Washington, D.C., 1980.*

Technical Aspects of Pennsylvania Barriers

The three mile strip of I-95 which was to have barriers on it was divided into four sections. Each of these was designed and contracted for construction separately. In a neighborhood consisting mainly of three-story residential middle and upper class townhouses located 70 to 110 feet from the highway, citizens chose a precast concrete panel and steel post barrier, dyed brick red and imprinted with a brick pattern. The post foundations can withstand a horizontal force of 30-lbf/ft^2. The post and panel system generally met Pennsylvania DOT's objective of being able to salvage certain barrier sections if their movement was required. Steel noise barriers were constructed on a bridge structure in this area.

Citizens in the second neighborhood, one similar to the one described above, chose a reinforced earth wall barrier. The wall is composed of a series of interlocking panels supported by metal straps that extend back from the wall into specially prepared backfill material. A concrete parapet topped with a high decorative fence will be erected on top of the wall. This concept enabled the development of approximately five acres of open space and parking area behind the barrier. This area was previously occupied by the cut and slope of the highway.

The third contract section, also an upper-income residential area, chose a wall of reinforced concrete faced with real brick. A reflection chamber was created between the barrier and an existing retaining wall. It was determined that absorptive treatment of the existing retaining wall was necessary if the new noise barrier were to produce the required noise attenuation.

The community in the fourth contract area contained an active artistic element that was interested in "having the barriers express architecturally the history of the area ... their ideas materialized into barriers in which multicolored concrete blocks were used to form a mural design."[1] The Pennsylvania DOT considered stuccoing the highway side of the barrier to avoid having motorists distracted by the design. However, since other states sometimes have designs on the motorists' side of the wall, the design was left visible. PDOT plans to evaluate the effects on traffic and drivers in the future.

First floor exterior noise level reductions in the barrier areas were predicted to range from 6 to 15 dB (L_{10} noise levels).

[1] *Ibid.*

Costs and Financing

The in-place barrier costs for the Philadelphia barriers ranged from $22/ft^2 for post-and-panel and reinforced concrete block barriers to $84.74/ft^2 for the reinforced concrete brick-faced barrier in area 3, with the latter high price due to complicated excavation, forming, shoulder removal and replacement, and brick-facing operations.

In 1976, about a year after the signing of the consent decree, Pennsylvania DOT developed financial problems that led in 1977 to the suspension of its Twelve-Year Capital Improvement Program and a major reduction in personnel. DOT was left without the funding necessary to meet the requirements concerning noise barriers required by the consent decree. Financial problems continued until June, 1978, when it appeared possible that money would be obtained outside DOT to match Federal interstate highway funds for barrier construction. In an action unprecedented in the state, the legislature in October of 1978 approved $250,000 in matching funds (transferred from revenue sharing funding) for barrier construction.

References

Knauer, Harvey S., "Noise Barriers Adjacent to I-95 in Philadelphia," Transportation Research Record 740, National Academy of Sciences, Washington, D.C., 1980.

5. Wisconsin

Overview

According to a study by Neil R. Wienser and Kumares C. Sinha, the State of Wisconsin has been concerned about freeway noise for some time. The Wisconsin Division of Highway constructed earth berms for sound attentuation along I-94 in Milwaukee and Waukesha Counties in 1972. These initial barrier efforts were very successful:

> An attitudinal study revealed that as a direct result of the berm construction there was a perceived reduction in sound levels in the neighborhood, and awareness of more privacy enjoyed by residents (both inside and outside of their homes) immediately adjacent to the freeway. The study concluded that "even minor attenuations of freeway noise of 5 dB or less are discernible within adjacent neighborhoods and, based upon the subjective responses to the attitudinal survey, are perceived to be greater than are actually measured."[1]

Local Involvement

The primary current barrier project is one along the Airport Spur Interchange, a cloverleaf interchange connecting the Airport Spur to I-94. This project was the direct result of citizens' protests designed to stop the planned construction of this interchange. The citizens did not succeed in stopping the project, but did commit the highway authority to the construction of sound barriers.

The public is not heavily involved in the barriers design and selection in Wisconsin. However, an informal survey indicated that community involvement would have led to more community satisfaction with the barriers.

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[1] *Neil R. Wienser and Kumares C. Sinha, A Study of the Effects of Earthen Attenuation Devices in Reducing and Improving Privacy in Neighborhoods Adjacent to Urban Freeways, unpublished, part of a program of research and training at Marquette University, sponsored by the Urban Mass Transportation Administration of the U.S. Department of Transportation.*

SECTION IV

EVALUATION AND DOCUMENTATION

SECTION IV

EVALUATION AND DOCUMENTATION

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SECTION IV

EVALUATION AND DOCUMENTATION

A. THE HIGHWAY NOISE EVALUATION PROCESS

Preliminary Screening of Candidates for a Hot Spot (Barrier) Project*

To qualify as a hot spot, an area must usually have a significant population that is exposed to an L_{dn} equal to or greater than 75 dB. The two most important factors in determining whether the highway area will qualify are the volume of traffic and the distance of the residents from the highway's edge.

State and local governments maintain records on traffic volume for most highways within their boundaries. The traffic volume is usually measured with a counting device connected to a pneumatic tape or tube containing that is laid across the roadway for a few days and is stated as the average daily traffic (ADT). The hourly distribution throughout the day is not ordinarily known.

Information on the fraction of traffic composed of heavy trucks and buses is valuable. If the fraction is not known, average figures for like roads can be used. Unless the highway is a designated truck route, the fraction of heavy trucks will rarely exceed 10 percent. The national average figure for heavily travelled highways is 8.5 percent.

If the ADT is less than 10,000 vehicles and the heavy vehicle fraction is 8.5 percent, it is very unlikely that the noise level at an abutting residence will exceed $L_{dn} = 75$ dB.

The nomograph** in Exhibit IV-1 provides a handy method for estimating the L_{dn} from easily obtainable data and is sufficiently accurate for use as a screening device. The nomograph is used as follows:

1) Draw a line from the annual average daily traffic on the left (for example, 10,000 vehicles) through the percentage of the traffic that is heavy trucks and buses (say, 10 percent). This is line 1 in the example. Mark the intersection of this line with the pivot line on the left.

**Some of the material in this section was presented in Section III so the two can be read independently.*

***From J.J. Hajed, "L_{eq} Traffic Noise Prediction Method," Transportation Research Record 648, National Academy of Sciences, Washington, D. C. 1977.*

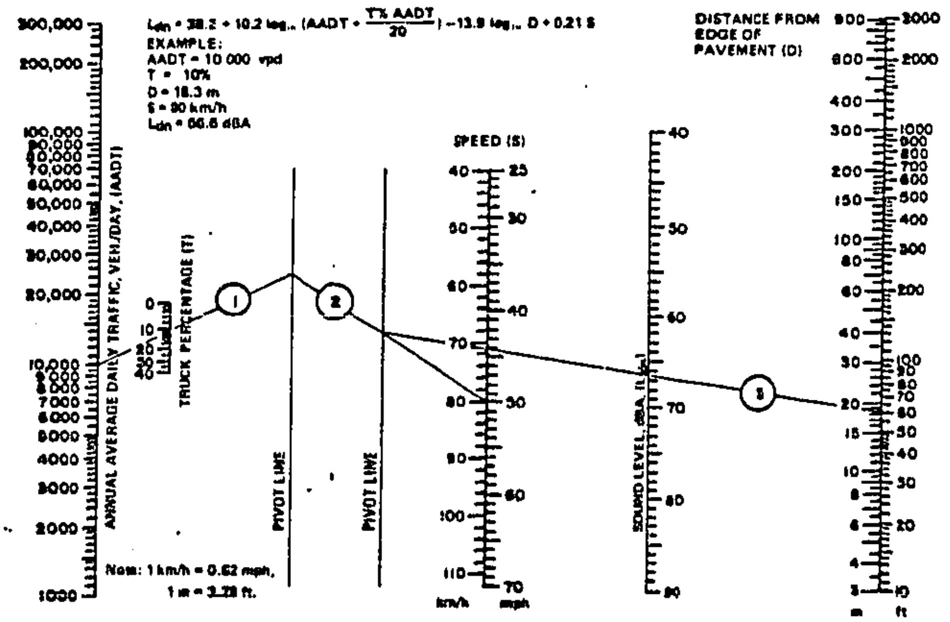

EXHIBIT IV-1: NOMOGRAPH FOR PREDICTION OF L_{dn}

2) Draw a line from this intersection to the speed limit on the stretch of highway under consideration (50 mph in the example). This gives line 2.

3) Draw a line from the intersection of line 2 with the pivot line on the right to the distance scale on the right. This gives line 3.

4) The intersection of line 3 with the sound level scale will give the estimated L_{dn}.

In the example line 3 intersects the sound level scale at between 66 and 67 dB, clearly less than 75 dB. Therefore, the case which this example represents probably would not qualify for a hot spot project, except possibly in noise sensitive areas such as hospitals and school zones.

If the planner experiments with the nomograph he will find that a large traffic volume, a high speed, and a short distance from the highway to the residence are usually required to achieve a 75 dB noise level. Special cases such as heavily travelled truck routes with 30 to 40 percent heavy vehicles, highways extraordinarily close to residences, and highways with heavy volumes of nighttime traffic are the best candidates for a hot spot project. The first two special cases are unlikely: Planners rarely construct truck routes close to residential areas and homes are rarely located extremely close to heavily travelled highways. The last special case is more common. The nomograph above assumes that nighttime traffic amounts to 10 percent of the daily traffic. Some formulas assume a 16 percent figure. Actual nighttime volumes may vary considerably from these norms.

The estimates obtained by using a nomograph are not a substitute for the actual measurements and detailed computer simulations incorporated into later steps, but they are useful for screening. Borderline cases should be included when more refined testing begins.

Investigating Candidate Highways

The simulation methods developed by FHWA to predict the noise levels near highways and the reduction of these levels by barriers are quite accurate. However, local officials and residents are pleased when actual data are used along with computer simulations. The two principal sources of data are an analysis of complaints and measurements of the noise levels.

Complaint Analysis

Ideally, a hot spot (barrier) program should be a preventive one, one that acts to protect the public's health in the early stages of highway planning. However, hot spot (barrier) programs often begin as reactive programs responding to citizens complaints.

In most communities noise complaints are received by a wide variety of individuals and organizations. Among them are elected officials and the police, along with other departments such as highway, traffic, environmental, fire, zoning, building, health planning, and public safety agencies. They also include newspapers, environmental organizations, citizens' and neighborhood organizations, and political parties. Each of these potential sources should be contacted and photocopies of noise-related correspondence, logs, or other complaints should be obtained. Ideally, the records would include the complainant's name and address, the date and time of the complaints, and the nature of the noise problem. The identity of the complainant in each case is important because the individual is a potential participant in later stages of the project and because it permits distinguishing between a large number of complaints from a variety of complainants and an equal number of complaints from a few regular complainants. Plotting the addresses of the complainants on maps will give some indications of the extent of the noise problem and will help to screen out complaints from outside the jurisdiction of the government with the hot spot project. The time patterns of highway noise can be inferred from the seasons, days of the week, and hours of the day of the complaints if their number is large. These time patterns and information on the types of vehicles complained about (trucks, motorcycles, car, sirens on emergency vehicles) can complement the traffic volume and traffic mix data that are available from the highway department.

Complaint records should be studied in detail before any noise meaurements or interviews are conducted. The investigator can benefit both himself and the complainant by calling the complainant to complete any records missing information. Complainants will be gratified to know they are being heeded, and the investigator will be able to make better choices of noise survey locations with complete information.

Complaints emanating from residences not close to heavily travelled highways; from isolated residences; and from commuters, shoppers, workers, and other nonresidents should be discounted following the initial study of the complete complaint records. Hot spot projects are limited to protecting residents from highway noise in the jurisdiction funding the project.

Measurement of Sound Levels

Sound Level Meters

An ordinary sound level meter can be used to tell the investigator whether a barrier is potentially warranted as a noise control device and whether more exact and specialized work is worthwhile. A sound level meter consists of a microphone (sometimes mounted directly on the meter, sometimes on an extension cord), an amplifier, a frequency weighting network, and a meter movement. The meter movement has a "fast" and a "slow" response capability to respond to rapidly changing sound levels, such as those from highway traffic, or to slowly changing levels such as those from fans or air conditioners. The "fast" setting should be used when making the measurements for hot spots. Sound level meters are simple to use and the manufacturers' instructions are comprehensive, clear, and easy to follow.

Any sound level meter used for investigating hot spots should meet the specifications of the American National Standards Institute (ANSI)[1], for a Type 1 or Type 2 meter. Type 2 meters are less precise than Type 1, but are perfectly acceptable for hot spot identification. Special purpose meters are designated by the letter "S" and are acceptable if they meet the accuracy requirements for a Type 2 meter, have a "fast" meter movement, and include an "A-weighting network". Such a meter will be designated as Type S2A meter and is used commonly for community noise measurements. Assistance in the choice of a sound level meter may be obtained from the Regional EPA office. Alternatively, regional offices have often agreed to lend local officials instruments for use in hot spot programs. However, since the number of available instruments is limited, a short wait may be necessary.

Sound level meters users should be aware of certain environmental conditions that may have a large effect on noise level readings. When roads are wet or when the measurements are being made downwind from the noise source, sound levels will be higher than they would under other conditions. This does not mean that measurements should not be made in these situations. On the contrary, if noise measurements are not made in periods of rain, the average sound level may be underestimated. Likewise, if there is prevailing direction for frequent strong winds, the monitoring program that excludes measurements in the winds will underestimate the average sound levels downwind and overestimate the noise levels upwind from the noise source.

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[1] *"American National Standard Specification for Sound Level Meters," ANSI S1.4-1971, American National Standards Institute, New York, N.Y. 1971, or its successor.*

Wind and precipitation can also affect measurements by reducing the ability of the sound level meter to record only the sounds associated with the highway. Even with a wind screen, the meter will detect noises caused by wind blowing across the microphone. Some microphones produce noises that make measurement unreliable when the humidity is high. Also, water damages most microphones, so measurements taken in the rain or heavy snow should be made with special care for the sound level meter. The user should follow the manufacturer's recommendations in all of these cases.

All sound level meters contain provisions for calibration during use. The procedure is simple, but mandatory. If the reference point has changed, a screwdriver adjustment brings it back to the proper value.

Scanning Surveys

The acoustical measurements in support of a hot spot program should be divided into two phases, a scanning survey and, a more thorough survey. The scanning survey phase has two purposes: to acquaint the local officials with the overall situation and noise levels, and to eliminate from consideration the locations at which the noise levels are clearly too low to qualify as hot spots.

A good place to start is with the residences of complainants, but residents of areas that are expected to have high noise levels but from which few complaints have been received should also be surveyed. Telephone complainants and request permission to enter their properties to make noise measurements. If the residence has a yard, the measurements should be made in the yard closest to the highway that is the source of the noise. If the residence has no yard, the measurements may be made in the street or alley, unless the complainant lives on the third or higher floor of a multiple unit building. In this last case it may be necesary to obtain entrance to the interior of the unit to make the measurements on a balcony, on a fire escape, or (least desirable) out an open window.

The scanning survey should be undertaken on a weekday unless the complaints have been about weekend traffic noise. The measurements should be made throughout the morning and in the late afternoon to include homeward bound commuters. Spend 15 minutes taking sound levels readings every 15 seconds at each location, recording them on data pads or accounting paper. Be sure to note accurately the location of the measurements relative to the residence so the distance from the measurement point to the highway can be scaled off drawings in the municipal engineering office. The scanning survey should include the hours when traffic, particularly heavy truck traffic, is heaviest. Only about 15 sites can be surveyed in an 8-hour day, so the first day should cover a large part of the range of complainants' locations, leaving others to be filled in later. This skipping method also will assure that all the measurements are not made in one region in the same few hours, during which traffic noise may not be its highest.

Typically, the results of a scanning survey will indicate that many of the complaints do not have daytime noise levels in excess of 75 dB, even at the noisiest hours. For such locations a check should be made of the nighttime levels to see whether they substantially exceed 65 dB. If they do not, the L_{dn} cannot possibly exceed 75 dB, and unless it is a sensitive area, the area will not usually be considered a hot spot.

Locations that are not eliminated at this point should be divided into two groups: clearcut candidates for more thorough sound surveys and borderline cases. The latter locations should be rescanned at times in the day that are different from the times of the first scan and should be scanned at night. The places remaining after this test will be the subjects of the more intensive acoustical surveys.

Thorough Surveys

Surveys conducted to test the prime candidates for hot spots programs are similar to the preliminary surveys in technical aspects, but require statistically valid sampling methods and measurements in more locations and on more occasions. In some instances, State highway departments are responsible for the testing and documentation needed at this stage. In order to qualify for Federal funds, State officials should perform the measurements using FHWA techniques and should be able, upon completion, to draw the noise contour maps necessary to prepare the noise plan. The contours will be affected by the grade and the relative elevation of the highway; by stopping, slowing, and acceleration portions; by prevailing winds; and by the absorption and reflection of the terrain and the buildings beside the highway.

When the contours are plotted, some interpretation of the results will be needed, in part to compensate for the limitations imposed by the effects of wind and precipitation on the survey, in part because the survey almost certainly will not have been done over a whole year, and in part because surveys are made over a period in which the surveyors and the quantity being surveyed change, at least slightly. Acoustical consultants, meteorologists, traffic engineers, and social scientists experienced in survey work all may be called on to assist in removing some of the errors and inconsistencies in the survey data.

Determination of the Impact

The first step in calculating the impact of the noise is to count the population that is within or on each contour line. Only the population that resides inside the 65 dB contours for sensitive land uses and inside the 75 dB contours for other land uses needs to be counted. Local voting registers, city directories, census, or other sources may be used to ennumerate the residents inside each contour. A common and inexpensive method is to use the real estate tax files, or existing aerial zoning photographs, to determine the number and types of housing units in each noise contour and to multiply these units by average rates of occupancy (3.0 for single family detached houses, 2.8 for townouses, etc.) that have been derived from county or municipal surveys.

If priority must be set for different areas, the next step is to multiply the number of people in each contour by the number of decibels by which the noise levels to which they are exposed exceeds 75 dB (65 dB in sensitive areas). Thus the impact of 85 dB on five people is equated with the impact of 80 dB on ten people. The impacts then are plotted on the same maps as the noise contours. Areas with the highest impacts normally are the ones that deserve the greatest attention.

Other criteria should be considered when setting priorities, too. One criterion is whether the residences were built before, during, or after the highway was planned and constructed. Residences that predated the highway get higher consideration than those built after the highway plan was adopted or the highway was built. Hours of occupancy of the residences are taken into account in some other jurisdictions. If the residents are single or childless working people, the priority for noise control is set lower than for residents with children and stay-at-home adults.

B. BARRIER SELECTION: ACOUSTICAL CONSIDERATIONS

Overview of the Barrier Design Process

The Noise Barrier Design Procedure

In the initial phases of barrier design there are several basic questions that must be answered: How high should the barrier be? How long? Where should the barrier be placed? What materials should be used? Should there be a wall or berm, or a combination of the two? In addition to questions concerned with the physical characteristics of the barrier, questions concerned with economics and the functional performance of the barrier must be answered as well: How much will the barrier cost? Will it be accepted by the community as well as the highway user? Will it create safety problems? Will there be maintenance or durability problems?[1] This section deals with the first set of questions, those concerned with technical acoustical aspects of barriers. For information concerning the second set of questions, the reader should refer to NOISE BARRIER SELECTION: NONACOUSTICAL CONSIDERATIONS.

Exhibit IV-2 depicts the noise barrier design process, as outlined in FHWA's "Noise Barrier Design Handbook." The first step is the specification of noise reduction goals. Second, a large number of design options are identified, considering both the acoustical requirements imposed by the noise reduction goals and the nonacoustical requirements related to safety, maintenance, and aesthetics. The various design options are evaluated in terms of their acoustical and nonacoustical characteristics as well as their costs. Based upon this evaluation, the option that best satisfies the design requirements and meets the needs of the local area is selected. This is the end of the process specified in FHWA's Noise Barrier Design Handbook; however, ideally after selection of a barrier design its physical dimensions should be optimized with the aid of a highway noise computer program before the design is finalized. Community participation should be included in all the phases of the barrier design process.[2]

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[1] *Myles A. Simpson, "Effective Design of Highway Noise Barriers Using the "Noise Barrier Design Handbook," Proceedings of Conference on Highway Traffic Noise Mitigation conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, 1978, p.127.*

[2] *Ibid, p.128.*

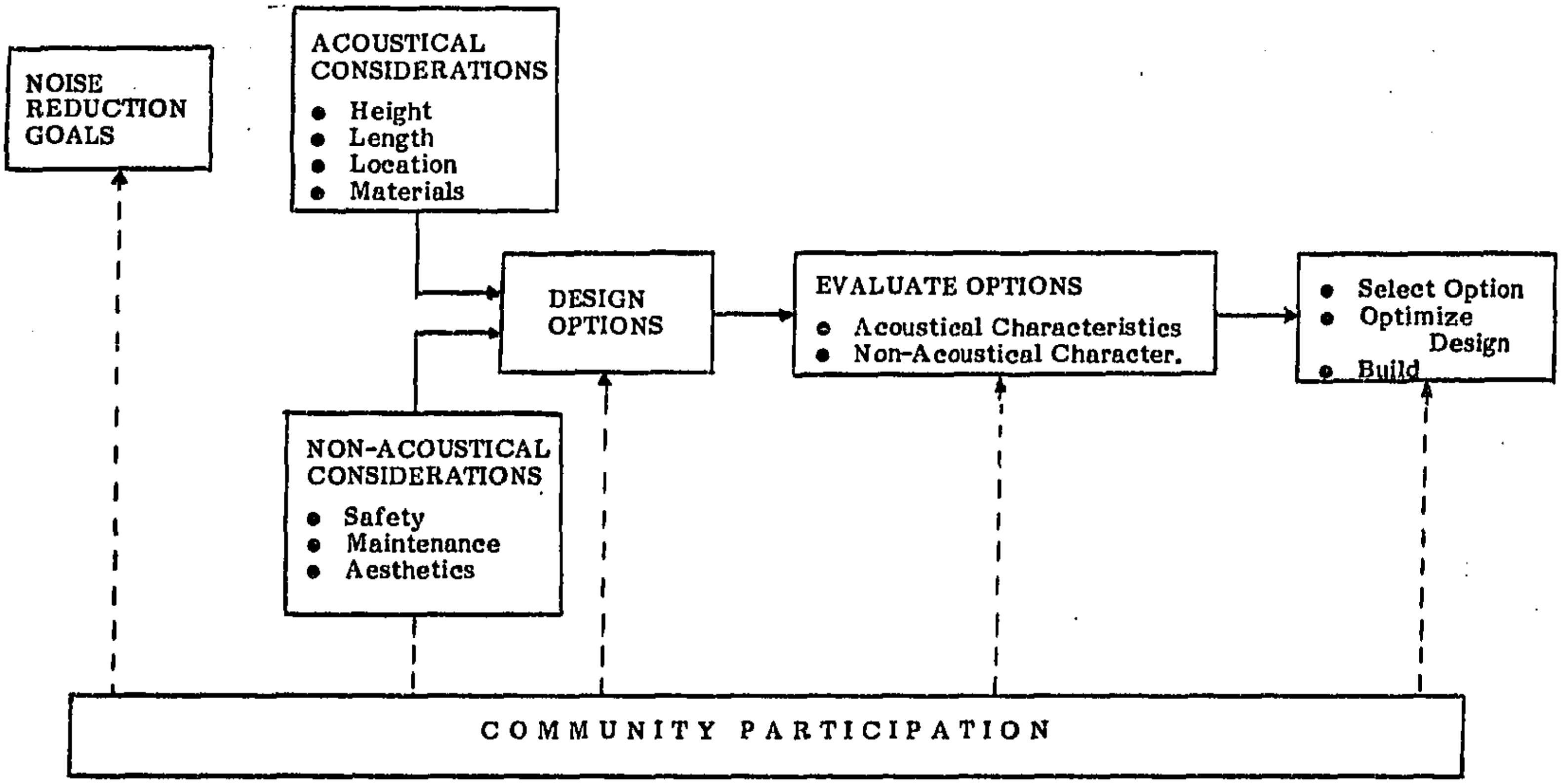

EXHIBIT IV-2: BARRIER DESIGN PROCESS FLOW CHART

Barrier Insertion Loss

Of primary importance in the design of an effective noise abatement barrier is determination of the proper noise reduction goal. To determine the noise reduction design goal, the handbook uses the concept of barrier insertion loss, which is the difference in levels measured at a receiver location before and after the construction of the barrier. As shown in Exhibit IV-3, the insertion loss is a function of several factors, each of which should be accounted for in calculating the effect of a noise barrier on the surrounding community. First, the insertion loss depends upon the barrier attenuation, (Δ_B), resulting from diffraction of sound from the highway over the top and sides of the barrier. The insertion loss also depends upon the transmission loss, TL, a measure of the ability of the barrier to transmit noise through it. The quantity Δ BAR is the change in barrier attenuation that results when parallel barriers on both sides of the highway cause multiple sound reflections, and some additional sound is diffracted over the top of the nearer barrier. Since the construction of the barrier may result in loss of attenuation from an already existing structure, the insertion loss also depends upon this existing shielding, called Δ_S. Finally, when sound propagates over absorptive ground there are certain ground effects which result in a higher propagation loss than when the terrain is hard and flat. These ground effects may account for the difference between the 3 and 4.5 dB per doubling of distance dropoff rates observed for reflecting vs. non-reflecting ground conditions.[1]

Design Goal Insertion Loss

The design goal insertion loss is the difference between the noise level measured or predicted at a site before construction of the barrier and the desired or criterion noise level:

$$\text{Design goal IL} = L\,(\text{before}) - L\,(\text{criterion})$$

In this equation the "before" and "criterion" levels may both be expressed in terms of either L_{10} or L_{eq} levels in dBA. In order to achieve the desired insertion loss, the barrier must therefore be designed to achieve a design goal noise reduction as follows:

$$\text{Design goal NR} = L\,(\text{before}) - L\,(\text{criterion}) + \max(\Delta_S, \Delta_G)$$

[1] *Myles A. Simpson, "Effective Design of Highway Noise Barriers Using the "Noise Barrier Design Handbook," Proceedings of Conference on Highway Traffic Noise Mitigation conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, 1978, p.128.*

$$IL = f\left(\Delta_B, TL, \Delta BAR, \Delta_S, \Delta_G\right)$$

$$NR = f\left(\Delta_B, TL, \Delta BAR\right)$$

$$IL = NR - \max\left(\Delta_S, \Delta_G\right)$$

where

Δ_B	=	barrier attenuation resulting from diffraction over the barrier top
TL	=	transmission loss through the barrier
Δ BAR	=	change in barrier attenuation resulting from multiple reflections from double barriers
Δ_S	=	shielding attenuation from other barriers between highway and receiver
Δ_G	=	attenuation from ground effects

EXHIBIT IV-3: DEFINING BARRIER INSERTION LOSS

Thus, the barrier attenuation, transmission loss, and change in barrier attenuation must be balanced in the design to provide a net noise reduction which satisfies this design goal.

In order to determine the various parameters in this last equation, the highway designer may use one of the available highway noise prediciton methods. Alternatively, for existing highways some of these parameters may be determined by actual field measurements in particular location of interest. As an added benefit, use of field measurements to determine "before" noise levels provides useful documentation of pre-barrier conditions and can be used to validate the analytical predictions.

Even if analytical methods alone are used to determine the noise levels for the "before" case, use of field measurements to determine possible ground absorption effects, Δ_G, will be most useful. Such an approach would involve measurement at a typical receiver location, say 5 feet above the ground, with simultaneous measurements 20 or 25 feet in the air. The difference in level between these two sets of data is a good measure of the amount of absorption caused by ground effects.

Further, just as it was important to obtain measurements at critical receiver locations before construction of the barrier to document existing levels, it is quite useful to make measurements after barrier construction to document actual barrier performance. Such data will provide a true measure of the actual insertion loss of the barrier. If the barrier has met its design goal, these measurements are useful from a community relations point of view. If the design has not been successful, it is important to recognize that fact, so that, if possible, the problem can be remedied. Even if this cannot be accomplished, analysis of the reasons that the barrier does not achieve its design insertion loss would provide useful information in the design of future barriers[1].

Basic Barrier Materials and Shapes

The materials for barrier construction (Table 1) are no different than those used for other types of structures. They are used alone or in various combinations.

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[1] *Myles, Simpson, "Effective Design of Highway Noise Barriers Using the "Noise Barrier Design Handbook," Proceedings of Conference on Highway Traffic Noise Mitigation conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, 1978, p. 129.*

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TABLE 1

Basic Materials Used in Barrier Construction

Mineral Aggregate
Portland Cement
Metal (Steel, Aluminum)
Wood
Earth
Plastic
Combinations

These materials and combination can be translated either into rigid shaped forms (Table 2) such as panels, blocks, planks, and sheets or plastic forms using concrete, stucco, and earth mounds. Depending on the basic material and the shape and nature of the unit used in constructing a barrier, fabrication may be off-site, on-site, or a combination of both.

TABLE 2

Basic Shapes of Structural Units

Panels Blocks Planks Sheets	Rigid Form
Concrete Stucco Mounds	Plastic Form

The ultimate form of the material is that of a wall or a mound serving as a barrier to sound transmission. Barriers may be constructed of one material or two or more distinctly different materials. A few of the possible barrier types are listed in Table 3.

TABLE 3
Examples of Barrier Types

Concrete block (many varieties including slumpstone)
Concrete (Precast or cast-in-place)
Metal
Earth Berm
Earth Berm and Concrete Block
Wood
Stucco on Chain Link Fence
Stucco on Metal Lath
Stucco over Wire and Paper
Sign Panels
Lexan (Transparent)
Steel and Fiberglass (sound absorbent)

When two materials are used, the contact may be longitudinal, as in the case of a wall structure atop an earth mound or vertical, as in the case of alternating panels or wall sections.

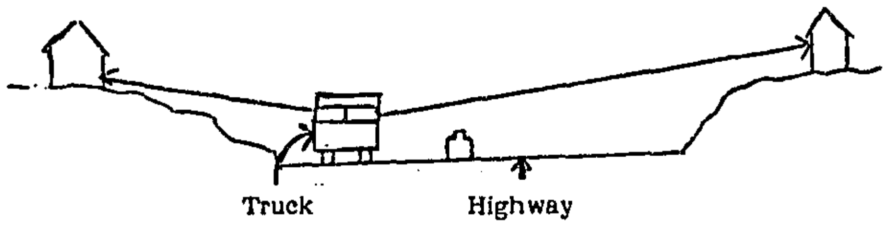
Sound Absorbing Materials

Reflecting Noise

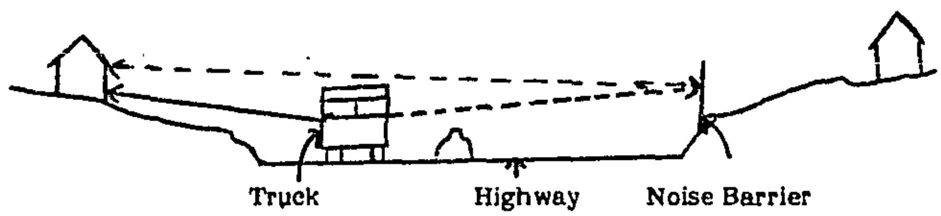
Most barrier construction materials are "hard" and tend to reflect noise. This reflection may mean that the barrier actually increases the noise to which a listener is exposed (Case 1) or the benefits of a barrier are reduced (Case 2).

Case 1: Reflection in a Single-Barrier System

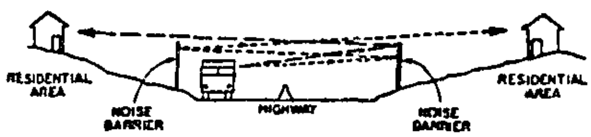
Noise Path Without a Barrier



Noise Path With a Barrier



Case 2: Multiple Reflections in a Two-Barrier System



What are Sound-Absorbing Materials?

A sound-absorbing material absorbs sound by forcing the air molecules to move in and around many tiny fibers or passages. As the air molecules are forced in directions other than a straight back-and-forth motion, they lose energy, and the sound intensity or level decreases.

Familiar objects made of materials that absorb sound include thick carpeting, stuffed furniture, and heavy draperies. Fabrics are soft and fibrous, characteristics that make them excellent sound absorbers.

How much sound a material absorbs, its effectiveness, is usually rated by the material's absorption coefficient, α. The absorption coefficient is defined as the ratio of the sound energy absorbed by a surface to the sound energy incident upon that surface. α may take on all numerical values betwen 0 and 1. For a perfect absorber, $\alpha = 1.0$; for a perfect reflector, $\alpha = 0$. The absorption coefficient is specified at a certain frequency, or over a range of frequencies. Commonly, the absorption coefficient of a material is specified in octave bands, from 63 Hz to 8000 Hz. For example, a poured concrete surface that has an absorption coefficient of 0.02 in the 500 Hz octave band reflects 98 percent of the incident sound in the octave band centered on 500 Hz. On the other hand, for a 2-inch thick glass fiber blanket spaced 1 in. away from a solid backing, α = 0.90 in the 500 Hz octave band; therefore, 90 percent of the incident sound energy in the 500 Hz octave band is absorbed, and as a result, the level of the reflected sound is 10 dB lower than the level of the incident sound.[1]

Criteria for Selecting Sound-Absorbing Materials

Materials should be selected to meet criteria based on the following characteristics (in order of importance):

1. Sound-absorbing capacity
2. Physical durability
3. Acoustical durability
4. Maintenance requirements
5. Flame, fuel, smoke ratings.

Sound-Absorbing Capacity

Sound-absorbing treatments for highway barriers must have absorption coefficients of 0.6 or higher on the barrier surfaces for octave bands of 250, 500, 1000, and 2000 Hz. Materials that do not meet these criteria should not be considered further.

Other Criteria

The other criteria listed above involved in selecting sound absorbing materials are discussed in NOISE BARRIER SELECTION: NONACOUSTICAL CONSIDERATIONS.

[1] *Christopher W. Menge and Neville A. Powers, "Sound-Absorbing Barriers: Materials and Applications," Proceedings of Conference on Highway Traffic Noise Mitigation conducted by the Tranpsortation Research Board for the U.S. Department of Transportation, December 11-15, 1978, p. 199.*

Some Specific Sound Absorbing Materials

Standard Effective Materials

There are four standard materials used as sound absorbers: resonant cavity concrete masonry units, glass fiber batts, wood fiber planks, and spray-on treatments such as vermiculite or perlite aggregate concrete.

Resonant cavity concrete masonry units are suitable for both free-standing acoustic barrier walls and for an absorptive treatment in locations such as tunnels and underpasses. The concrete masonry units are a standard concrete masonry block with slotted apertures to allow a resonance inside the block. One type of block is a proprietary product called "Soundbox," as manufactured by the Proudfoot Company.

Glass fiber batts are a suitable material for use on free-standing acoustic barriers, tunnels, and underpasses. The glass fiber batts are two inches nominal thickness, one and a half pound cubic foot density and wrapped in a protective covering of 1.5 mil thickness mylar. The batts then are stapled to wood runners which allow a minimum two inches air space behind the glass fiber batts. The front face of the glass fiber batts is protected by the use of random wood battens which leave minimum of 30 to 40 percent of the surface area exposed.

The third type of acoustic absorption material is pressed wood fiber boards. To be suitable for use in an exterior location this material should be manufactured with a suitable binder and protected from deterioration weathering by the use of exterior non-bridging type latex paint. The pressed wood boards should also be treated with fire-retardant chemicals in the manufacturing process. These boards may be nailed or attached directly to the supporting structural system, allowing a six to sixteen inch air space behind the board for optimum performance. In addition, the wood fiber boards should be located where they are not subject to road splash. It must be emphasized that, while several wood fiber planks are available, the feasibility for exposure to weathering and cleaning must be verified for the specific product under consideration.

The fourth type of acoustical absorption material is a spray-on system of Portland cement concrete with a light-weight perlite or vermiculite aggregate. This product may be sprayed on a high rib metal lath which in turn maintains a two-inch air space behind the material. Due to the possibility of this material spalling in freezing temperature, it is not recommended for use where exposed to saturation, then freezing. This material should also be protected by the use of a non-bridging exterior latex paint or silicone treatment[1].

Plantings

Dense evergreen trees, shrubs, vines, and grass are often considered as possible materials for noise abatement. They are often proposed both as sound barriers and as sound absorbers. In both cases, they exhibit such serious deficiencies that, apart from their use to meet other criteria for highway design (beautification, visual screening), they should not be considered to meet sound-attenuation criteria for highways.

Growing materials are particularly unsuitable for use as sound-absorbing materials beside highways. To be effective a plant's leaf structure would have to be similar in fineness and density to glass fiber. At present, a plant with these characteristics has not been identified[2].

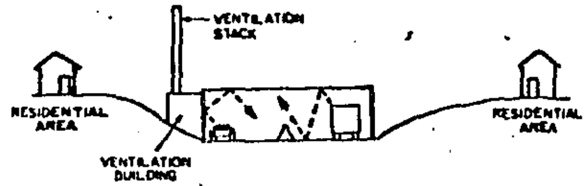
Alternatives to Sound-Absorbing Materials

Sound-absorbing materials may be undesirable because of cost maintenance requirements, or design constraints. There are a few alternatives to sound-absorbing materials that may be considered for particular conditions.

Alternative: Covered Highway

By covering a highway, excessive noise levels can be reduced dramatically, as shown in Case 3.

Case 3: Covered Highway



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[1] *Noise Barrier Design Handbook*, Federal Highway Administration, U.S. Department of Transportation, 1976, pp. 3-55 - 3-57.

[2] *Menge and Powers, op. cit., pp. 200-202.*

Although the noise problems can be virtually eliminated with this procedure, other factors such as cost and ventilation requirements are usually primary considerations. The cost is usually much higher than even the most expensive noise barrier design, and tunnels must be ventilated, unless they are very short. Ventilation systems often require a high exhaust stack and additional structures to house the motors and fans. If not designed properly, ventilation systems can create their own noise problems.

Alternative: Berms

Earth berms can be placed on both sides of a highway to act as noise barriers, as shown in Case 4.

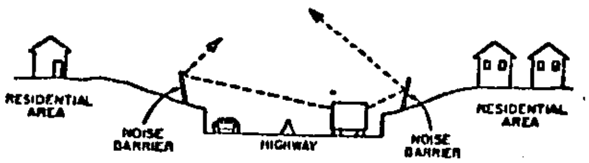
Case 4: Earth Berms as Noise Barriers

The berms, because of their shape, will not allow sound to reflect back and forth. They will act effectively as single, independent barriers, as long as no vertical walls are placed on top of them. As an alternative to absorptive barriers, berms have limited application, since a significant amount of right-of-way property is required. This alternative is particularly difficult in urban areas where space is limited.

Alternative: Sloped Barriers

A configuration of sloped barriers has been tested recently in an acoustical scale model study for the Harbor Tunnel Thruway in Baltimore, Maryland. It is shown as Case 5.

Case 5: Sloped Barriers



For this particular configuration (a depressed highway with residential areas on both sides), hard reflective barriers sloped away from the highway at an angle of 10 degrees from the vertical were found to be as effective as an absorptive vertical two-barrier system.

Although very little information about the overall effectiveness of sloped barriers exists, sloped barriers should prove to be effective for configurations other than that of the Harbor Tunnel Thruway. Model studies will generally be required to determine optimum barrier locations and slopes, at least until enough data are collected to develop generalizations. For other configurations, sloped barriers may have to be higher than vertical absorptive barriers. Once the performance characteristics of sloped barriers are known, cost and installation limitations will be compared with those of absorptive two-barrier systems. Only then will the best applications for each approach be defined.

Sloped barriers, however, will not replace sound-absorbing materials in all applications. Where deep cuts require vertical walls or space is limited, sound-absorbing treatments will be the only effective means of eliminating the multiple reflections that degrade a two-barrier system's performance[1].

References

The sources listed below contain detailed information on the topics discussed in this section. All are highly recommended to state or local authorities involved in the technical aspects of barrier design.

Federal Highway Administration Noise Barrier Handbook, 1976.

Federal Highway Administration Highway Noise Barrier Selection, Design, and Construction, 1978.

Menge, Christopher W. and Neville A. Powers, "Sound-Absorbing Barriers: Materials and Applications," Proceedings of Conference of Highway Traffic Noise Mitigation conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, 1978.

Simpson, Myles A., "Effective Design of Highway Noise Barriers Using the "Noise Barrier Design Handbook," Proceedings of Conference on Highway Traffic Noise Mitigation conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, 1978.

[1] *Ibid, p. 201.*

C. BARRIER SELECTION: NONACOUSTICAL CONSIDERATIONS

Introduction

In choosing a barrier design and material, community planners are concerned not only with the effectiveness of the barrier, but also with safety, durability, maintenance, aesthetic, and cost considerations. Each of these latter factors is discussed here. The reader should refer to BARRIER SELECTION: ACOUSTICAL CONSIDERATIONS for information on the noise reduction effects of various barrier designs.

Safety

Motorist Hazards

Visibility

Barriers must be designed carefully to avoid hazardous effects on traffic and the general public. Special care must be taken to avoid obstructing visibility for traffic rounding curves, merging from freeway entrances, and merging to frontage roads and cross roads passing over the freeway.

Horizontal stopping sight distance should be provided for all traffic. A compromise in acoustical effectiveness may be necesary to allow sufficient merging sight distances on entrance ramps. Walls can be overlapped as much as is judged safe.

Some controversy still exists as to whether walls at signalized intersections of cross streets and ramps or frontage roads can be safely brought to the standard visibility offset for signalized intersections. Some engineers advocate the uncontrolled intersection sight distance be used where possible at controlled intersections to provide the extra margin for emergency vehicles and persons running the stop sign or traffic signal. Others feel the noise wall is not different from a corner grocery store at a signalized urban intersection and can safely be brought close to the corner. The argument can become emotional, centering around the worth of a life versus the value of noise abatement. In Minnesota the state's department of transportation resolves each case after an on-site review by the district traffic engineer. In any case, walls are set back as much as possible to provide maximum intersection sight distance.

Transparent walls are not considered a reliable alternative in providing safety visibility for motorists, because reflection occurs under some lighting conditions and keeping panels clean enough for adequate safety is next to impossible with acceptable maintenance budgets[1].

Obstacles

Collision potential for errant vehicles exists no matter how far an obstacle is placed from the pavement.

While barriers are most effective acoustically when placed near the roadway, efforts should be made to use safety clear zone criteria to locate the barrier. When site conditions permit, barriers should be placed 9 m (30 ft.) from the shoulder if on level ground. Greater offsets are required if the barriers will be downhill from the roadway. Exposed corners or posts facing high speed traffic within the clear zone should be avoided unless protected by a guardrail. The guardrail may be erected separately or mounted on the barrier itself. If there is an intervening curb, the height of the rail should be adjusted upward to compensate for vaulting vehicles.

Guardrails should not normally be placed along city streets carrying low speed traffic on the residential side of a wall, although exposed corners are discouraged. Wall ends in exit ramp areas should be protected by an appropriate crash cushion[2].

Effects on Traffic

Noise barrier designers and local authorities are often concerned that continuous walls might tend to constrict traffic flow, lower speeds, or produce accidents. To avoid this problem, very tall walls (20 or more feet) should be placed 30 to 40 feet from the roadways. In Minnesota, where this policy is followed, engineers monitoring the accident situation report no noticable increase in congestion or accidents after walls were erected. In fact, accidents in some locations apparently were reduced but further study is needed to determine whether the barriers had any influence on this.

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[1] *Ronald M. Canner, Jr., "Minnesota's Experiences with Noise Barrier Systems," Proceedings of Conference on Highway Traffic Noise Mitigation Conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, 1978, p. 253.*

2 *Ibid., p. 253.*

Fire Hazards

Fire risks can never be completely eliminated, but care should be taken to reduce the probability of fire as much as possible. The effects of a lightning strike on the barrier should be considered. A metal wall could carry a lightning charge a long distance, increasing risk of personal contact.

Among the sound absorbing materials that might be used in barriers, one class of materials - polymer foams - do not meet acceptable standards. Polymer foams produce cyanide or other highly toxic gases when burned, and although some foams are rated "self-extinguishing," they can continue to burn if fueled by other burning materials that might be present in an automobile fire. Most fabric sound absorbers, on the other hand, can be treated if necessary with flame retardants, which would make their flame, fuel, and smoke ratings acceptable for placement near highways.

Finally planners should avoid barrier designs that prevent firefighters from seeing or gaining access to fire hydrants. One community resolved the problem by installing fire hose openings, simply a hole covered with a square board nailed or hinged over it, opposite every hydrant on adjacent roads and mounting coded markers on both sides of the wall.

Other Safety Hazards

Although barriers prevent road surfaces from being blown clear of snow, snow-drifts are not usually a problem since most barriers are in urbanized areas which have less drifting potential and strong maintenance programs.

Walls designed with potential scalers in mind may actually improve freeway safety by preventing pedestrian and animal crossings which formerly went over, through or under chain link right-of-way fences. Walls are usually constructed at least a few feet inside the right-of-way to allow access for future maintenance if needed. Chain link right-of-way fences are usually removed and adjacent land users may be allowed upon the remaining right-of-way behind the wall[1].

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[1] *Ronald M. Canner, Jr., "Minnesota's Experiences with Noise Barrier Systems," Proceedings of Conference on Highway Traffic Noise Mitigation Conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, 1978, p.254.*

Durability

A noise barrier should withstand weathering and normal abuse and still retain its fundamental value for its intended life. Durability requirements can be met through attention to detail in design features, connections, and material specifications. For instance, timber barriers should be of appropriate species and must be seasoned and treated with a preservative against insects and rot. Earth mounds should be protected against erosion. Concrete barriers must use materials not susceptible to salt action and provide adequate cover for reinforcing or prestressing steel. Metal walls must be protected by galvanizing and long lasting corrosion-preventing coatings[1].

Barriers must also be able to withstand wind loads of about 75 mph and should be built to endure the weight of the expected snow and ice loads.

Maintenance

Since we must maintain everything we build, maintenance requirements play an important part in barrier selection. The primary consideratons, ease and frequency of repair, should be taken into account both when choosing an architectural design for the barriers and when choosing barrier materials.

Noise barriers on the right-of-way line provide the easiest access for maintenance. Barrier designs should include access gates for maintenance work for walls located off the right-of-way or on certain types of terrain. Access gates should be designed on a case-by-case basis according to the types of equipment that will have to pass through them.

Certain types of barrier material, notably prestressed concrete panels,will require virtually no repairs. However, concrete walls attract graffiti which may have to be removed frequently. To remedy this problem, the wall can be treated with anti-graffiti material coating which does not absorb paint, or it can be blocked off by a chain link fence. Wood plank or earth mound barriers may also be good selections in terms of their maintenance. Wood planks on posts are easily repaired and dismantled and discourage graffiti. Earth mounds may also be easy to maintain, especially if there is a large supply of earth nearby, and are not subject to assault by graffiti artists.

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[1] *Ronald M. Canner, Jr., "Minnesota's Experiences with Noise Barrier Systems," Proceedings of Conference on Highway Traffic Noise Mitigation Conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, 1978, p. 257.*

Aesthetics

Appearance

Importance of Appearance

Noise barrier development differs from highway design because material selection and alignment can have a profound visual impact on both the motorist and the roadside land user. A much greater emphasis must be placed on the appearance of a barrier than has been put into the appearance of a road.

The appearance of a noise barrier is probably the one item by which the vast majority of the public will judge the merits of this public works project. True, the residents behind the wall will judge it on its acoustical value, but they also judge it on its looks and what it does to their surroundings. The transportation engineers will judge it on its cost, its durability, its strength, and its safety. However, these groups are only a small proportion of those that view the barrier daily. A "successful" noise barrier should be visually pleasing or at least not grossly displeasing to the public. The question of how much extra to pay for appearance has no simple answer. One cannot build a Taj Mahal and expect the public to swallow the costs. On the other hand there is no premium on ugliness. The challenge is to obtain publicly acceptable functional good looks out of the few noise abatement dollars available[1].

Dealing with Appearance Issues

Quality of appearance is difficult to quantify. People have different preferences and they change. Candidate barrier systems should not be rejected solely for appearance reasons. Instead, the final selection of barrier systems for each project should be made after considerable input from the residents and community where the barrier is to be located. In Minnesota, landscape architects present the designs they feel are acceptable for the specific site in a public meeting. Their selections are based upon suitability of the system for the terrain and neighborhood style, and continuity of the wall designs the motoring public will pass on their route within a matter of minutes[2].

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[1]*Ronald M. Canner, Jr., "Minnesota's Experiences with Noise Barrier Systems," Proceedings of Conference on Highway Traffic Noise Mitigation Conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, 1978, p. 254*

[2]*Ibid., p. 254.*

Difficulties Encountered

The extreme heights needed and narrow right-of-ways available make designing pleasing barriers along existing freeways very difficult. Frequently a very high straight wall must be "shoe-horned" into a narrow right-of-way on a steep side slope, with no room for trees, shrubs, wall bays, or other refinements that help reduce the adverse visual impact of a noise wall.

Pleasing wall designs are often considerably more difficult to develop when the terrain is flat and the right-of-way is narrow than when the designer has wider right-of-ways, undulating terrain and curved roadways to work with. On the other hand, if terrain is rugged, achieving acoustical effectiveness becomes more difficult and expensive. In general, a design tailored from the beginning for pleasing appearance will not entail large cost penalties. Avoid the situation where a landscaper is later asked to try to do something to hide a visual monster erected with little regard to its appearance.

Noise abatement systems along new highways are best developed concurrently and integrally with the project layout so all parts of the project can better harmonize and blend with the surroundings. The results of recent attempts to integrate pleasing noise barriers into urban freeway projects on new locations should be interesting to review when completed[1].

Appearance Factors

Configuration

Appearance depends much on how height changes and alignment changes are handled. Stepping down the wall ends or turning corners helps reduce their visual impact. Frequent jogs or bays in the wall plan are interesting. A smooth serpentine alignment can often be pleasing. These features also facilitate massed planting on both sides of a barrier otherwise impossible in a narrow right-of-way[2].

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[1] *Ronald M. Canner, Jr., "Minnesota's Experiences with Noise Barrier Systems," Proceedings of Conference on Highway Traffic Noise Mitigation Conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, 1978, pp. 254-255.*

[2] *Ibid., p. 255.*

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Texture

Surface texture of walls can be created at little added cost by raking concrete surfaces, exposing posts, hiding posts, adding battens and using color patterns. Treated timber planks and glued laminated wood panels have a wood grain texture visible to persons passing nearby[1].

Color

Paint or stain may be applied successfully to the surfaces of all materials with the exception of earth and possibly, plastic. Certain woods and steels will weather or oxidize to an interesting appearance following installation.

Where stucco is used, the top coat can have color incorporated into it. Color can also be added to concrete during the mixing process, although this is not as economical as might be desired. In the manufacture of concrete blocks, choice of aggregate and addition of color to the matrix can produce striking effects.[2]

Initial color is sometimes a problem with timber walls because it is usually governed by the type of preservative chosen. All eventually fade to a weathered brown or gray color.[3]

Site Compatibility

Some materials are more compatible with a particular environment than with another. As an example, the use of slumpstone block is acceptable in most western or southwestern urban areas, but probably would look out-of-place in eastern cities, particularly in older areas where brick was used extensively. The manner in which the barrier flows with the terrain is also important, particularly where alternate cut and fill or rapidly changing terrain situations are encountered.

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[1] *Ronald M. Canner, Jr., "Minnesota's Experiences with Noise Barrier Systems," Proceedings of Conference on Highway Traffic Noise Mitigation Conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, p. 255.*

[2] *Randolph F. Blum, "Visual Quality in Noise Barrier Design," Proceedings of Conference on Highway Traffic Noise Mitigation Conducted by the Transportation Residents Board for the U.S. Department of Transportation, December 11-15, 1978, pp. 161-162.*

[3] *Canner, op. cit., p. 255.*

Barriers must also be compatible with adjoining barriers and careful thought should be given to continuity of appearance along any given route as it traverses an urban area. With the advent of state and local noise ordinances, new residential developments may have developer-constructed barriers which either abut existing barriers or which will be contiguous with future barriers. Often these developer-constructed barriers are not designed with any factor in mind other than cost and height[1].

Graffiti

Graffiti is an important aspect of appearance. Problems with graffiti can be handled in one of three ways. First, the barrier itself may be made of a material that does not attract graffiti, such as earth berms or, to a lesser extent, wood posts and planks. Alternatively, the barrier could be treated with an anti-graffiti material which can be washed. Finally, access to the barrier can be reduced with the use of chain link fences or certain architectural designs.

Costs

Source of the Cost Data

The cost information presented below is based on the experience of the State of Minnesota in 1977.

Barrier Systems Costs

Introduction

Every dollar spent on noise barriers means fewer dollars available for needed roadway and safety improvements. Costs for noise wall systems cover a wide range. Exhibit IV-4 shows some general comparisons between estimated costs of typical designs accepted for use by the Minnesota Department of Transportation. These costs do not include costs for site preparation, landscaping, engineering, or maintenance.

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[1] *Ronald M. Canner, Jr., "Minnesota's Experiences with Noise Barrier Systems," Proceedings of Conference on Highway Traffic Noise Mitigation Conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, 1978, p. 260.*

EXHIBIT IV-4: ESTIMATED COSTS FOR NOISE WALLS
($1,000/KM/SIDE OF HIGHWAY)

Type of Barrier	4.5 m (15 ft.) Barrier (1000's)	Ratio to WPWF	6m (20 ft.) Barrier (1000's)	Ratio to WPWF
Wood Post Wood Facing (WPWF)*	$ 170	1.0	$ 250	1.0
Concrete Post Wood Facing*	230	1.4	320	1.3
Concrete Panels	280	1.7	320	1.3
Glued Laminated Wood Panel	400	2.4	550	2.2
Metal Post Metal Facing**	560	3.3	800	3.2
Embankment Mound	260	1.6	NA	NA

*Single Faced
**Double Faced

Barrier Costs on New vs. Existing Highways

Barrier costs are usually lower when the barrier is constructed at the same time as the highway rather than as part of a retrofit program. This is because new highway construction planners take barrier needs into account and sometimes availability of excess earth and excess right-of-way will permit elimination of walls in favor of barrier mounds.

Panel Barriers

Examination of Exhibit III-5 shows that unit costs of panel designs, particularly the glued laminated wood panel wall system, are much more sensitive to heights than unit costs of post supported wall systems. This is because embedment and size increases affect the whole panel, not just the posts. The low wall is inefficient because substantial embedments are needed for even low wall heights. The inefficiency of high panel walls is due to the need for embedments and thicker panels throughout the panel.

Earth Mounds

Earth mound barrier costs increase rapidly with height, but may be extremely cost efficient when low walls are needed, especially if waste dirt is in good supply. Earth mounds are also advantageous in that they are not susceptible to graffiti problems and need not be painted.

Post and Plank Systems

At 15 and 20 foot height wall levels, timber post and plank systems are by far the least expensive to contruct. However, appearance considerations might lead to the choice of an expensive sysem such as the glued laminated wood panel. Part of the saving arises from the fact that post and plank systems can be arranged to straddle sewers and powerlines rather than requiring major working of these other necessary systems. Wood plank and post systems are also easily repaired and dismantled and discourage graffiti.

Panel/Earth Mound Combinations

Substantial cost savings can sometimes be achieved by combining a low earth mound with a panel wall. At going prices in the Twin Cities, a 2.44 m (8 ft.) wide earth mound with one-on-three side slopes is less expensive than all walls (except the timber post

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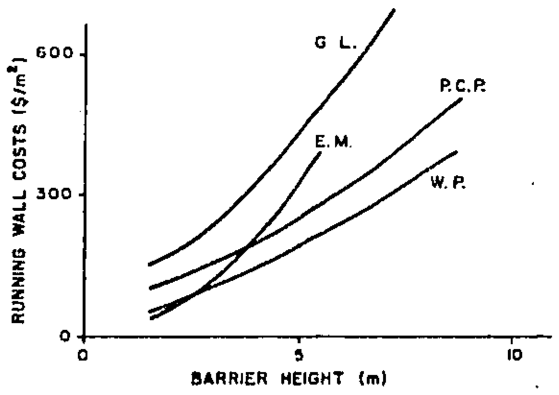

Key to Wall Type Abbreviations

C.P.	Treated wood plank facing on prestressed or reinforced concrete posts
E.M.	Earth mound
G.L.	Glued laminated wood panel wall
P.C.P.	Prestressed concrete panel wall
W.P.	Treated wood plank facing on treated timber posts

EXHIBIT IV-5: COMPARATIVE COSTS FOR UNIT LENGTH OF COMMON MINNESOTA NOISE BARRIER SYSTEMS OF VARIOUS HEIGHTS wall) up to about 3 m (10 ft.), if enough right-of-way is available. Cutting 1.5 to 3 m (5 to 10 ft.) from the height of a panel wall with an earth mound can cut total barrier costs by up to 25 to 50 percent, depending on local availability and cost of earth fill. A mound also tends to reduce the apparent height of the barrier, making it more visually acceptable, and reduces its accessibility to errant vehicles.

Cost Savings Techniques

Wall lengths can be reduced by turning the corner at the edge of the residential development being protected, saving $10,000 to $20,000 per barrier end if the right-of-way is available and not too expensive. This is because the length of barrier extending parallel to the extending highway necessary to adequately protect the edges of a development from flanking noise is about two or four times the setback of homes behind a barrier.

Total Barrier Project Costs

Barrier costs already discussed do not include costs of construction work necessitated by the barrier installation. Such items as site preparation, drainage corrections, special foundation designs, earth retaining designs, and landscaping can contribute materially to the barrier project costs. Typical project costs are about 10 to 20 percent higher than the barrier cost alone. The overall average cost of noise barrier projects in Minnesota over the last six years is about $430 per meter ($130 per lin. ft.), including all work items required for site work, furnishing, installing, and landscaping the required barrier. These figures are based on 51.5 km (32 lin. miles) of barrier averaging 5.2 m (17 ft.) in height. More recent barriers are more expensive than earlier walls because of inflation and a trend toward more costly systems.

As stated earlier, noise barriers included with major contracts for new freeways usually cost substantially less than walls retrofitted on existing highways. Indeed, some rough data imply that barrier costs, when part of a major grading contract, are on the order of one-half to one-third the cost of a retrofit barrier. However, extracting true barrier costs items from major contract bids is inexact, at best.

Engineering Costs

Another substantial element in noise barrier costs is engineering costs. These are costs to the agency for planning, design, construction, contract administration, and inspection. A study of barriers built in Minnesota in 1976 and 1977 showed that total engineering costs averaged 16 percent of construction contract amount. A study of four projects showed that preliminary engineering includes public involvement meetings, layout, surveys, location and design approvals preparation, and processing of detail plans, specifications and estimates prior to receiving construction bids. Post-letting costs ranged between 7.5 and 18 percent, averaging 10.6 percent of the total construction contract. Post-letting costs include contract administration and inspection costs.

Summary

Communities planning to build noise barriers should obtain copies of the Federal Highway Administration's "The Noise Barrier Design Handbook." This handbook was intended to be a tool for highway designers, but is also useful to local authorities concerned with nonacoustical aspects of noise barriers, discussed here.

Other good sources of information include the following:

Blum, Randolph F., "Visual Quality in Noise Barrier Design," Proceedings of Conference on Highway Traffic Noise Mitigation Conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, 1978.

Canner, Ronald M., Jr., "Minnesota's Experiences with Noise Barrier Systems,"Proceedings of Conference on Highway Traffic Noise Mitigation conducted by the Transportation Research Board for the U.S. Department of Transportation, December 11-15, 1978.

D. ECONOMIC COSTS AND BENEFITS OF BARRIERS

Barrier Costs

Construction and Maintenance Outlays

The construction of noise barriers can result in a substantial investment of highway dollars. Noise barriers normally are expensive, as the case studies show. Although they contribute only a small fraction of the cost of a new highway, for an existing highway, especially one that has a narrow right-of-way, barrier construction is an expensive, separate project which draws attention in a budget. Still, where the noise levels are high and the exposed population is numerous, barriers are a cost-effective solution to the noise pollution problem.

The alternatives may be more expensive, and frequently they offer less satisfactory solutions. However, they may be useful and should be examined. Rerouting traffic may defeat the purpose of the highway and frequently merely transfers the noise problem to another location. Speed limitations may increase travel time and congestion and lead to requests for more highways; in addition, feasible speed reductions often do not reduce noise levels very much. Insulation of buildings close to the highway is an expensive alternative if a large number of dwelling units are involved, and insulation does nothing to reduce the noise in the yard where people like to garden, cook, and play.

The earlier highway noise is considered, the less costly the solutions are likely to be.[1] If the highway is a new one, or if major reconstruction or widening is contemplated, noise reduction, including the possibility of barriers, can be included in the project planning. Major economies can be obtained, for example, by using earth from cuts to build berms and by considering all the drainage problems and all the underground pipes and cable disturbances at the same time. In some cases highway noise problems may be mitigated during the design phases so that barriers may be unnecessary. Certainly, designing barriers when the highway is landscaped will result in construction that is more compatible with the environment and will reduce planning costs.

Construction of barriers along existing highways is more expensive, but has an advantage in that the projects can be scheduled for countercyclical effects. When the

[1] *Federal Highway Administration, Highway Noise Barrier Selection, Design and Construction Experience: A State-of-the-Art Report, 1975.*

construction industry is in a slump, public works projects often can help stabilize employment and can be performed at lower costs than when men and equipment are in demand for other kinds of construction. In some situations highway barriers can be constructed when prevailing costs are relatively low and when unemployment benefits can be replaced by wages.

Other Economic Costs of Barriers

In economic terms, a barrier's cost is not limited to the expenditures made for design, materials, construction, and maintenance. The economic cost of a barrier also includes the opportunity cost of foregone projects. For example, rather than constructing a barrier, funds might have been used to improve environmental quality along the highway in some other way, such as landscaping or increasing litter clean-ups.

Other economic costs associated with barriers include those occurring due to traffic disruptions during construction and possible unexpected expenses, such as the law suit judgment rendered in Minnesota requiring the state to pay damages to three property owners who belived their properties were adversely affected by the noise barriers. That suit is still under appeal at this time.

Economic Benefits of Noise Barriers

Property Value Improvement

One expected benefit of a noise barrier project is appreciation in the value of homes adjoining the barrier. Most residents adjacent to a barrier seem to believe it enhances the value of their property. The actual changes, however, have been difficult to measure for several reasons, including the following:

1. The expected changes are small, a few percent, and may not be detectable with statistical confidence unless the sample is large.

2. Differences in individual properties make comparisons difficult.

3. Market conditions cause changes in the value which mask differences caused by barriers and lower noise levels.

The results of studies performed to date are inconclusive, though they do indicate that properties are never adversely affected by noise barriers. An extensive study conducted in Minnesota analyzed the effect of barriers on residential property values, on speed of sale, and the difference between asking price and sale price. Several locations were analyzed to make two kinds of comparisons: first, a comparison between the values of homes and empty lots adjacent to the barrier and similar homes and lots in the same neighborhood but not close to the barrier; second, a comparison of the value of homes and empty lots adjacent to the barrier and similar homes and lots beside the highway in other neighborhoods where there is no barrier. The study found that sales prices of homes adjacent to noise barriers were neither positively nor negatively affected by the barriers, and that there was no significant difference in the time required to sell or between the asking price and selling price of homes adjacent to the barrier when compared to other homes. Vacant building lots may have had their value increased by the barriers[1]. To the extent that this occurred, the city benefited with increased property tax revenues. Unfortunately, the Minnesota Department of Transportation was unable to compare the values of the same house or lot (relative to other properties in the neighborbood) before and after the barrier was built.

Some communities may justify increases in assessed value of properties shielded by barriers on studies that have shown that lower highway noise levels are accompanied by increases in property values.

Other Economic Benefits

High noise levels affect the mental and physical health of those individuals subjected to them. These adverse affects may cause the individual to lose sleep, to be less productive, to make more frequent trips to a doctors, and possibly even to suffer impaired hearing. All of the effects involve a cost to both the individual and society. Avoiding these effects with noise reduction programs, such as the barrier program, is therefore a benefit to all concerned.

[1] *Highway Noise Abatement, volume II, technical report, Minnesota Department of Transportation, January 1980, section II. p. iii.*

E. FINANCING A BARRIER PROJECT

Methods of Financing a Barrier Project

Most barrier projects are financed 75 to 90 percent with Federal funds, with the remainder provided by the State. (The Federal government's contribution may be larger than 90 percent; it may be as large as 95 percent in Public Lands States, those that have a large concentration of Federal public domain and nontaxable Indian lands. Exhibit IV-6 gives further details). A few barrier projects are financed 100 percent with State funds or 100 percent with Federal funds. Federal monies are channeled to the States through the Federal-Aid Highway Program. State funds for barriers may be obtained in any of several ways. Each of the financing alternatives is discussed below.

1. Federal Funding

Cost Sharing Program

Most barrier programs receive 75 to 90 percent of their funding from the Federal government — 90 percent when the barrier is to be erected along an interstate highway and 75 percent for all other highways. Barrier project monies are provided through the Federal-Aid Program authorized by the Federal Aid Highway Act of 1978 and administered by the Federal Highway Administration (FHWA) of the U.S. Department of Transportation. Each year the FHWA publishes a list of funds available to each State for the upcoming fiscal year. Since the Federal-Aid funds are not earmarked solely for noise reduction activities, barrier projects have to compete with other State projects for the monies.

There are significant limitations on the use of Federal funds for barriers and planners should be sure that their projects will qualify[1]. Projects for barriers along existing highways not undergoing expansion or improvement, Type II projects, normally can not be approved for new or recent housing developments, or expansions of existing developments. The land use (residential, in almost all cases) and activities (residence, school, library, hospital, nursing home, etc.) must have existed on or before March 16, 1976 for the project to qualify. Exceptions and special situations are described in the reference cited above.

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[1]*Details are given in The Federal-Aid Highway Program Manual, Volume 7, chapter 7, Section 3, "Procedures for Abatement of Highway Traffic Noise and Construction Noise," Federal Highway Administration, May 14, 1976.*

INTERSTATE CONSTRUCTION PROGRAM

STATE	Ratio of designated public lands area 1/ to total area of State	Percentage of cost of Federal-aid projects payable by Federal Government 90% Federal 10% State
Arizona	.4305	94.31
California	.1485	91.49
Colorado	.1029	91.03
Idaho	.2299	92.30
Montana	.1209	91.21
Nevada	.7010	95.00 2/
New Mexico	.2490	92.49
Oregon	.2222	92.22
South Dakota	.1079	91.08
Utah	.4238	94.24
Washington	.0640	90.64
Wyoming	.2556	92.56

1/ Area of unappropriated and unreserved Public Domain Lands and nontaxable Indian lands.

2/ Maximum amount.

NOTE: Based on latest available area data furnished by the Department of Interior.

Source: *U.S. Department of Transportation, Federal Highway Administration, FHWA NOTICE N 4540.6, Table 3, May 31, 1979.*

EXHIBIT IV-6: SLIDING SCALE RATES OF FEDERAL-AID PARTICIPATION IN PUBLIC LANDS STATES

Projects for barriers along new and reconstructed highways, Type I projects, are divided into Type IA, projects on highways where access by intersecting streets and driveways is limited, and Type IB, projects on highways where access is not limited. Noise control requirements for the Type IA projects are more stringent than for Type IB because the relatively frequent openings in noise barriers on unlimited access highways greatly reduce the effectiveness of the barrier.

The Federal Highway Administration urges state authorities to be as cost effective as possible when constructing barriers. There is not, however, an upper limit on the expenditure (on a per mile basis, for example) the state is allowed. There are also no absolute requirements on how much noise reduction a barrier must achieve or how high noise levels must be for a project to receive Federal funds.

Demonstration Projects

The Federal Highway Administration's Demonstration Division provides 100 percent financing for innovative projects. Some of the projects receiving 100 percent financing are the results of ideas born at the State level, proposed to and approved by FHWA. Other demonstration projects may be researched and developed at the Federal level and offered to the States on a first-come, first-served basis. Funds are limited, and barrier projects must compete with other types of highway projects for approval.

Demonstration projects are funded in the interest of advancing knowledge and technology in highway construction and operation. For this reason, demonstration projects are subject to relatively large reporting requirements.

2. State Funding

The state is usually responsible for 10 to 25 percent of the outlay necessary for a barrier project. There are several possible sources for these funds. States may finance projects using general revenues, special bond issues, part of the State gasoline tax, or revenues from toll roads. In only one state, Minnesota, was a fixed part of the revenue set aside for highway noise reduction. There, between 1975 and 1978, one percent of the gasoline tax was earmarked for these projects.

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A state may elect to finance a barrier project wholly with its own funds, either because the State's Federal-Aid Highway program funds are already committed or because of a wish to avoid the longer project planning time involved when Federal funds are used. One state which has used 100 percent state financing is Virginia. In that State, a barrier on a toll road had to be financed totally from State funds since Federal funds cannot be expended on toll roads. All of the required monies were obtained through state toll revenues.

References

Federal Highway Administration, The Federal-Air Highway Program Manual, Volume 7, May 14, 1976.

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SECTION V

HOT SPOT (BARRIER)
PROGRAM EVALUATION

SECTION V

HOT SPOT (BARRIER) PROGRAM EVALUATION

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SECTION V

HOT SPOT (BARRIER) PROGRAM EVALUATION

A. EVALUATION OF PROGRAM OBJECTIVES

No program should be undertaken without a plan for evaluation. The major objectives of the Hot Spot program areas follow:

1. In all sections of major highways that pass through densely populated residential areas in which the highway is the predominant noise source, reduce the L_{dn} in the yards of the residences to 75 dB or lower; where barriers are installed reduce the L_{dn} by at least 10 dB.

2. Obtain public support for the program before, during, and after construction of barriers.

3. Cause the value of the residential real estate bordering the highways to increase in value.

4. Plan and execute the Hot Spots program economically and cost-effectively with contributions to the economic benefit of the community.

The success of the Hot Spots program in attaining each of its objectives must be evaluated using quite different methods.

B. EVALUATION OF THE NOISE REDUCTION OBJECTIVE

The evaluation of the Hot Spot program's attainment of its objective of noise reduction must be measured in two steps. The first step is to determine the fraction of the length of the highways that met the Hot Spot criteria that actually were treated under the program. The reasons for failure may have been inappropriateness of the barrier technique (highrise residences, safety restraints), lack of local funds, or rejection by the citizens. These represent technical, financial, and political failures, respectively.

The second step is to measure the noise reductions that were achieved by the barrier when they were constructed. For a thorough evaluation two sets of acoustical measurements and one set of calculations are needed. The acoustical measurements should be in the same yeards of the same houses before and after the barriers were installed and the landscaping was completed. The locations that were used for the scanning and the detailed noise measurements in the planning stage should be revisited and the same measurements should be made with similar equipment at similar times of day, week, and year. These acoustical data can be compared to give before and after information which can be interpreted as comparisons, "everything else being equal." To determine what part of the difference in the noise levels is causally related to the barriers, it is necessary to calculate the noise levels at the same location without the barrier but with the traffic characteristics as they are with the barrier. This calculation can be made from current traffic mix, speed, and volume data as a function of time of day, using the FHWA methods. The difference between the predicted and the observed noise levels can be used to correct the measured differences. Where the traffic count and the mix have not changed materially, simple before and after acoustical measurements, as described above, can be made.

C. EVALUATION OF THE PUBLIC SUPPORT OBJECTIVE

A partial measure of the extent to which the program had public support is the fraction of the highway lengths that had expenditures for barriers approved by the voters or citizens' groups to whom the issue was placed. A more satisfactory and complete measure is the results of surveys of the opinions of the bordering or nearby residents before and after adoption of the barrier program, such as were conducted in Minneapolis and other areas. In that case the responses were received from nearly three quarters of the residences abutting the barrier, a very high ratio. This response ratio is itself a measure of public participation which indicated great interest in the issue.

It is important to use the results of the pre-barrier survey in the design of the post-barrier questionnaire. Because residents tend to form their opinions about the worth of barriers before they are built and to maintain that opinion after they are completed, it is important to distinguish and to evaluate separately the responses from residences that changed hands during the interval between the surveys. Frequently the respondents' comments are the most informative indication of public support.

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Ideally, a consulting firm or university department that specializes in designing and conducting surveys should assist in this evaluation, since it is difficult to be sure that the results of a survey of the public are indications of the quantity or quality that one wants to measure. An alternative for communities that find the technical expertise they need unavailable or too expensive is to use surveys developed for other barrier program users.

Other measures of support are the degree of public participation by the public in hearings, in decision making, in questioning their elected and appointed representatives, and in letters to newspapers or calls to radio and television stations. Citizens and government officials who lead hot spot (barrier) projects should keep attendance records for meetings and logs of phone calls received, and should contact other possible comment receivers during the evaluation.

D. EVALUATION OF THE PROPERTY VALUE IMPROVEMENT OBJECTIVE

Changes in the value of property bordering the barriers will be difficult to measure for several reasons, including:

1. The expected changes are small, a few percent, and many not be detectable with statistical confidence unless the sample is large.

2. Differences in individual properties are likely to make comparisons difficult.

3. Market conditions are likely to cause changes in the values which mask differences caused by barriers and lower noise levels.

Objective comparisons can be made by determining the difference in value between houses abutting the highway and similar houses farther from the highway before and after the installation of the barriers. If the areas are full of tract or row housing with many or all houses substantially identical and with a relatively high turnover, such comparisons are relatively easy. If the houses are all different and the turnover is low, such comparisons may be almost impossible. The ideal situation is to have the same house sold before and after installation of the barriers with no substantive improvements betweentimes.

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Other objective measures of increased real estate value are the number of building permits for improvements to houses abutting the highway that are issued before and after construction of the barrier. Such improvements are indications of the owners' beliefs that the property is worth improving, and the cost of the improvement is a clue to the degree of appreciation of the property. In Pennsylvania, for example, a study of building permits would reveal definite positive expectations for the effects of barriers on real estate values: new housing construction and redevelopment in the areas benefited by the barriers in that state increased significantly.

Usually opinions of realtors, property appraisers, and lending institutions are used as subjective measures of changes in property value. If the properties along the barrier are reassessed after the barrier is installed, the change in assessed value is a valid indicator.

Other measures of the change in value are the rate of sale, the time it takes to sell property abutting the highway before and after the barrier is constructed, and the change in the rate of turnover of abutting properties.

E. EVALUATION OF THE COST-EFFECTIVENESS OBJECTIVE

Studies of the cost-effectiveness of a barrier program should be conducted before and after program implementation. The cost-effectiveness evaluation is principally one of determining whether the program is the cheapest method of attaining the objectives. The possible alternative methods of protecting the residents from the high highway noise levels are the following:

- Provide distance and landscaping
- Reroute and slow traffic considerably
- Insulate the residences
- Repave the highway with smoother materials
- Relocate the residents to houses farther from the highway.

The first of these alternatives may be the best solution in some cases, especially near long-term construction sites. The second alternative causes major disruption to the transportation system and may merely relocate the noise problem. The third alternative does not change the outdoor noise levels, so the residents are exposed to the same noise when they are in their yards or in rooms with wide open windows. The fourth alternative may prove to be a viable one in the future, but has not yet been shown to effect lasting noise reductions as large as those attainable with barriers. The last alternative is desirable only when the number of dwellings is small and when the noise levels are dangerously high. All four alternatives are expensive (they are arranged in rough order of increasing cost), and some do not achieve the same objectives. Comparison of various strategies will normally be made before barriers are erected.

If the improvement on real property values along the highway has been measured, such an improvement is a measure of the economic contribution of the hot spots (barrier) program to the community. Present value calculations of any increased property taxes can be applied to reduce the cost of the program. Other measures of the economic contribution to the community are the stimulation of construction activity and the resulting employment. The former can be estimated from the contract award data, and the latter can be estimated from the employment records of the project. If the barriers were constructed during a period of construction inactivity, all the jobs and construction money can be regarded as marginal gain rather than substitutional.

SECTION VI

HOT SPOT IDENTIFICATION AND AERIAL PHOTOGRAPHS

SECTION VI

HOT SPOT IDENTIFICATION AND AERIAL PHOTOGRAPHS

Data on traffic volume and mixture from Standard Metropolitan Statistical Areas (SMSA's) larger than one million in 23 States (including the District of Columbia) were collected. Raw data were transformed into reasonably accurate estimates of noise levels in order to identify specific sites where the level of noise would be sufficient for consideration as a hot spot.

After screening the available data (see Appendix A for the screening methodology), specific sites were selected for more detailed analysis. Aerial photographs were obtained of the specific sites where traffic counts were taken in order to determine whether the high noise levels emitted by vehicular traffic were likely to reach nearby residences. These steps identified actual — areas with residences — and potential — areas without structures — problem areas of interest to citizens and local officials concerned with noise reductions and compatible land use planning.

Exhibit VI-1 lists more than 225 sites (places where traffic counts are taken) where noise levels were high enough for the sites to be potential hot spots. Concerned citizens can use this list as one aid to identify probable noise problems in their areas. It must be noted that the potential hot spot identification is based on existing traffic counts. Since the traffic counting locations are limited, it is safe to assume that the number of actual hot spots far exceeds the number that have been identified.

Citizens and local officials who know that there is a potential hot spot in their area can investigate the availability of remedies (see preceding sections). It is important to note that the calculated noise levels are only estimates and that further verification is necessary before additional steps are taken. The procedures described in Section IV may be used as a guide.

Asterisks appear in front of some of the sites in Exhibit VI-1. These asterisks indicate particularly noisy sites for which aerial photographs were obtained. (The number of the asterisks indicates the number of photographs.) The photographs are reproduced in Exhibit VI-2. On each photograph an area has been encircled to emphasize the most probable location of the noisiest spot. Also, every photograph is identified by State, County, highway and place on highway to facilitate verification.

ARIZONA

Highway	County	Hot Spot Location	Est. Ldn
I 10	Maricopa	Exits 128-129	75.2
		Exits 149-154	81.1
		Exits 155-162	77.4
I17	"	Jct. I-10 - exit at Cachis Ave.	80.2
		Cachis Ave. - Deer Valley Rd.	77.6
60	"	Jct I-17	75.9
		Jct. Apache Blvd.	75.5
85	"	Jct. Dysart Rd. - Jct. 35th Ave.	77.0
		Jct. I-17	78.4

CALIFORNIA

Highway	County	Hot Spot Location	Est. Ldn
5	L.A.	Rte. 605 - Rte. 14	84.7
7		Rte. 405 - Valley Blvd.	84.8
10	"	Rts. 142 - Mile 48.27	83.3
11	"	all	83.3
57	"	all	81.4
* 60		L.A. interchange - Rte. 71	84.7
* 91		beginning - Rte. 605	84.6
* 134		all(?)	81.9
210		Rts. 95 & 134W - Rte. 30E	80.5
* 405		Rte. 19 - Rte. 5	82.7
* 605		Carson St. - Rte. 210	83.4
5	Orange	Rte. 1 - Rte. 39	81.0
55	"	all	81.2
57	"	all	81.0
91		all	83.2
605		Rte. 405 - county line	80.8
* 10	San Bern.	all SB - Kubic Rd. in Riverside	79.5
15	"	Rte. 138 - Rte. 395	78.4
60	Rvrside/SB	all SB - Rte. 194 in Riverside	78.2
* 91	Riverside	all Riverside	81.1

EXHIBIT VI-1: LIST OF POTENTIAL HOT SPOTS

CALIFORNIA (Cont'd.)

	Highway	County	Hot Spot Location	Est. Ldn
	5	San Diego	8th St. - Rte. 209	79.9
*	8	"	Rte. 163 - Rte. 67	81.6
	15	"	Rte. 163 - Miramar Rd.	79.6
	94		Rte. 5 - Rte. 125	78.8
*	805	"	Sweetwater Rd. - Rte. 5	80.2
*	17	Alameda	Rte. 262 & (Ala) - Rte. 80 (Ala)	84.3
	24		Rte. 13 - Rte. 680 (Ala)	79.2
*	80	San Fran	thru Ala - thru cc	82.7
	92	San Mateo	Hayward/San Mateo Br.	77.8
	101		thru SF, SM, and MAR.	82.4
*	238	Alameda	Rte. 580 - Rte. 17 (Ala)	80.3
	280		Westborough Blvd. (SM) - Rte. 101	77.8
*	580	Alameda	thru Ala	81.1
	680	Ala/Con.Cost.	thru Ala & CC	81.5
	17	Santa Clara	Rte. 280 - Rte. 237	80.1
	101		all	80.9
	780		all	79.2
	680		King. Rd.	76.4

COLORADO

Counties: Denver, Adams, Jefferson, Arapahoe, Boulder, Gilpin

	Highway	County	Station Mile Post #	Approx. Distance	Est. Ldn
	2	Denver	0 - 9.945	10 mi.	80.2
*	6	Jefferson	277.355 - 296.322	19 mi.	83.0
*	25	Denver	181.872 - 229.097	47 mi.	85.1
	30		0 - 3.984	4 mi.	78.3
	33		0 - 3.829	4 mi.	79.7
	35	Adams	7.806 - 10.075	2 mi.	80.2
	36		35.016 - 56.894	22 mi.	80.8
	40	Denver	296.309 - 307.298	10 mi.	78.7
*	70		249.049 - 308.416	53 mi.	84.7
	76	Adams	6.293 - 12.479	6 mi.	81.1
	83	Denver	70.327 - 77.275	7 mi.	77.7
	85	Adams	203.850 - 236.564	33 mi.	80.7
	88	Denver	0 - 14.113	14 mi.	80.2
	95		0 - 12.996	13 mi.	77.6
	121	Jefferson	5.337 - 26.416	21 mi.	78.2
	225	Denver	0 - 12.311	12 mi.	79.4
	270	Adams	o - 5.216	5 mi.	78.7
	285	Denver	255.076 - 272.576	17.5 mi.	80.2

EXHIBIT VI-1 - (Continued)

FLORIDA

Highway	County	Hot Spot Location	Est. Ldn
92	Hillsborough	Counting Station #3	76.2

GEORGIA

	Highway	County	Station	Est. Ldn
*	I-75,I-85	Henry	Atlanta 0650-0128	79.5
	I-75S		Stockbridge 0151-2719	78.1
	I-83E		Atlanta 0650-0319	77.8
	I-75N		Atlanta 0650-0147	77.7
	I-285		Atlanta 0650-0243	77.2
	I-20W	Douglas	Douglasville 0097-0716	77.0

INDIANA

Highway #	County	# Lanes	Counting Station No.	Estimated Noise Ldn(db)
I465	Marion	6	465	79.5
I70	Wayne	4	070	79.4
I70	Hancock	4	270	79.0
I65	Lake	4	165	78.4
I70	Putnam	4	170	78.4
I65	Jackson	4	265	77.6
I465	Marion	4	365	77.6
I65	Marion	8	565	77.3
I69	Huntington	4	069	75.4

KANSAS

Highway #	County	# Lanes	Station	Est. Ldn
I70	Kansas	2-8 lanes	ADT - 12278	74.9

KENTUCKY

Highway #	County & Location	Est. Ldn
I75	N. Kenton County (Station 252,272 - 794,072) to N. Boone County	80.6

EXHIBIT VI-1 - (Continued)

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LOUISIANA

	Highway	County	Counting Station	Est. Ldn
*	I10	Orleans	188	80.4
*	I10		187	79.6
	I10	Jefferson	186	78.8
	I10	Orleans	17	78.3
	I10	St. Tammany	7	76.6
	I10		5	75.2

MARYLAND

	Baltimore Highway	County	Mile Posts	Est. Ldn
	40	Balt.	0.00	75.0
	50	Ann	0.00 - 4.26	76.0
	70	Balt., Howe	2.86 - 13.60	79.5
	83	Balt.	0.00	76.3
*	95	Balt., How.	0.00-15.29 0.00-4.23(new county)	78.0
	695	Balt.	7.80	79.8

(Washington, D.C. area)

	50	Prince Georges	13.14	76.3
*	95		13.57-34.61	78.9
*	270	Montgomery	7.77 & 18.42 (two spots)	76.9 & 78.2
	301	Prince Georges	1.00	75.3
*	495	Montgomery	1.11	77.0

MINNESOTA

Counting Station	Highway	Counting Station Location	Noise Level(db)
301	I94	Victoria St., St. Paul	77.8
303	I35,E	Arlington Ave., St. Paul	75.9
304	I35,W	CSAH1; Bloomington	77.4
354	TH12	CSAH 17; Lake Elmo	76.9
703	I694	I35,W; New Brighton	76.3
406	CSAH 62	France Ave; EDINA	75.0

EXHIBIT VI-1 - (Continued)

NEW JERSEY

County	Highway Particulars	Highway Counting Station	Estimated Noise Level Ldn (db)
Bergen (317.94)	N.J.-17	2-1-01	77.8
	US-AW	2-3-06	75.6
	N.J.-208	2-4-25	77.0
	I-80	2-1-10 etc.	83.2
Gloucester (148.42)	I-295	7-1-14	79.2
Essex 538.19	N.J.-21	3-3-09	76.9
	N.J.-21	2-3-13	75.7
	Doremus Ave.	3-3-19	75.1
Morris 181.64	N.J.-23	2-1-05	75.1
	I-80	1-1-19	77.8
	I-287	1-1-21	76.7
Union 367.52	U.S.-1	4-3-05	80.0
	U.S.-22	3-1-18	76.6
Bergen	N.J.-17	2-4-02	77.1
Burlington	I-295	7-1-13	77.3

OREGON

	Rte.	County	Counting Station	Ldn
*	5	Clackamas	03-011	80.5
	205		03-016	76.5
*	80N	Multnomah	26-001	77.1
	26		26-002	79.4
	26		26-003	75.2
*	5		26-004	82.0
	405		26-005	78.7
	80N		26-013	81.3
	5		26-016	81.9
*	5		26-019	82.1
	5		26-026	80.2

EXHIBIT VI-1 – (Continued)

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Cleveland Area

	Rte.	Begins At	Ends At	Est. Ldn
	2	US 6 in Cleveland Mile 14.64 (Cuya)	W. Corp. Mentor Mile 06.12 (Lake)	79.0
	6	Memorial Shoreway	W. 28th St.	77.7
	17	SR 21 Mile 17.60 (Cuya)	Warner Rd. Mile 17.77 (Cuya)	79.1
	21	S. Corp. Cuya. Hts. Mile 09.76 (Cuya)	Approach to E. 71st St. Mile 10.04 (Cuya)	77.0
***	71	Wayne Co. Line Mile 00.00 (Madi)	End at IR90 in Cleveland Mile 19.12 (Cuya)	83.3
	76	IR 71 Mile 00.00 (Madi)	Summit Co. Line Mile 12.03 (Madi)	78.5
	77	Miller Rd. Mile 00.82 (Cuya)	IR 90 in Cleveland Mile 15.97 (Cuya)	82.2
	84	SR 306 Mile 08.14 (Lake)	SR 306 Mile 08.14 (Lake)	77.3
*	90	IR 71 Mile 14.90 (Cuya)	Ashtabula Co. Line Mile 29.21 (Lake)	81.9
	271	Summit Co. Line Mile 00.00 (Cuya)	IR 90 Mile 01.75 (Lake)	79.6
	480	Lee Rd. in Cleveland Mile 22.38 (Cuya)	W. Corp. Warrensville Mile 22.93 (Cuya)	75.5

Columbus Area

	Rte.	Begins At	Ends At	Est. Ldn
	23	IR 270 N Mile 23.02 (Fran)	S. Corp. Delaware Mile 10.25 (Dela)	76.7
*	70	Clark Co. Line Mile 00.00 (Madi)	Licking Co. Line Mile 02.38 (Fair)	79.1
*	70A	US 33 Mile 02.29 (Fran)	Ends at IR70 in Columbus Mile 06.15 (Fran)	82.8
	71	(Entire length through Delaware, Franklin, and Madison Counties is a hot spot area)		82.4
	270N	IR 70 in Columbus Mile 00.00 (Fran)	N.E. Corp. Worthington Mile 16.46 (Fran)	79.9
	270S	IR 70 in Columbus Mile 00.00 (Fran)	Re-enter Columbus Mile 16.47 (Fran)	79.9
	315	IR 70 in Columbus Mile 00.00 (Fran)	IR 70A Mile 01.84 (Fran)	77.7

EXHIBIT VI-1 - (Continued)

Cincinnati Area

Rte.	Begins At	Ends At	Est. Ldn
50	Fairbanks St. Mile 17.73 (Hami)	Fairbanks St. Mile 17.73 (Hami)	76.8
50	Ramp Ent. 6th St. Expwy. Mile 19.36 (Hami)	SR 264 Mile 20.54 (Hami)	77.2
* 71	Kentucky St. Line Mile 00.00 (Hami)	Co. Rd. 7 Mile 16.83 (Warr)	80.8
74	North Bend Rd. Mile 14.66 (Hami)	US 27 Mile 19.08 (Hami)	78.3
** 75	(Entire length through Hamilton and Warren counties is a hot spot area)		83.2
275	Hall Rd. Mile 21.23 (Hami)	E. Corp. Blue Ash Mile 30.96 (Hami)	80.1
562	SR 4 in Cincinnati Mile 00.00 (Hami)	Re-enter Cincinnati Mile 03.20 (Hami)	78.2

TEXAS

Dallas Area

Highway	Counting Station	County	Est. Ldn
35W	L-30-70	Terrant	77.2
20	L-202	Parker	77.8
45	L-452	Ellis	79.8
81	M-1089	Wise	75.8
35E	M-1150	Denton	77.1
30	M-1180	Dallas	79.1
20	M-1181	Dallas	77.2
175	MS-17	Dallas	77.3
183	MS-55	Dallas	79.6
72	MS-121	Collin	76.5
20	L-703	Kaufman	77.8
635		Dallas	78.7
35E		Dallas	81.2
138		Dallas	81.3

Houston Area

Highway	Counting Station	County	Est. Ldn
90	L-89	Harris	77.2
290	M-1039	Harris	76.6
290	M-1039	Harris	76.8
* 45	MA-16	Harris	80.7
10	MS-125	Harris	78.8
59	MS-174	Montgomery	78.3
* 610		Harris	82.8

EXHIBIT VI-1 - (Continued)

VIRGINIA

Highway	Counting Station	Location	Est. Ldn
95	619,634	Prince Williams	78.51
95	634,642	Prince Williams	78.46
95	610,619	Prince Williams	75.19
95	642,123	Fairfax	78.82
95	123,Rt. 1	Fairfax	77.41
95	Rt. 1,642	Fairfax	79.56
95	642,617	Fairfax	79.93
95	617,644	Fairfax	80.34
95	644,895,495	Fairfax	79.27
95	395,495,241	Fairfax	79.40
95	241,Rt. 1	City of Alexandria	79.32
95	Rt. 1	City of Alexandria	78.32
395	95,495,236	Fairfax Co. & City of Alexandria	77.43
395	Rt.236 - Seminary Rd.	City of Alexandria	77.83
395	Seminary Rd.- Rt. 7	City of Alexandria	77.41
395	Rt.7 - Rt.120	City of Alexandria	77.66
395	Rt.120 - Rt.127	City of Alexandria	77.55
395	Rt.27, Hayes St.	City of Arlington	77.28
395	Hayes St., Rt. 1	City of Arlington	77.34
395	Rt. 1, 14th St. Bridge	City of Arlington, D.C. Border	79.51
66	Rt. 50, 123	City of Fairfax	77.05
66	123,243	Fairfax	77.02
66	243,495	Fairfax	77.72

WASHINGTON

Seattle Area (King County & Snohomish County)

	Highway	County	Mile Posts	Est. Ldn
******	5	Snohomish/King	144.03-206.29	80.0
*	18	King	2.43 - 3.53	76.8
	167		26.10	76.1
*	405		0.27 - 4.22	77.2
	513		0.19	75.4
	518		2.78 - 3.55	75.7
	520		0.75 - 5.17	75.8
	522		5.87	75.2

Portland Area (Clark County)

	Highway	County	Mile Posts	Est. Ldn
**	5		.29 - 9.73	80.3

EXHIBIT VI-1 - (Continued)

WISCONSIN

	Highway	County	Station #	Est. Ldn
*	I-94	Milwaukee	40-0003	79.4
	I-94		67-0003	78.3
*	I-894		40-0007	79.2

WASHINGTON, D.C.

Location	Est. Ldn
Washington-Baltimore Pkway N.E. (S50)	80.9
Kenilworth Avenue NE	77.7
Southwest Freeway SW	77.9
Frederick Douglas Memorial Bridge SE	78.2
Mason Memorial Bridge SW	79.6
Woodrow Wilson Bridge SW (95,495)	77.9
Cabin John Bridge	77.3

EXHIBIT VI-1 - (Continued)

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CALIFORNIA

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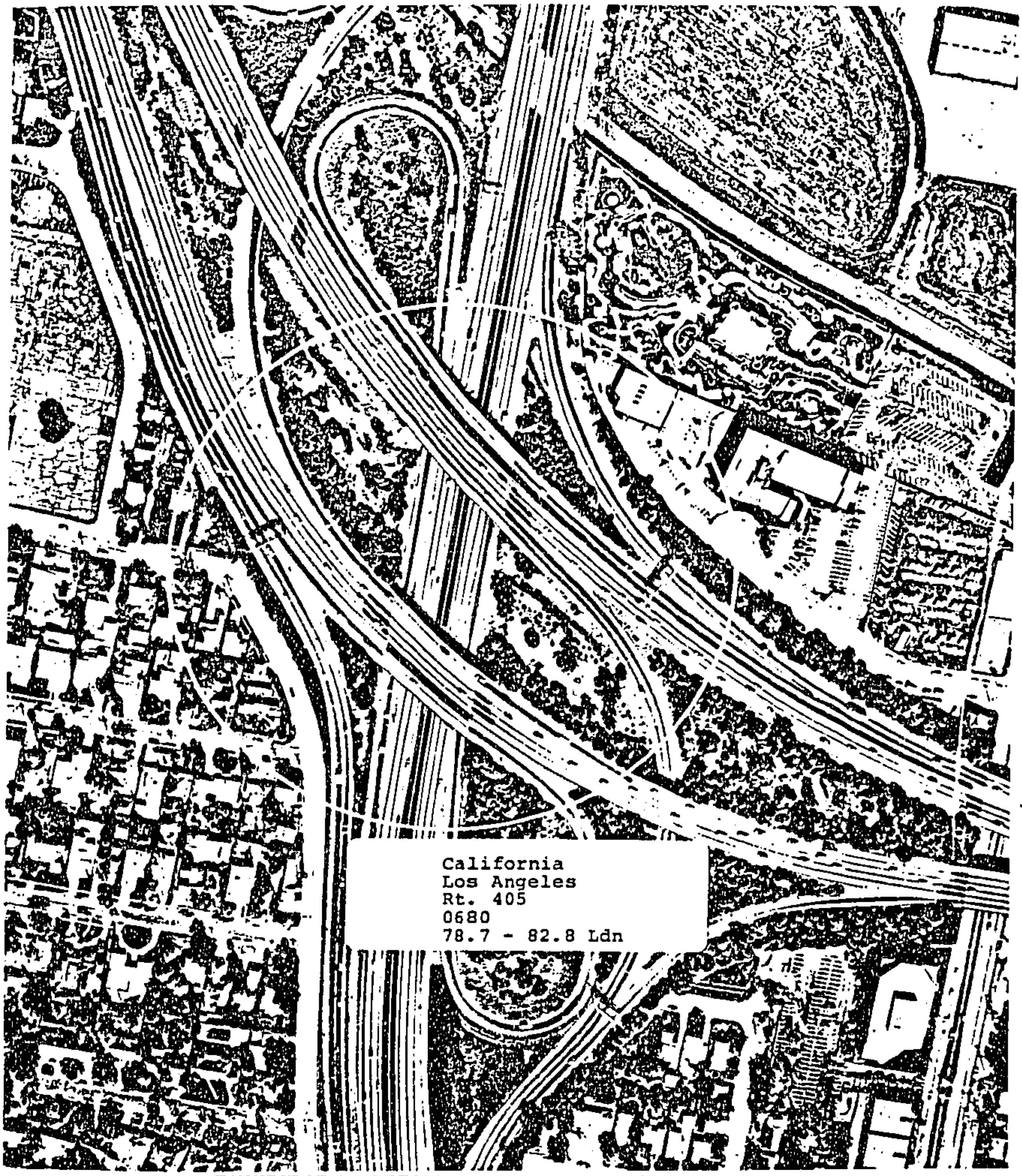

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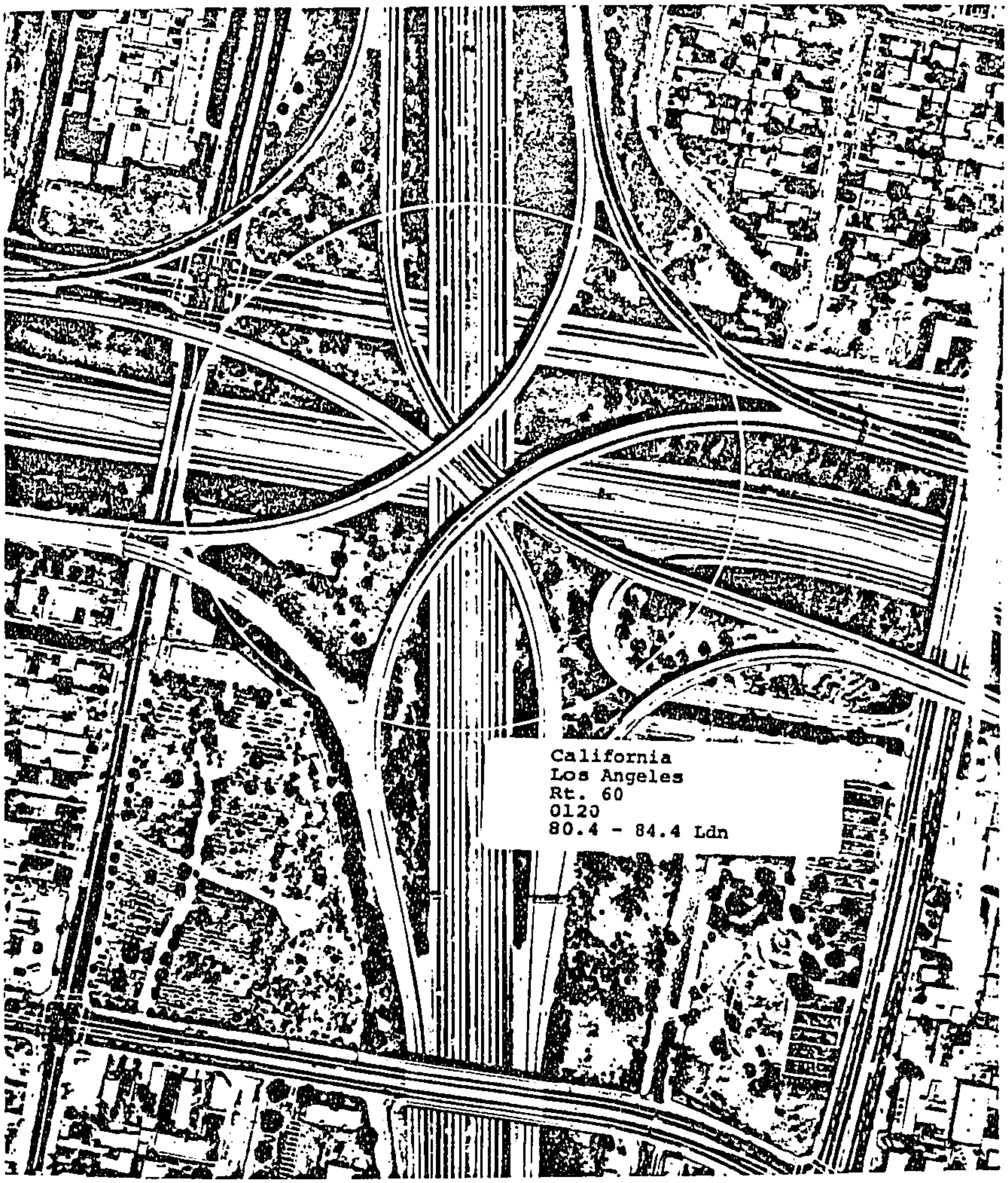

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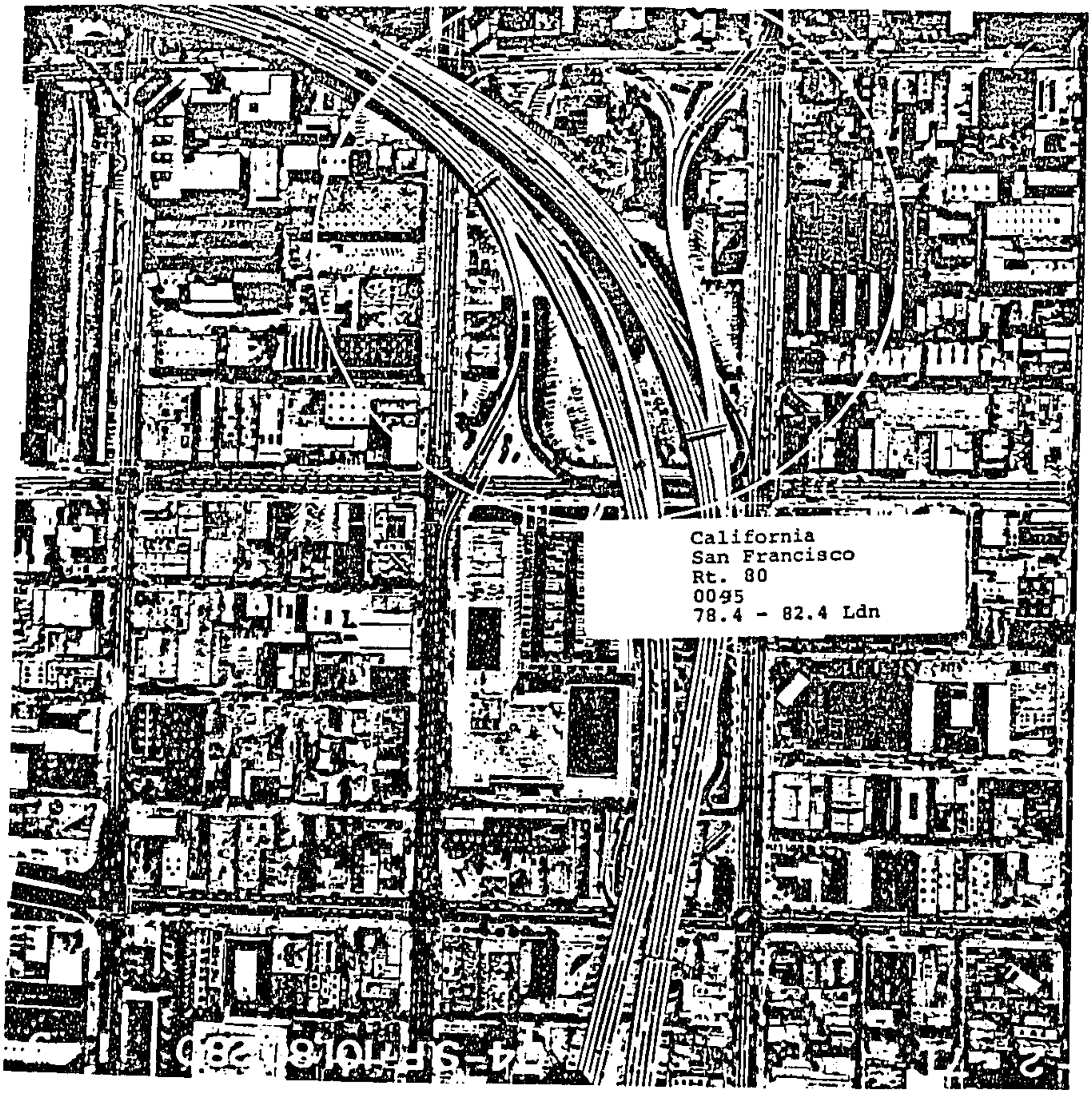

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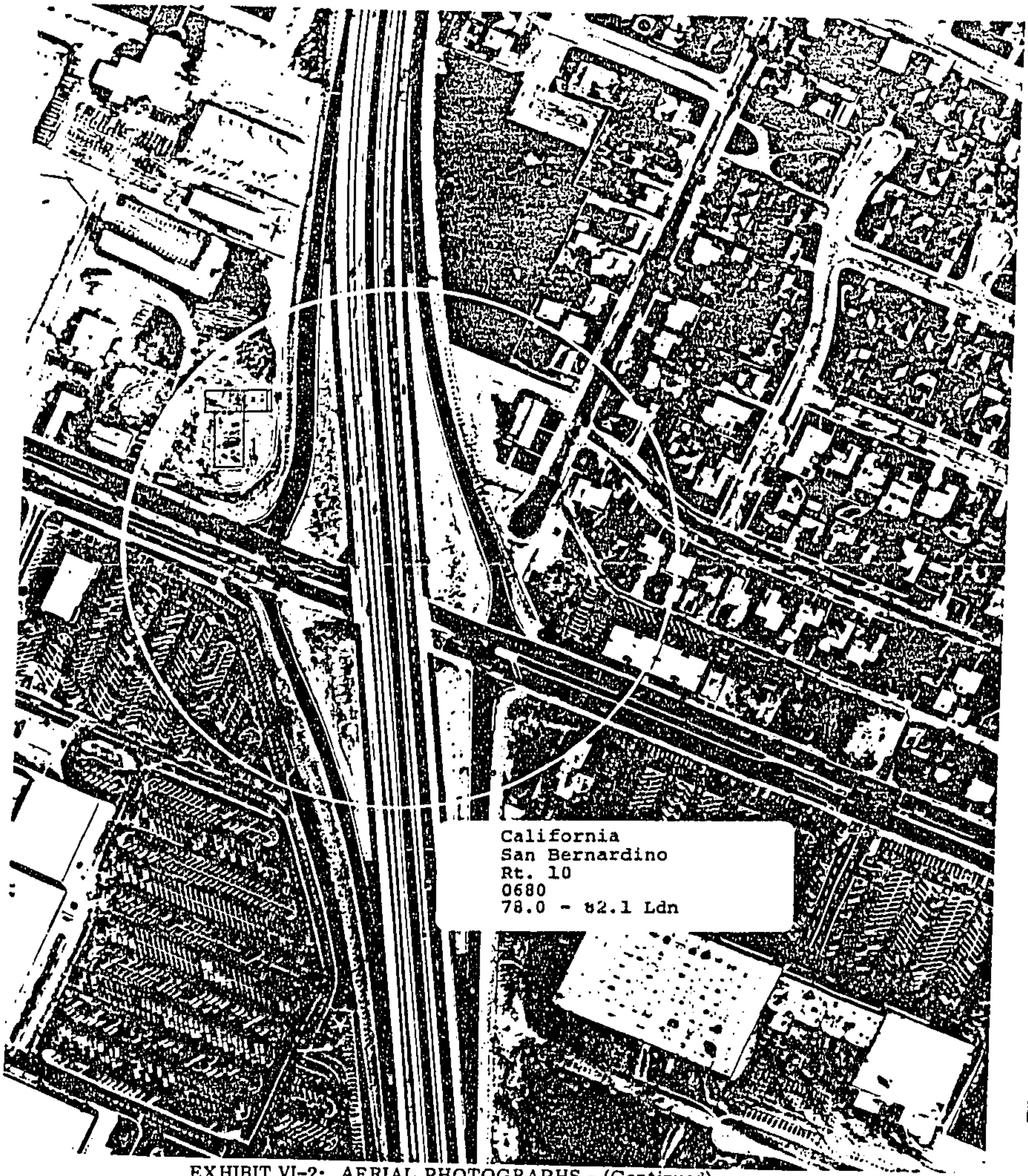

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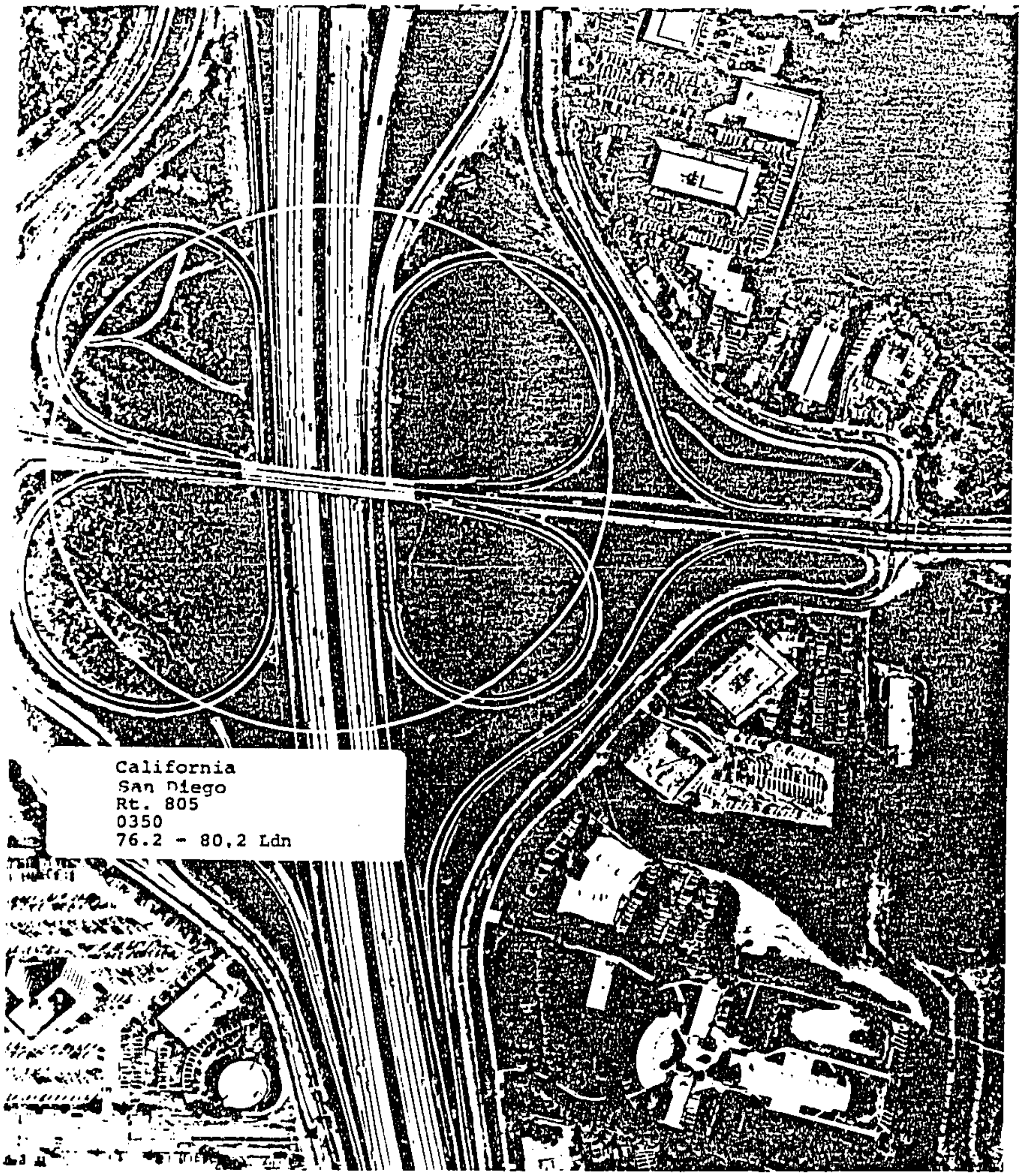

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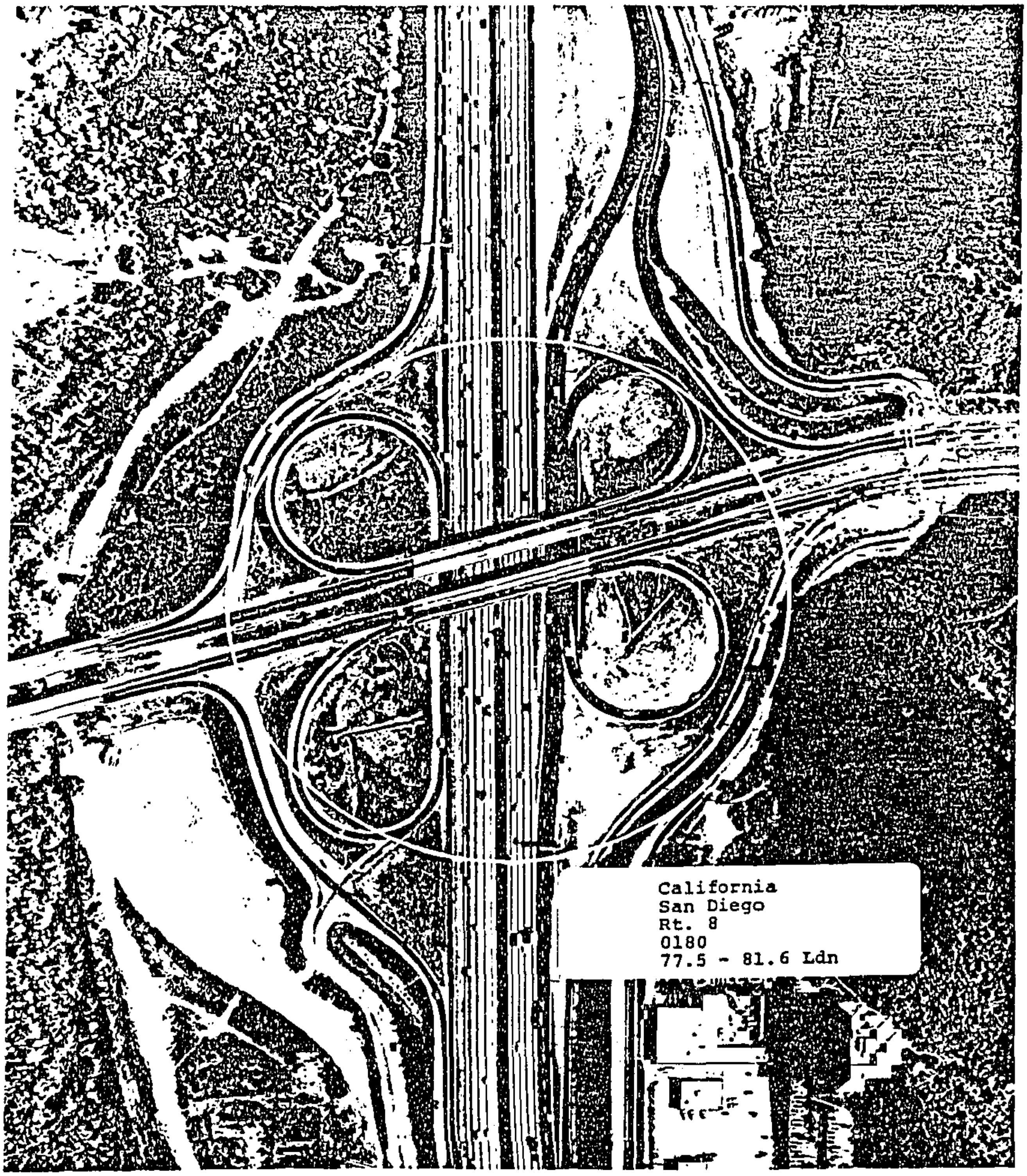

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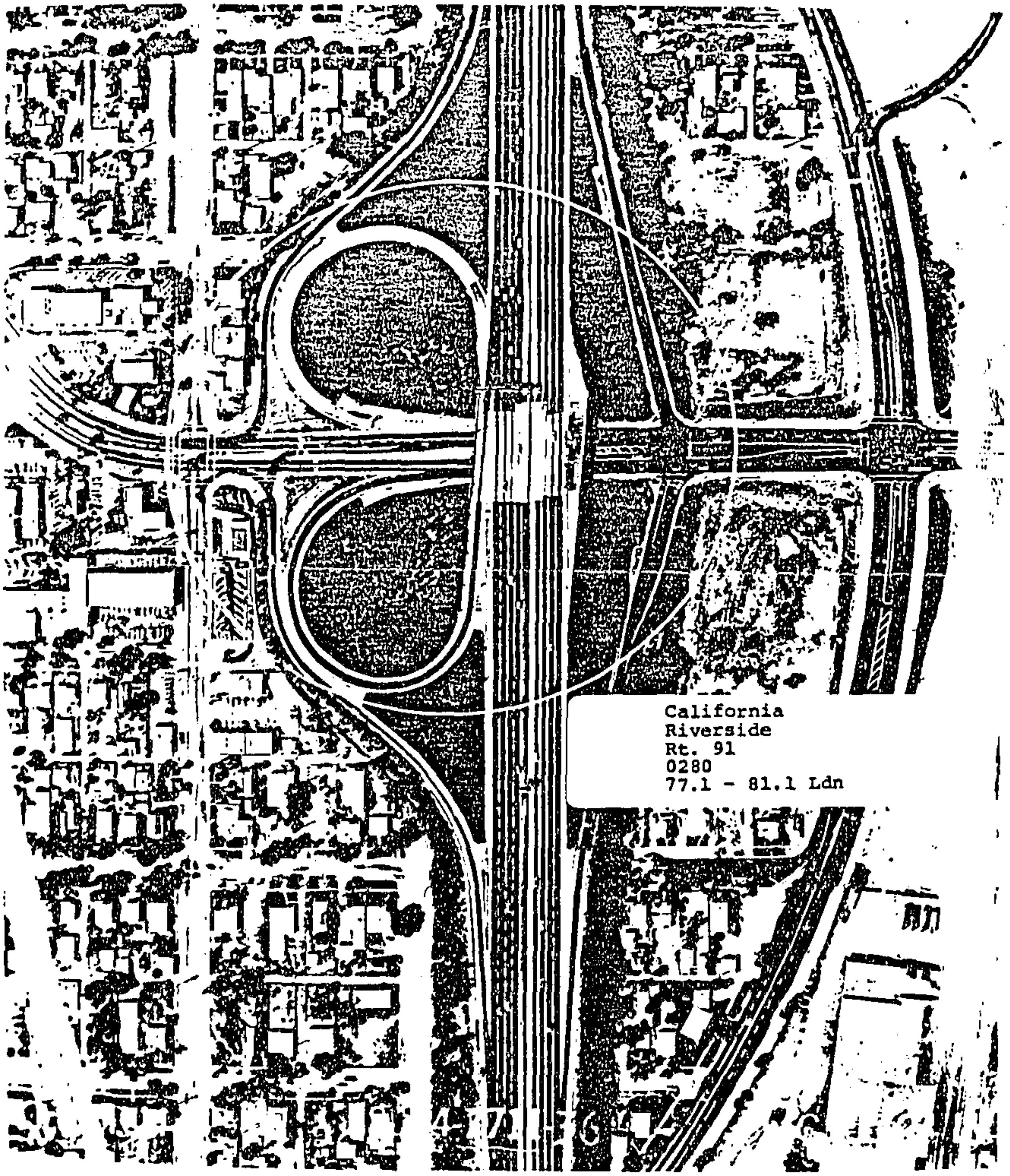

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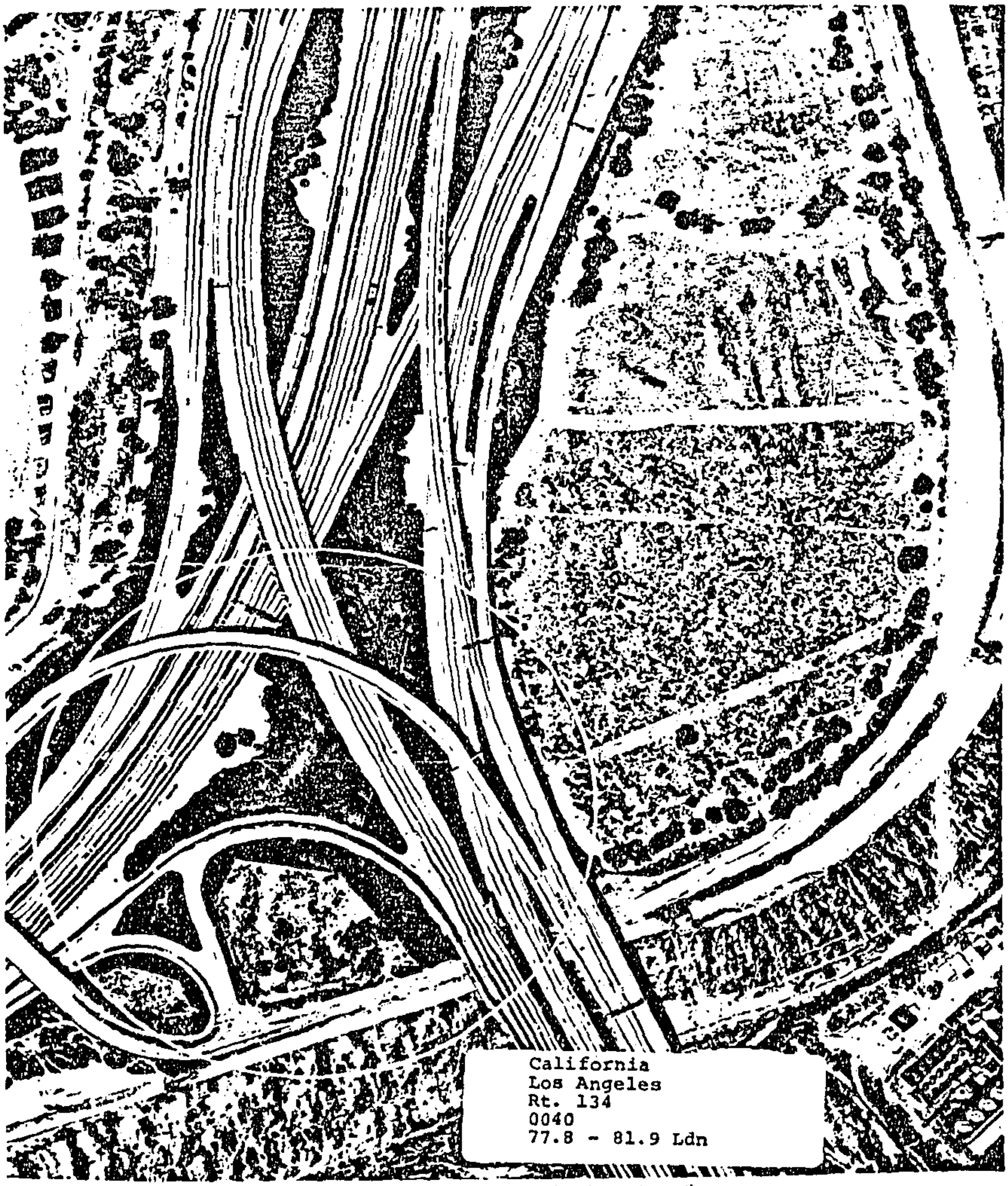

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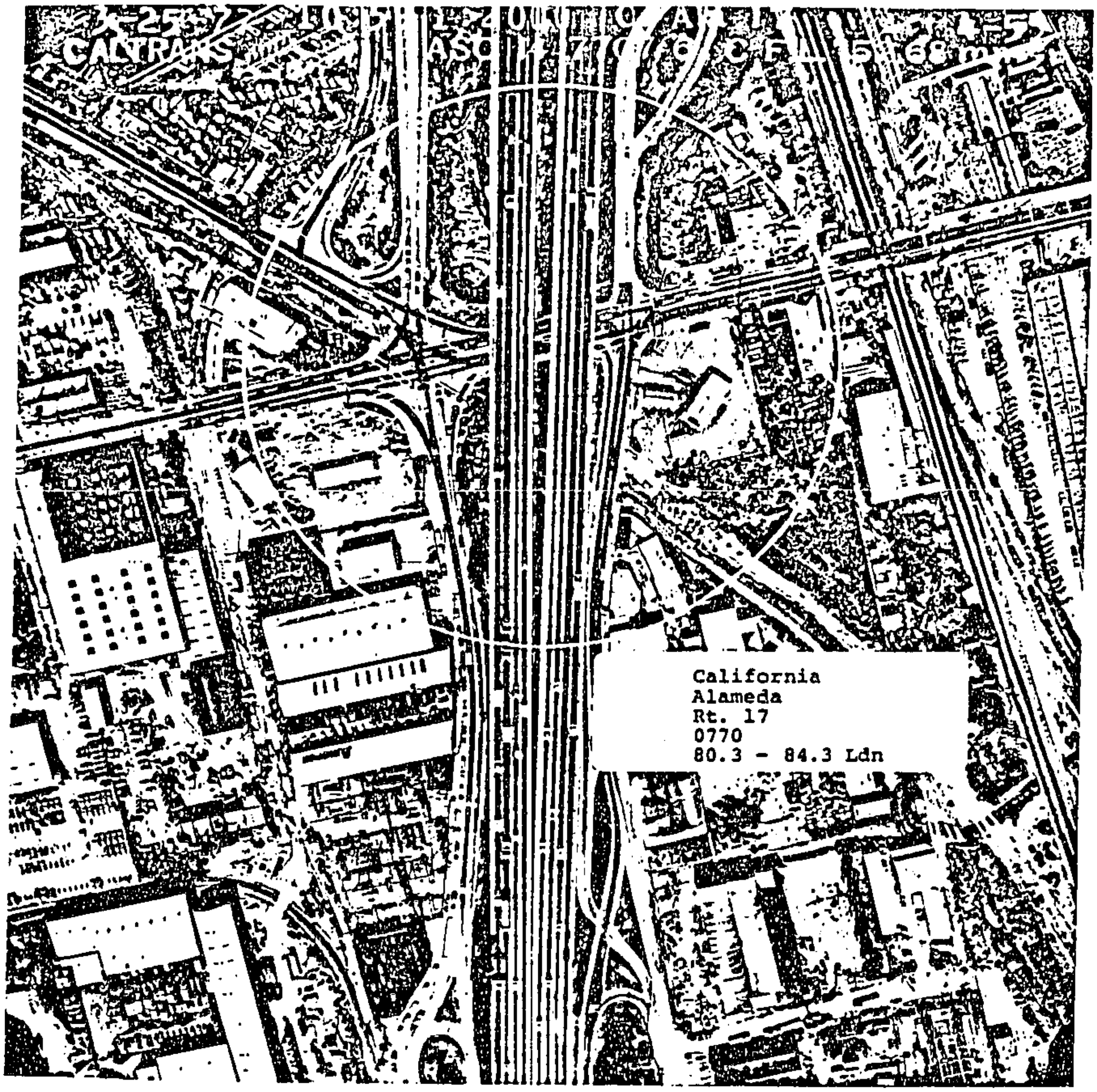

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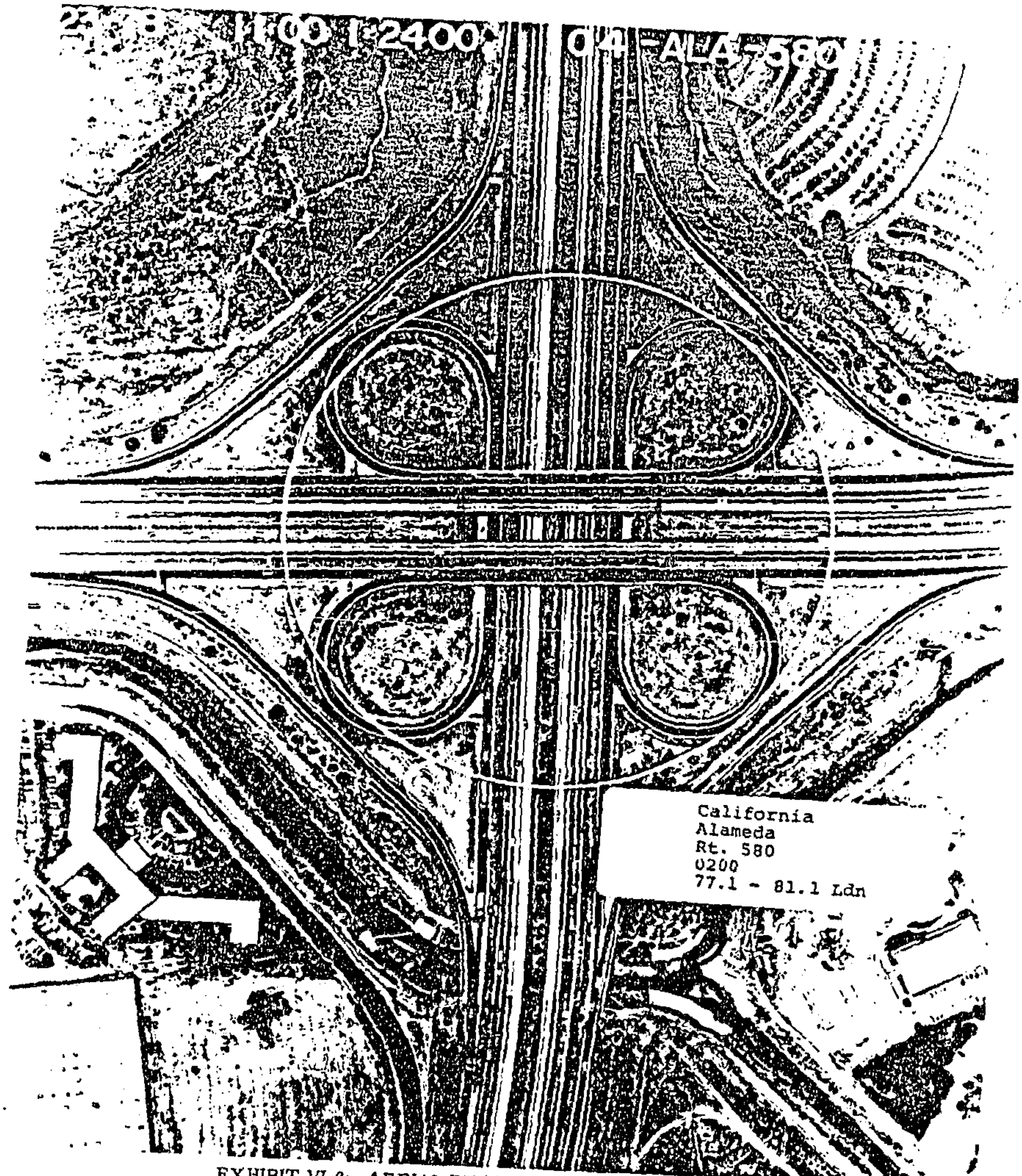

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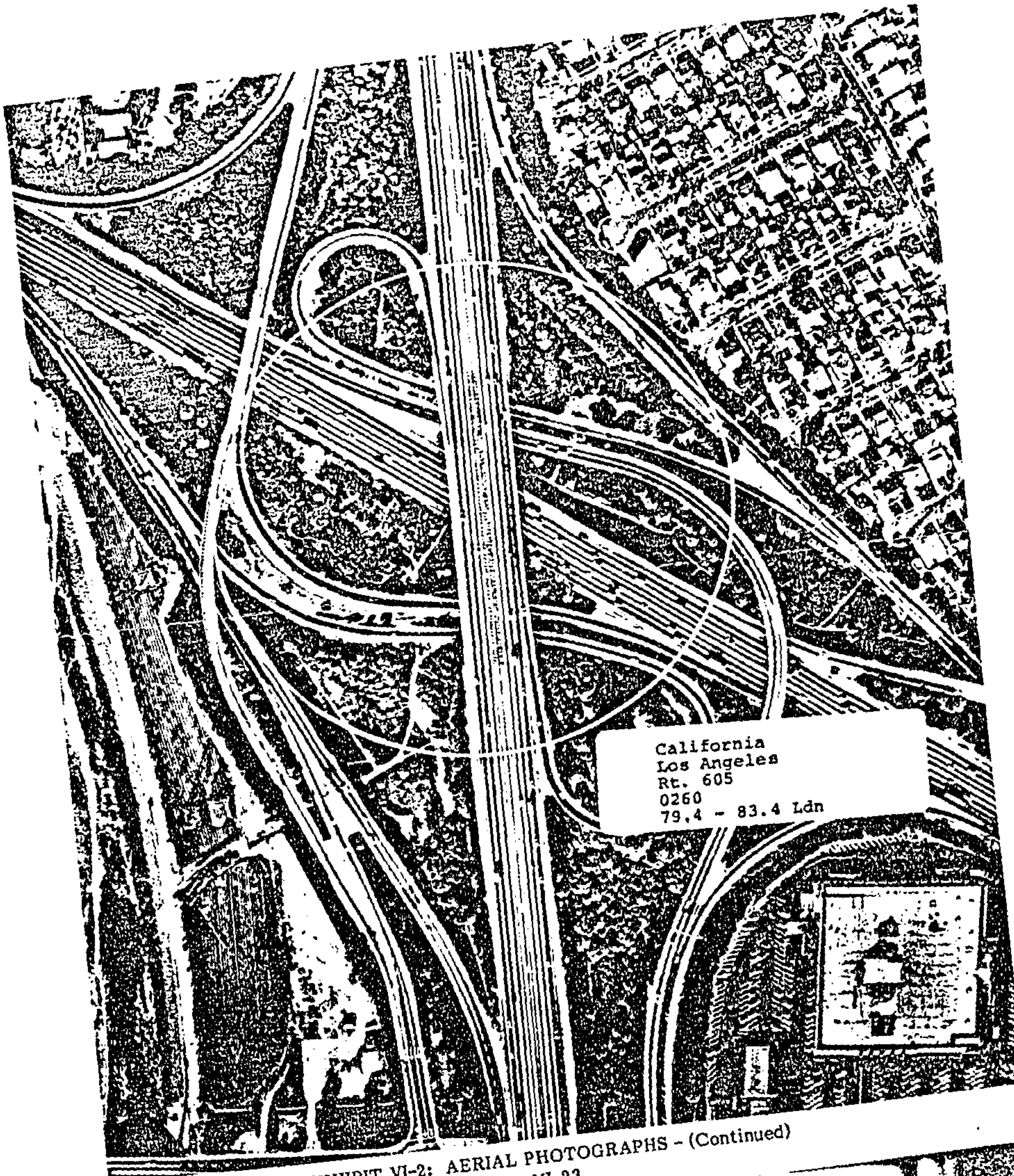

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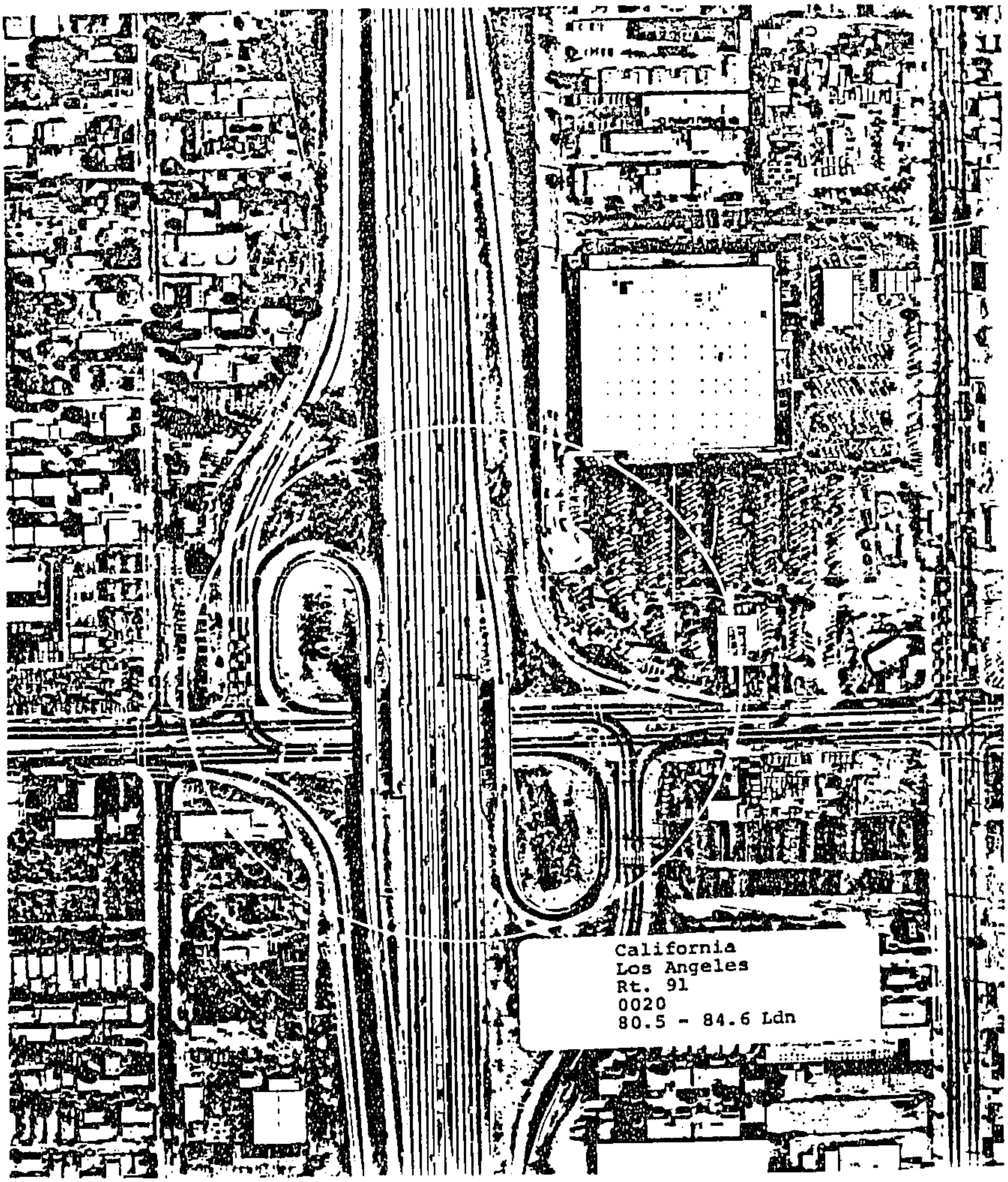

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COLORADO

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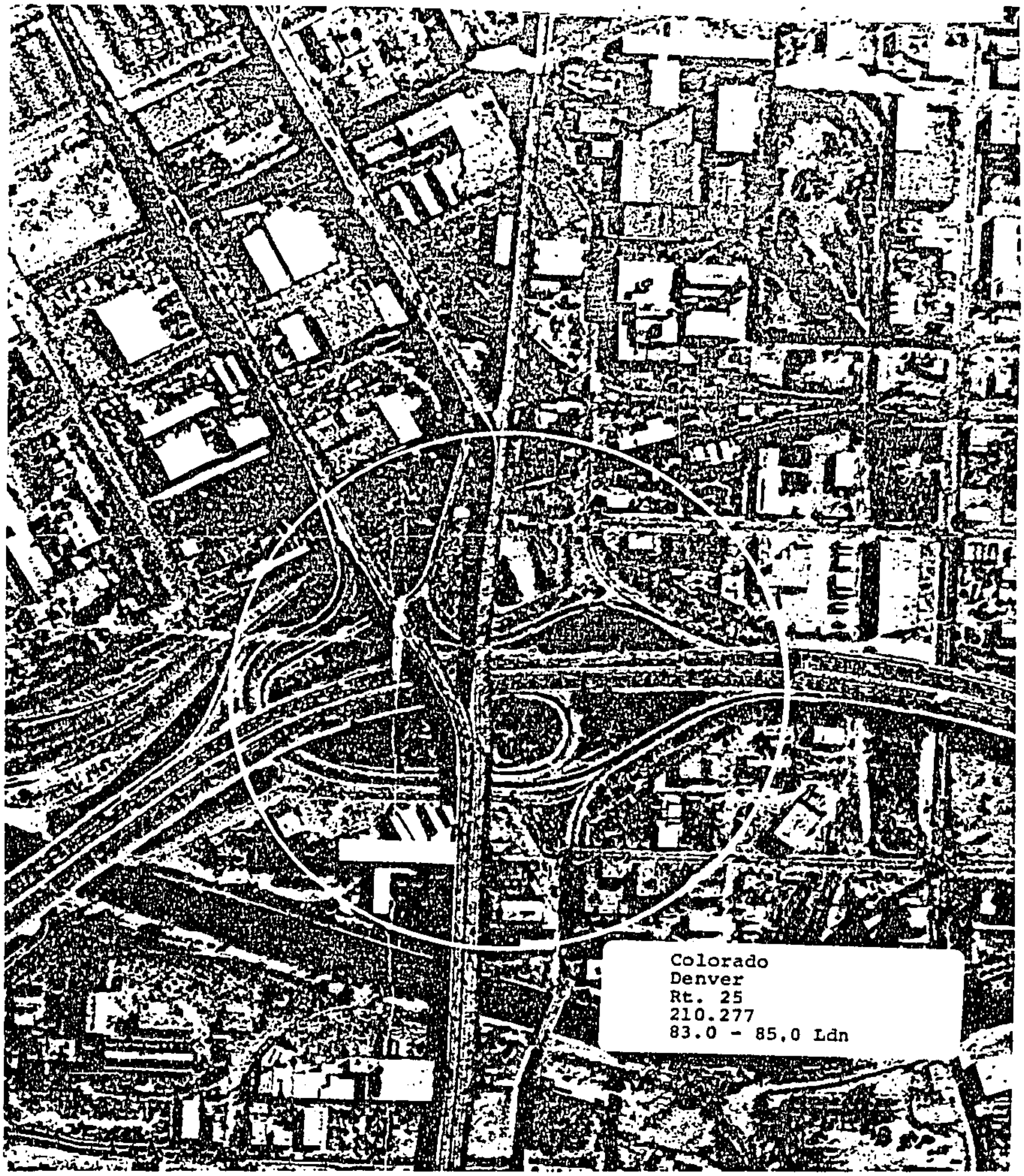

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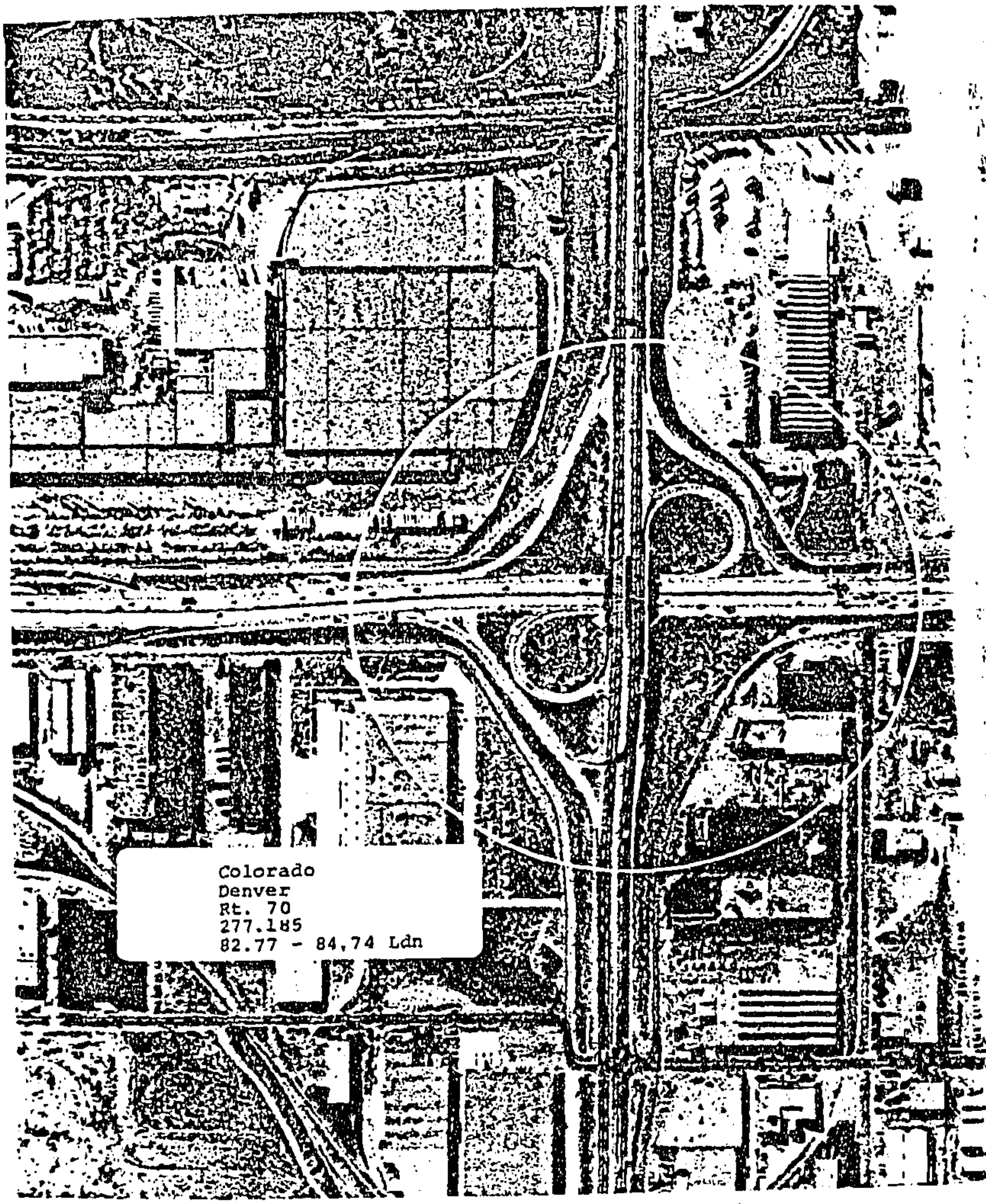

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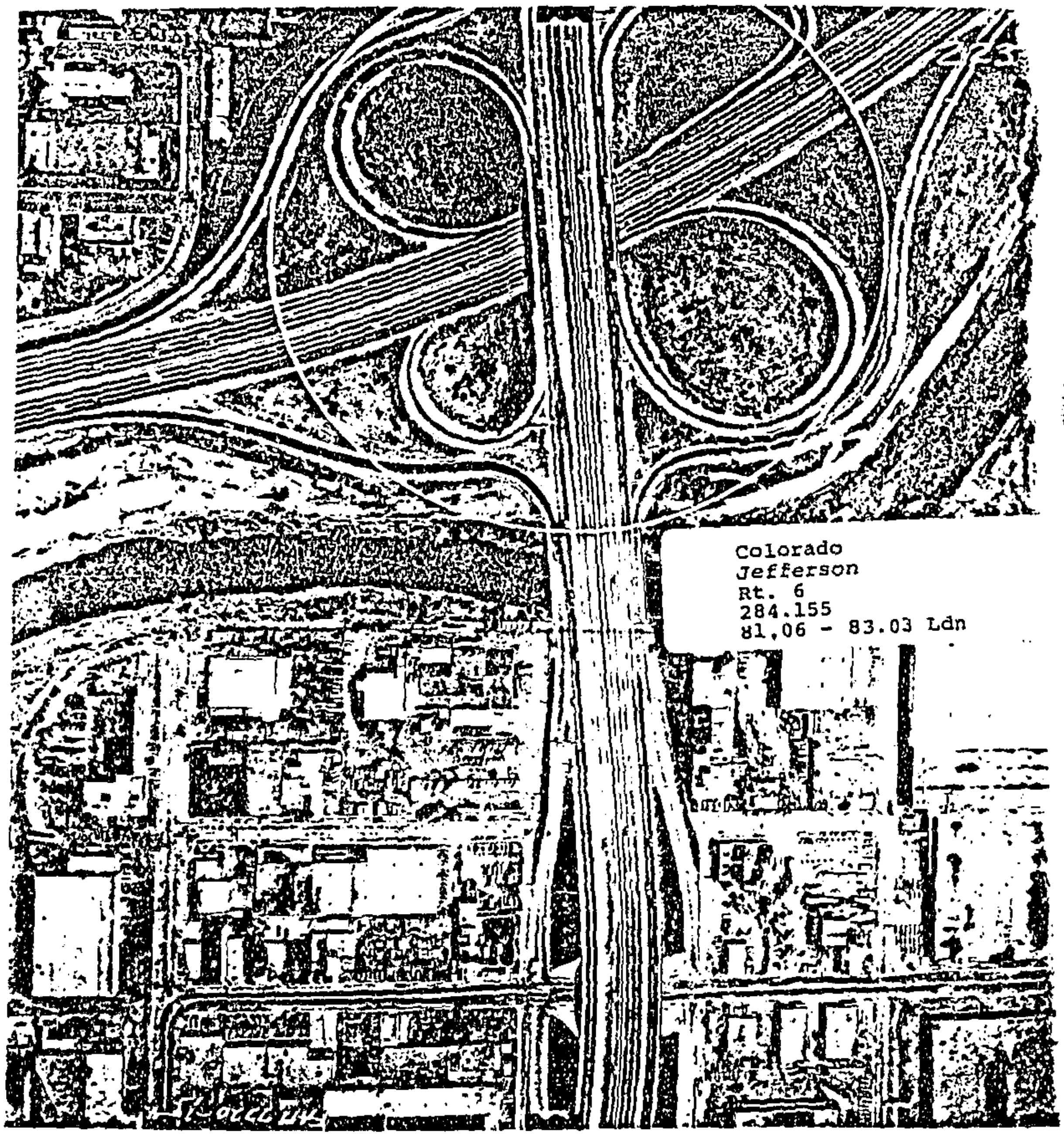

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GEORGIA

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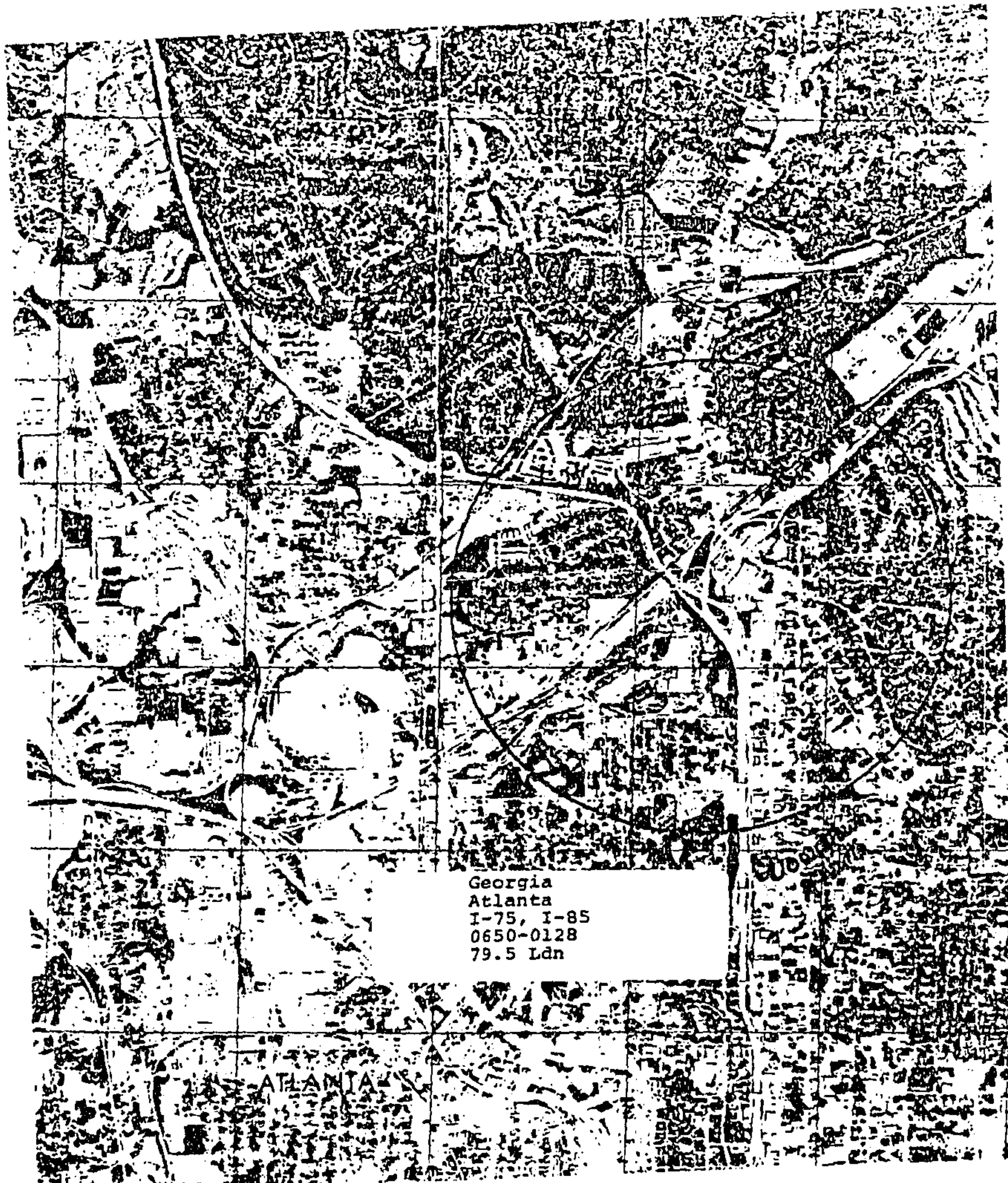

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LOUISIANA

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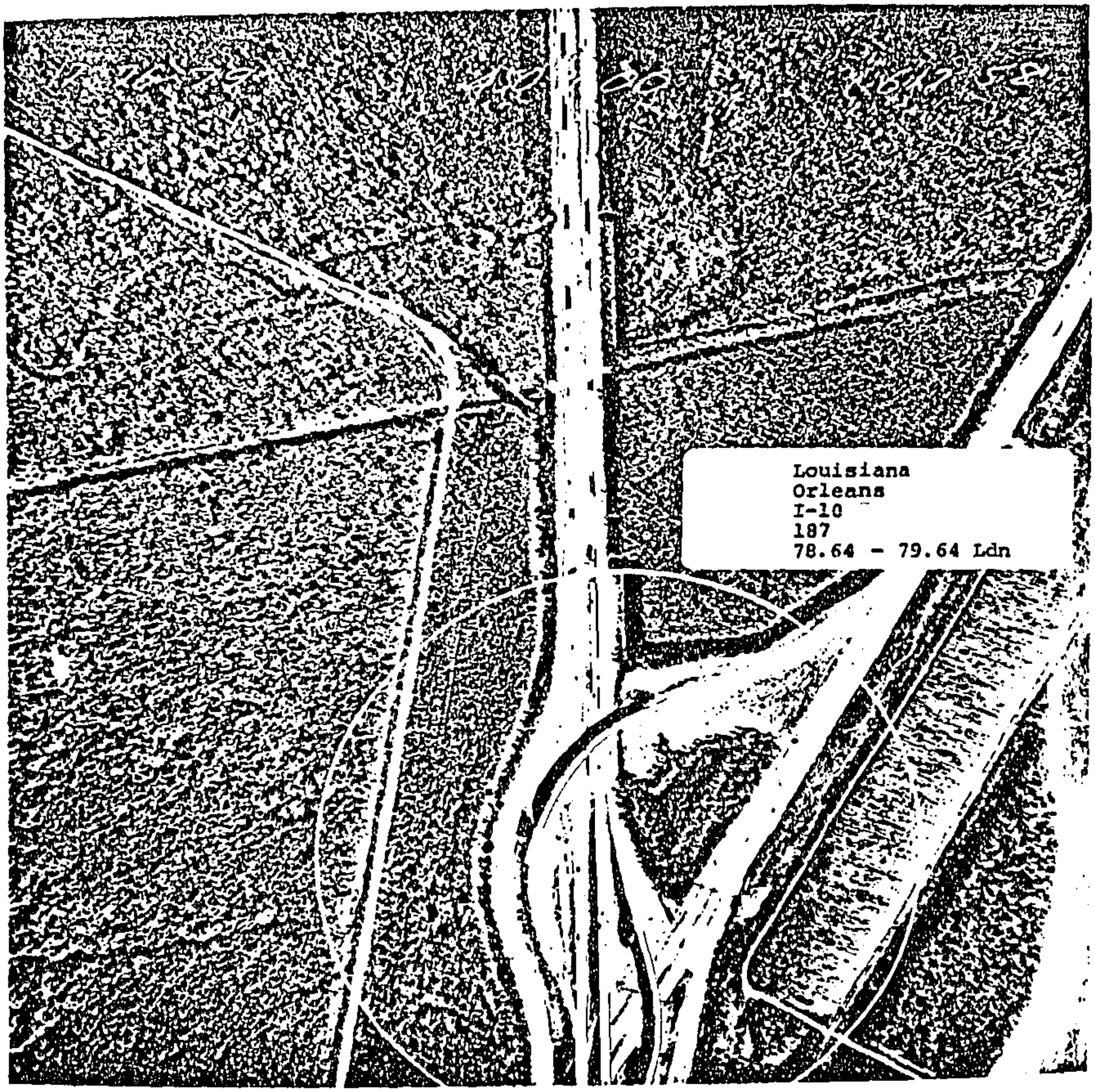

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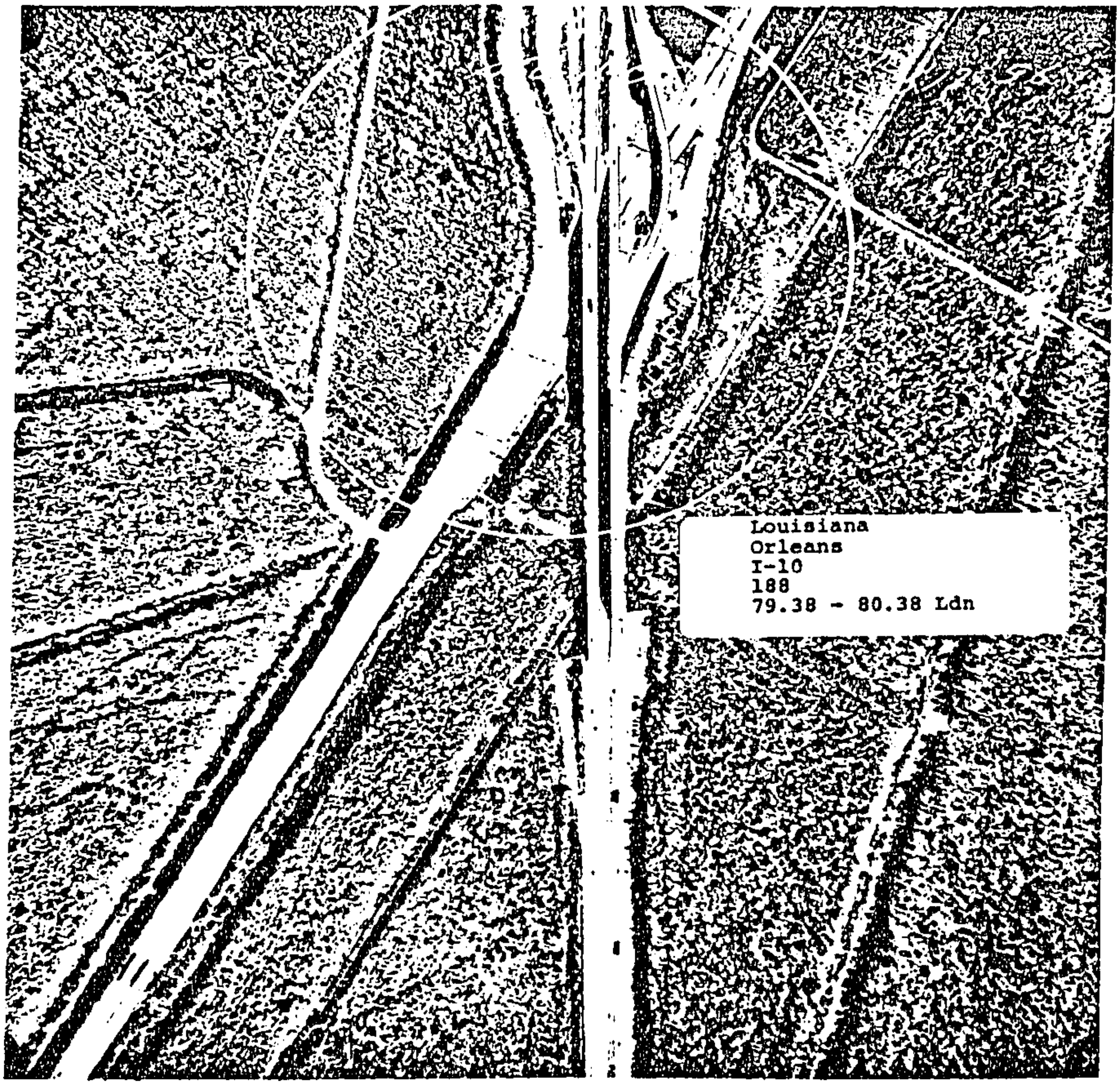

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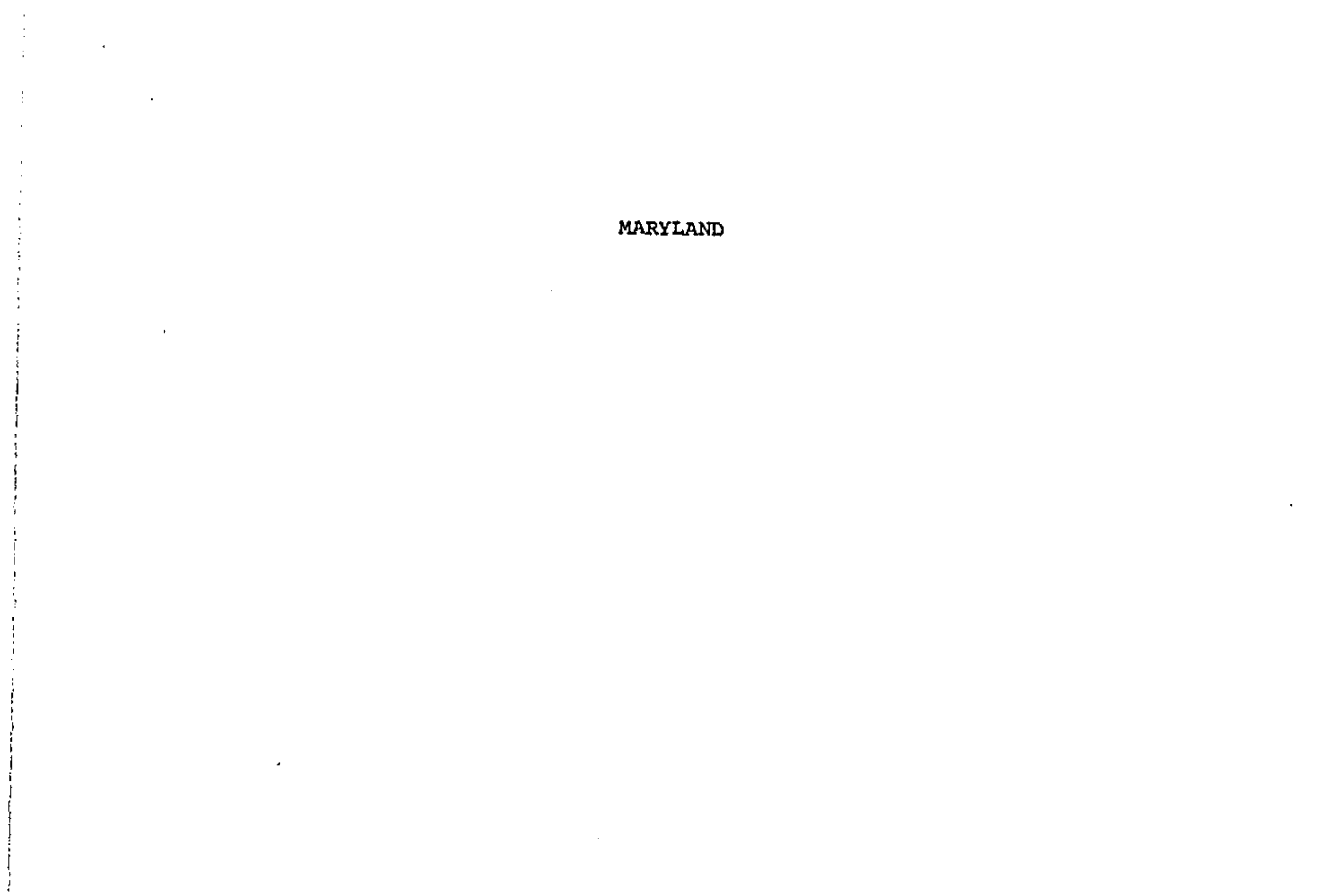

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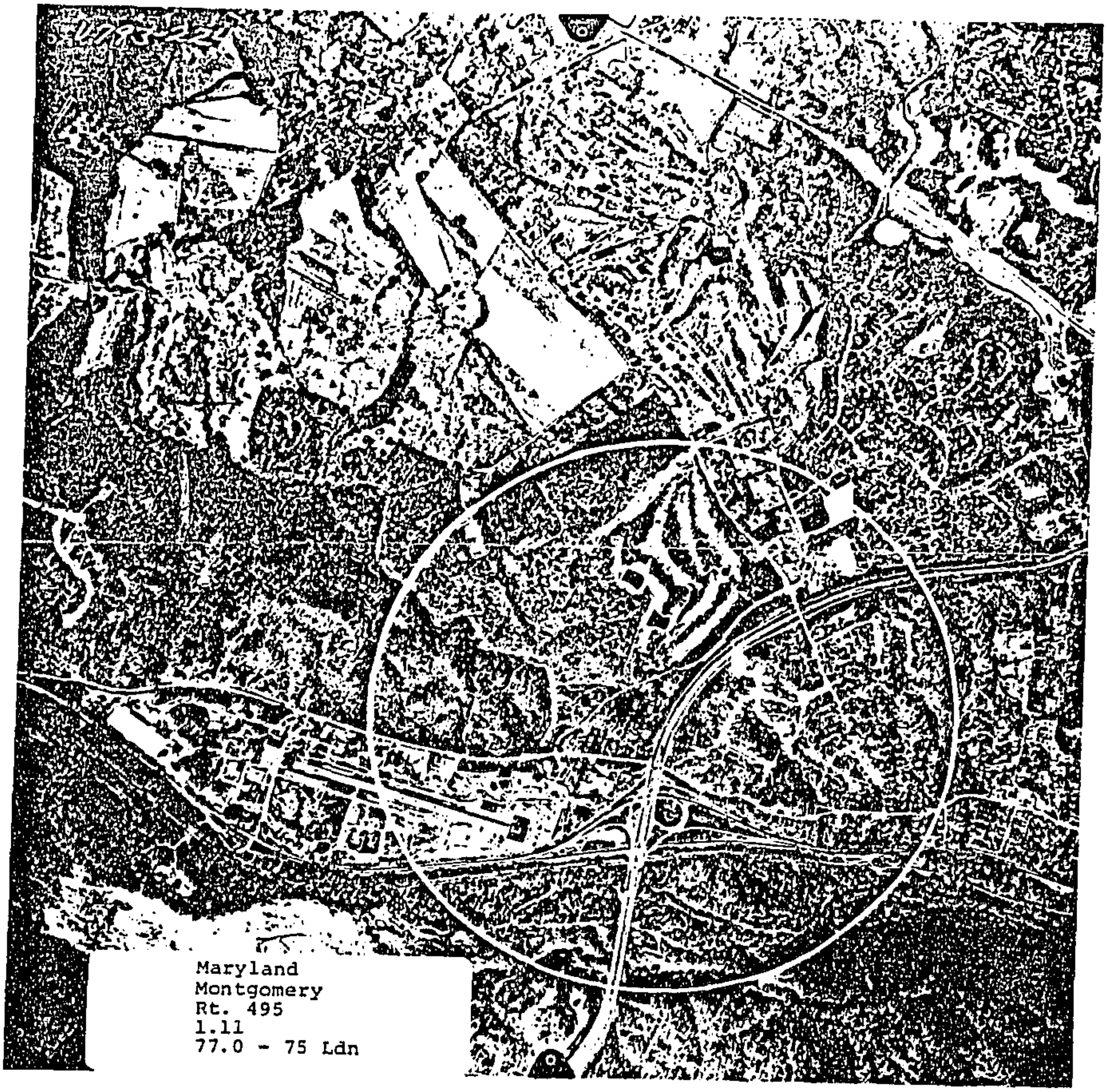

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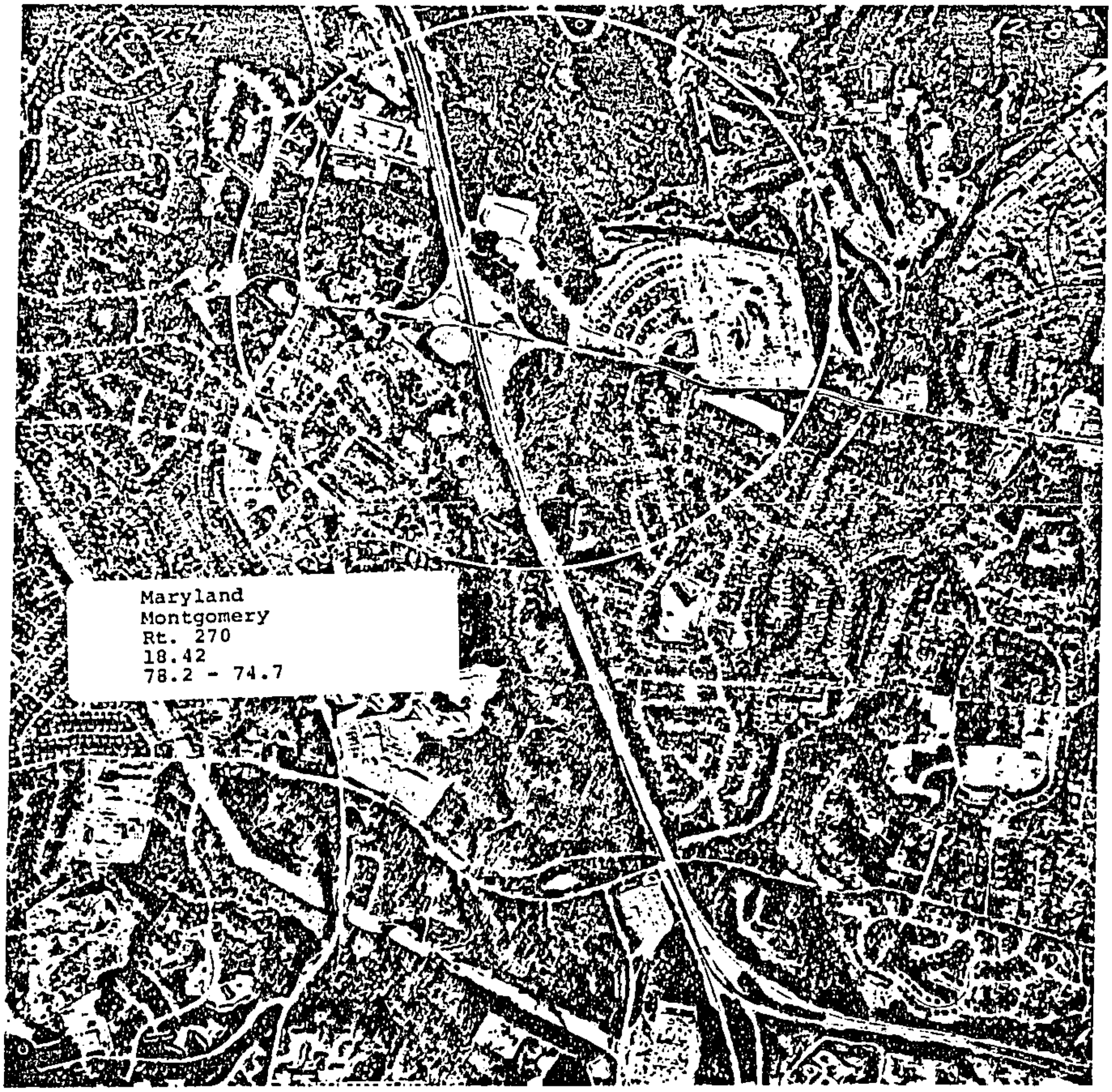

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OHIO

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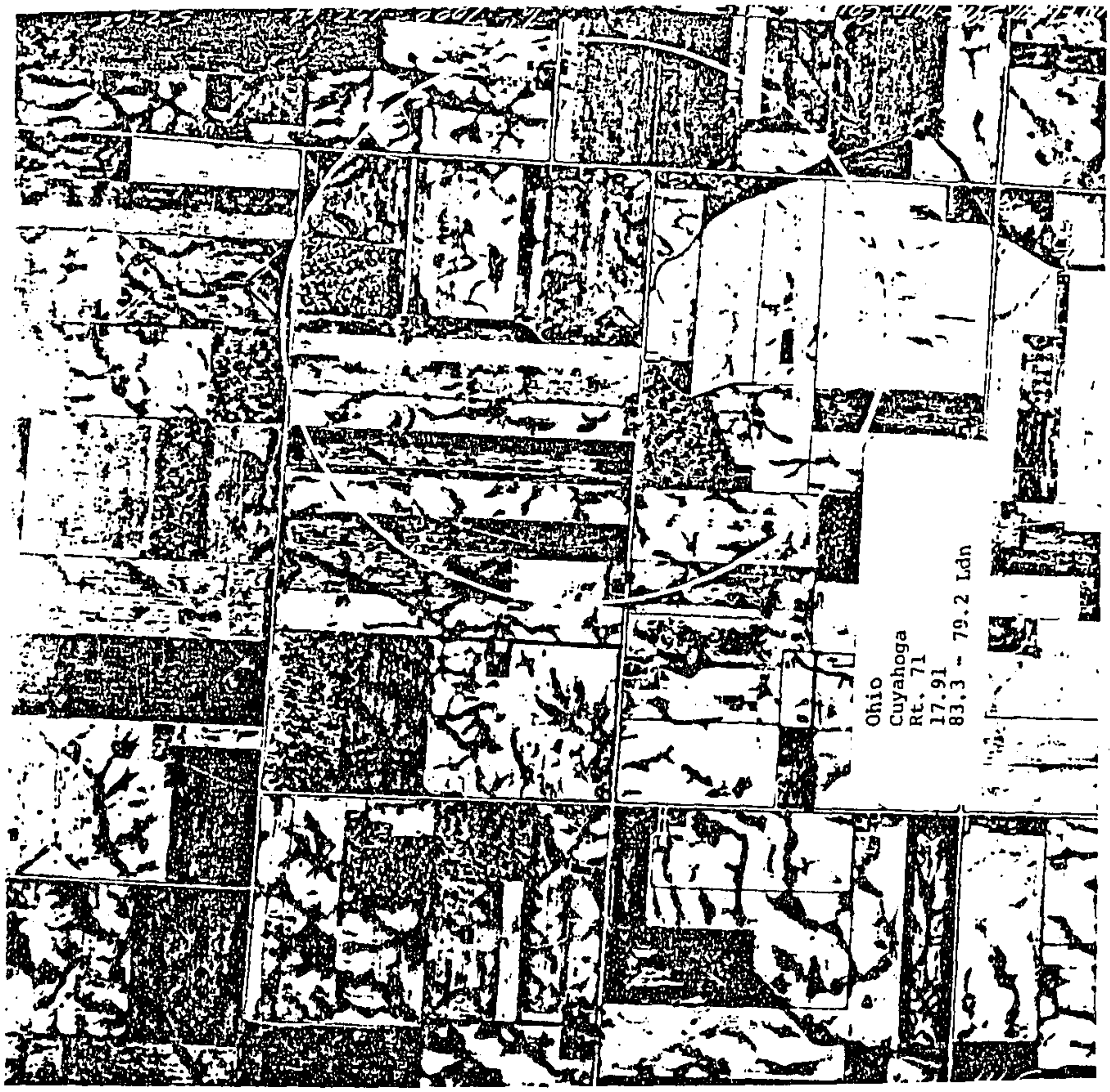

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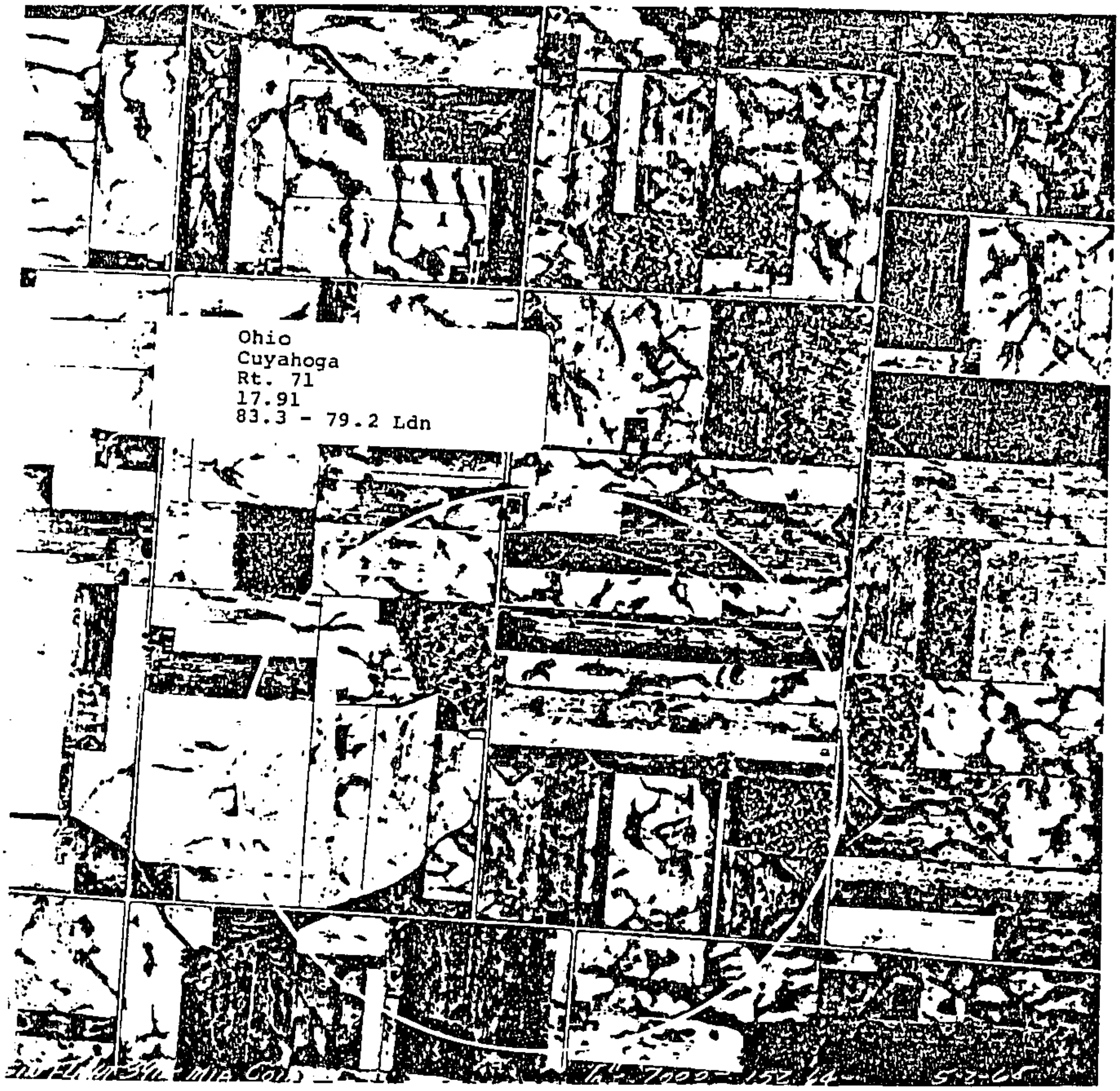

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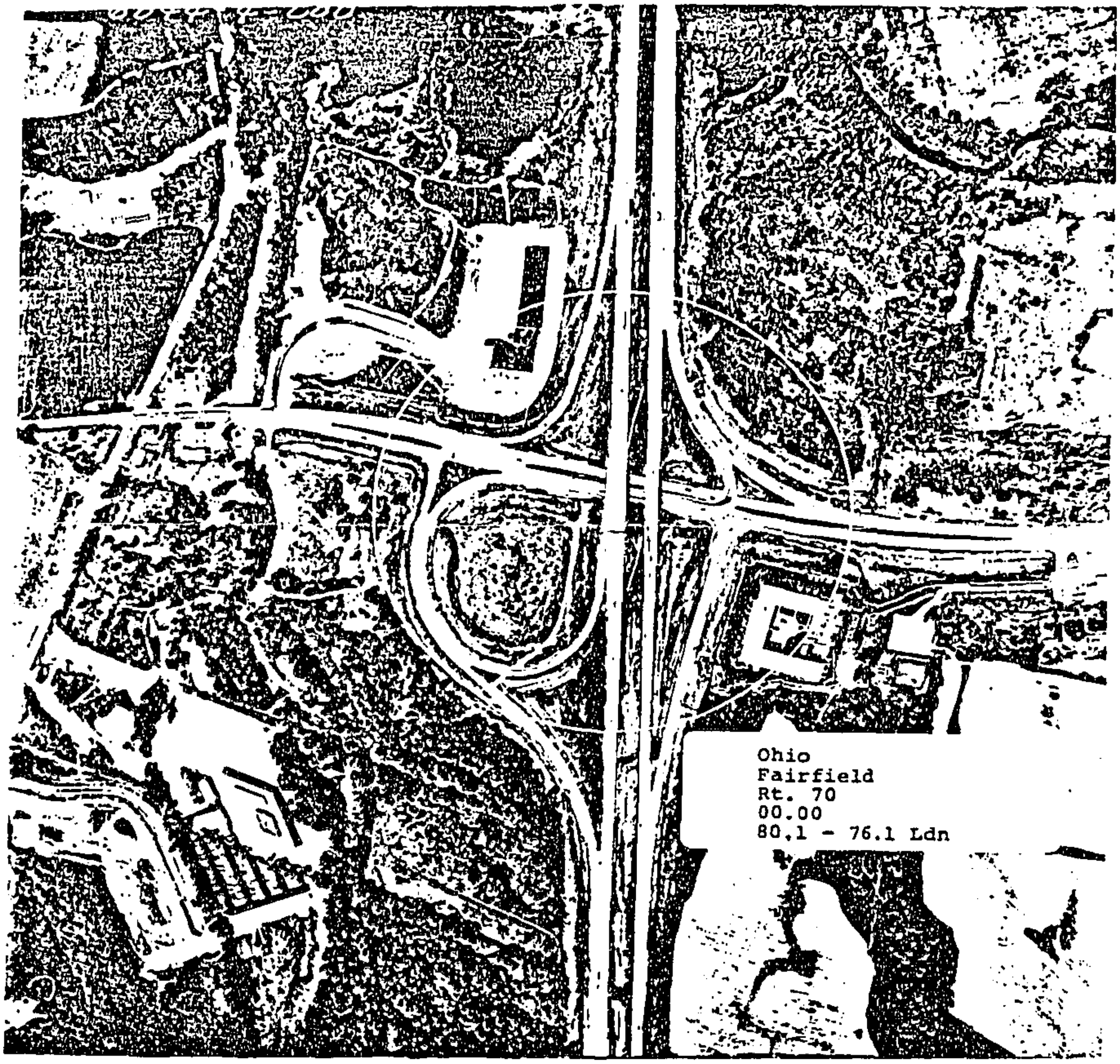

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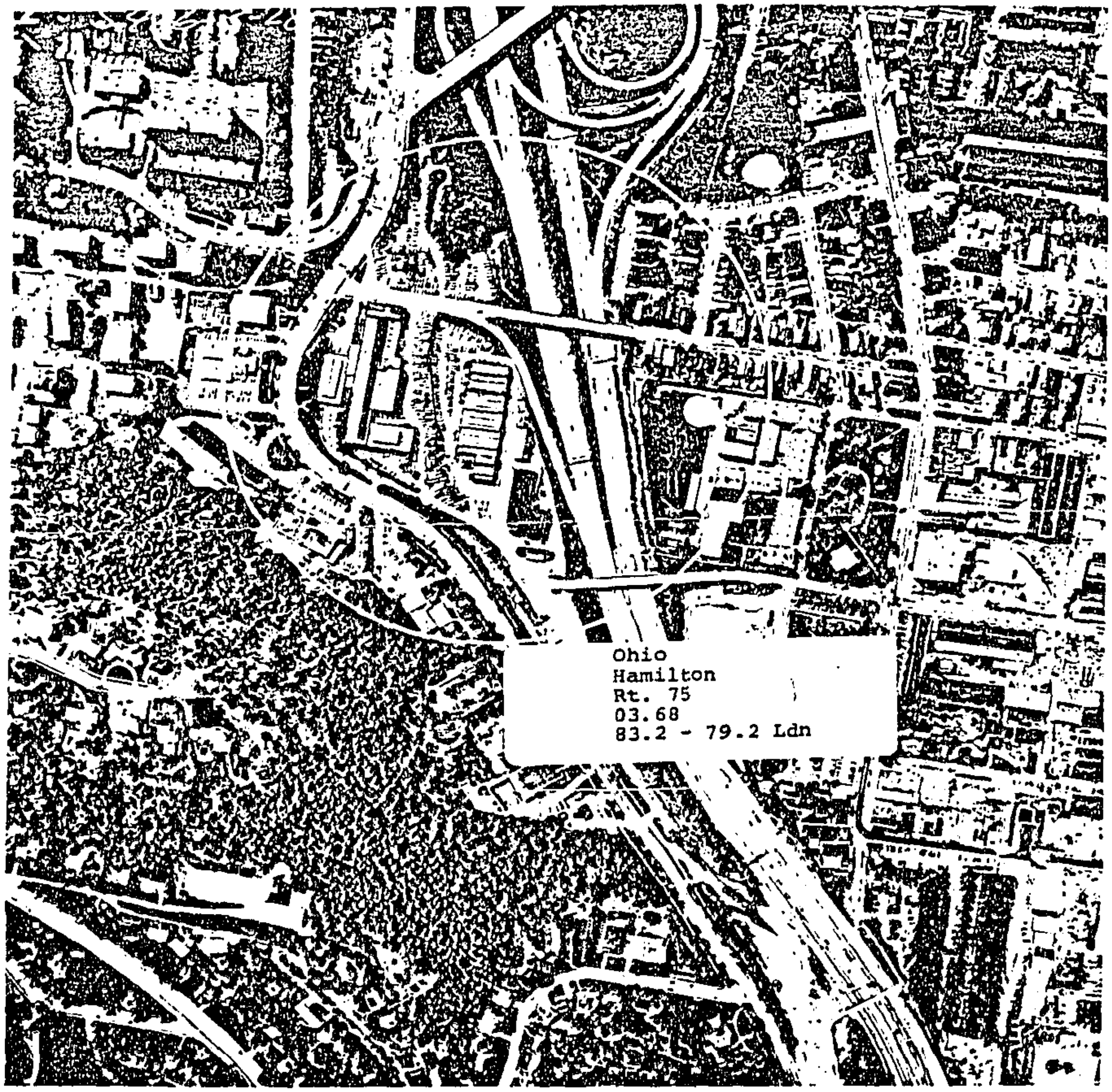

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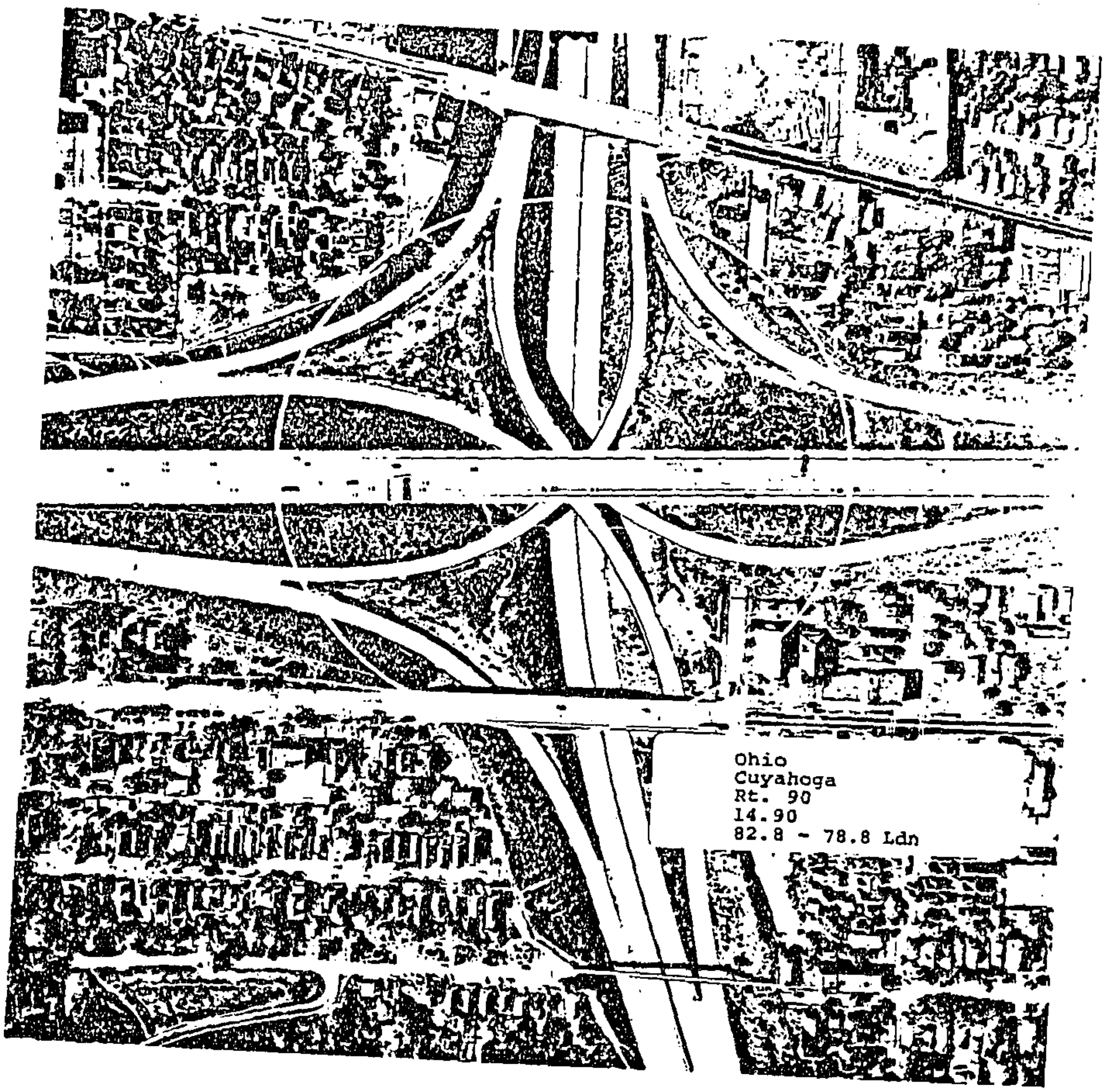

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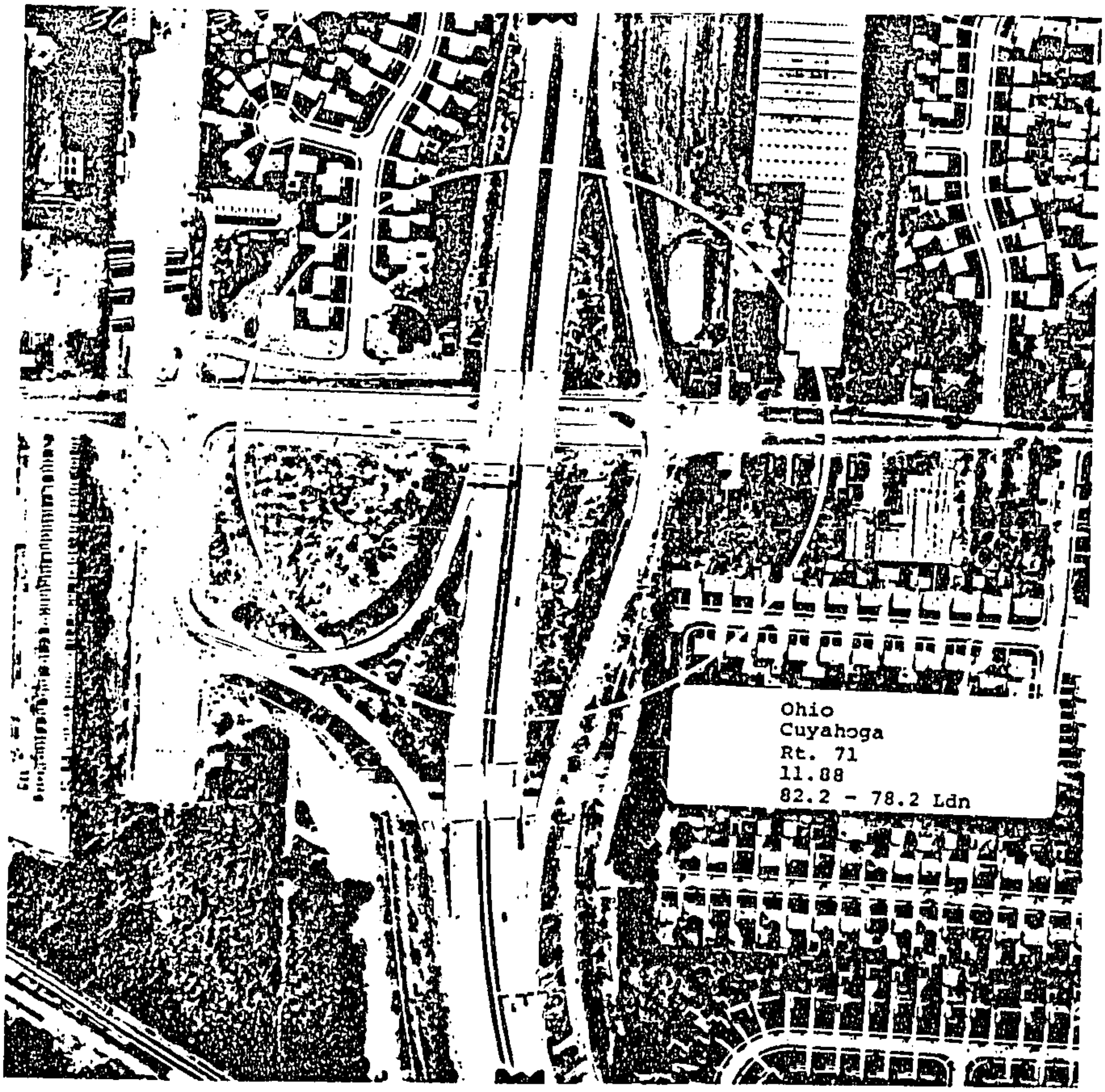

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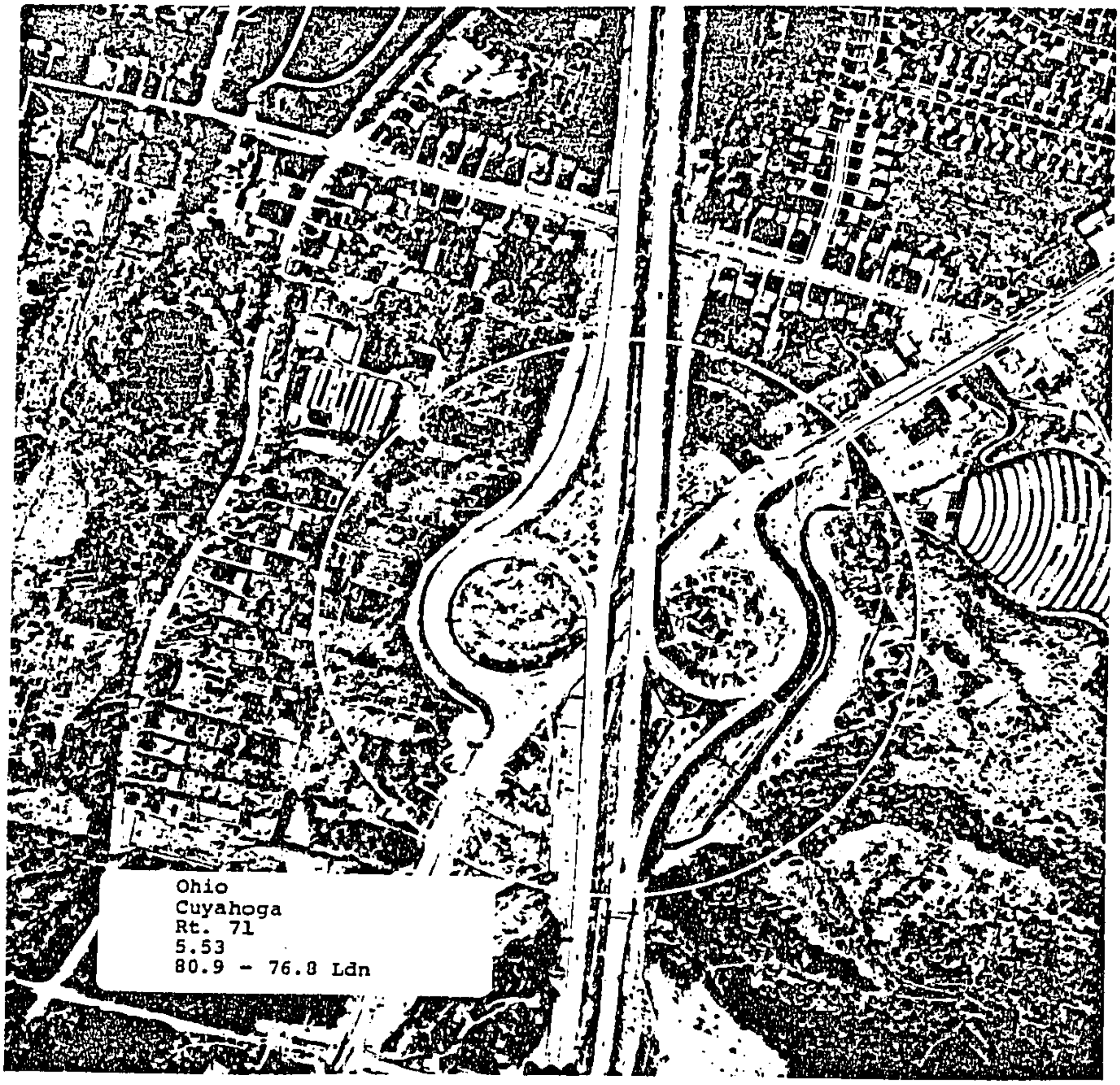

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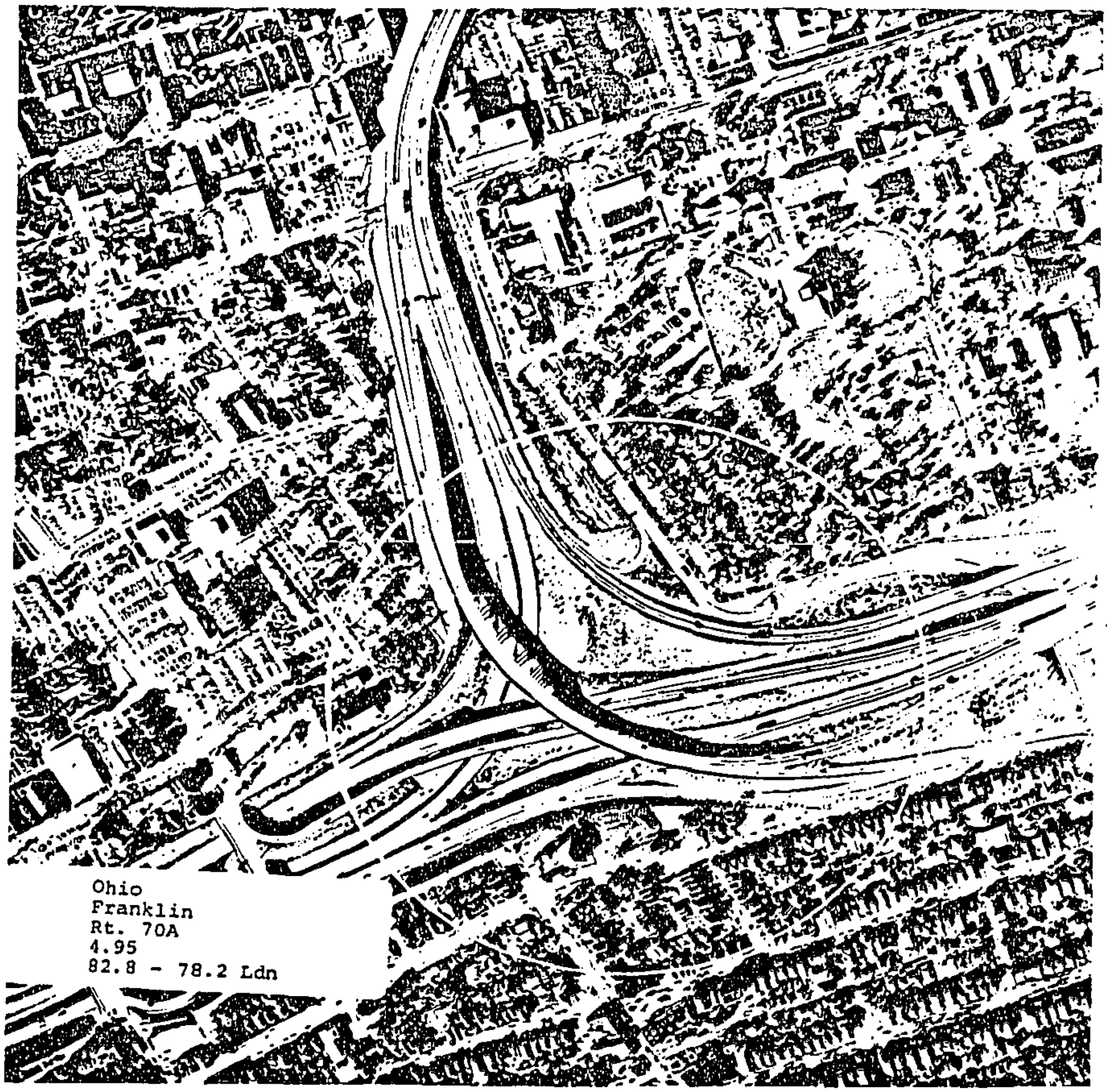

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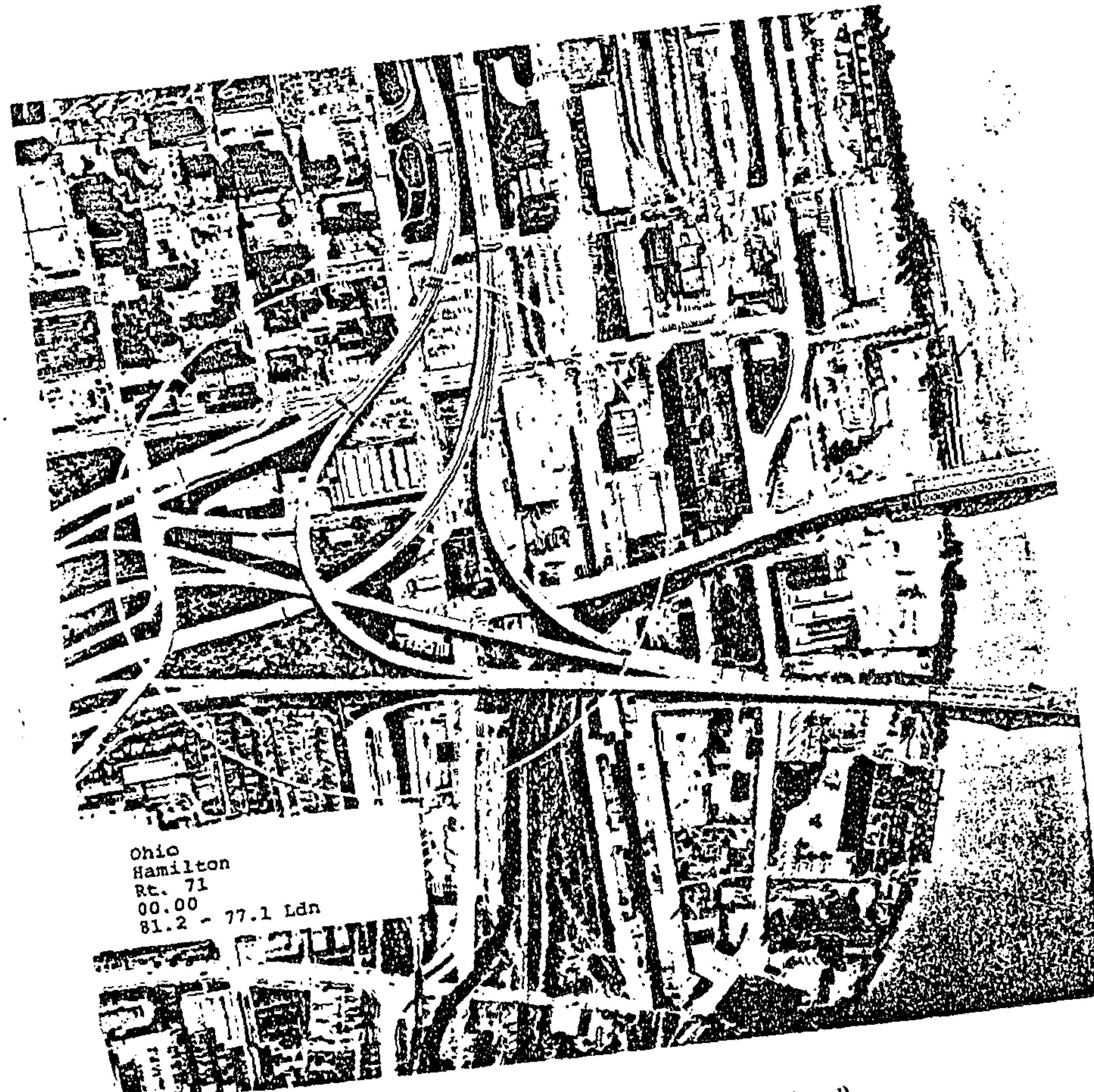

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OREGON

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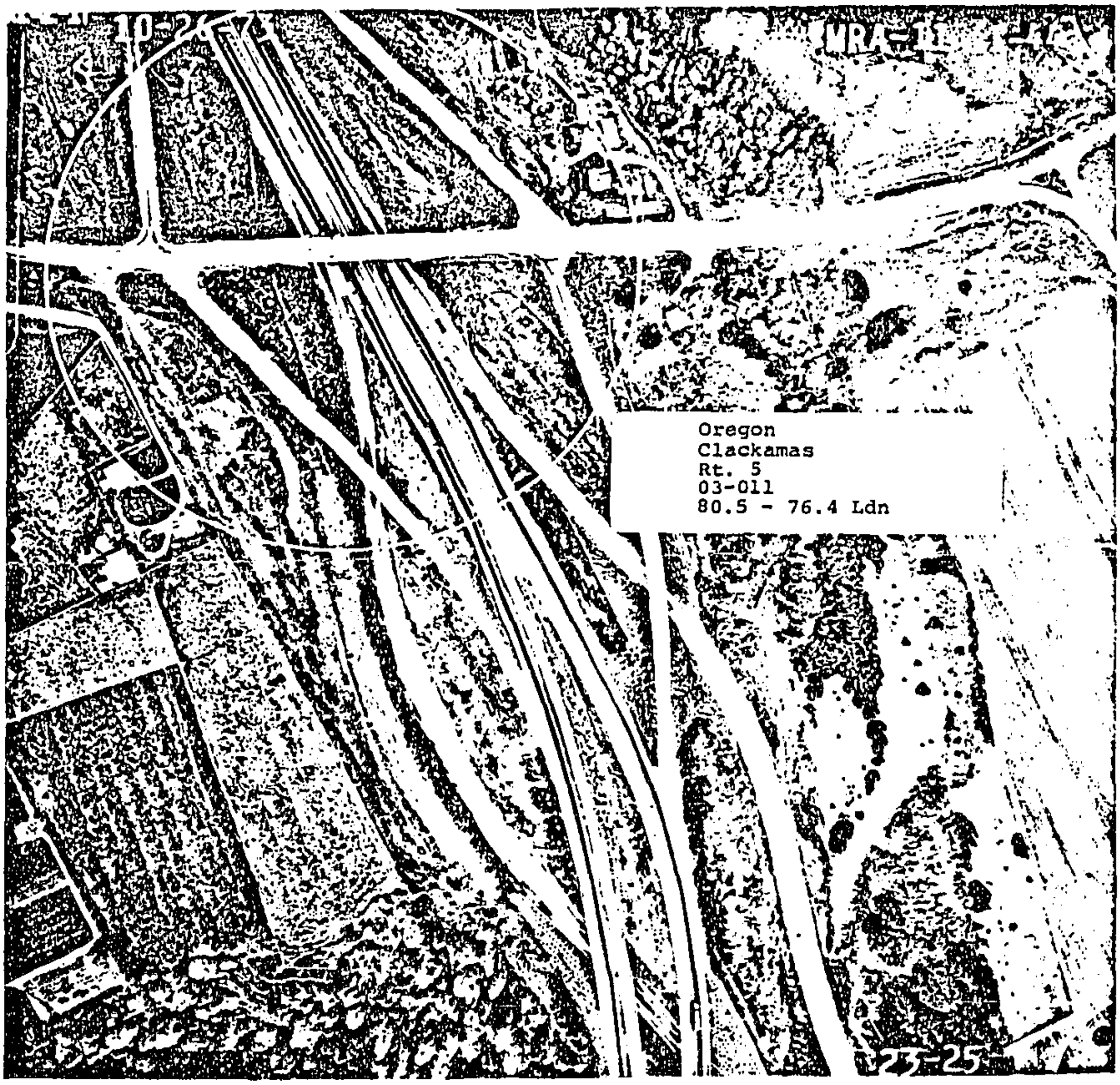

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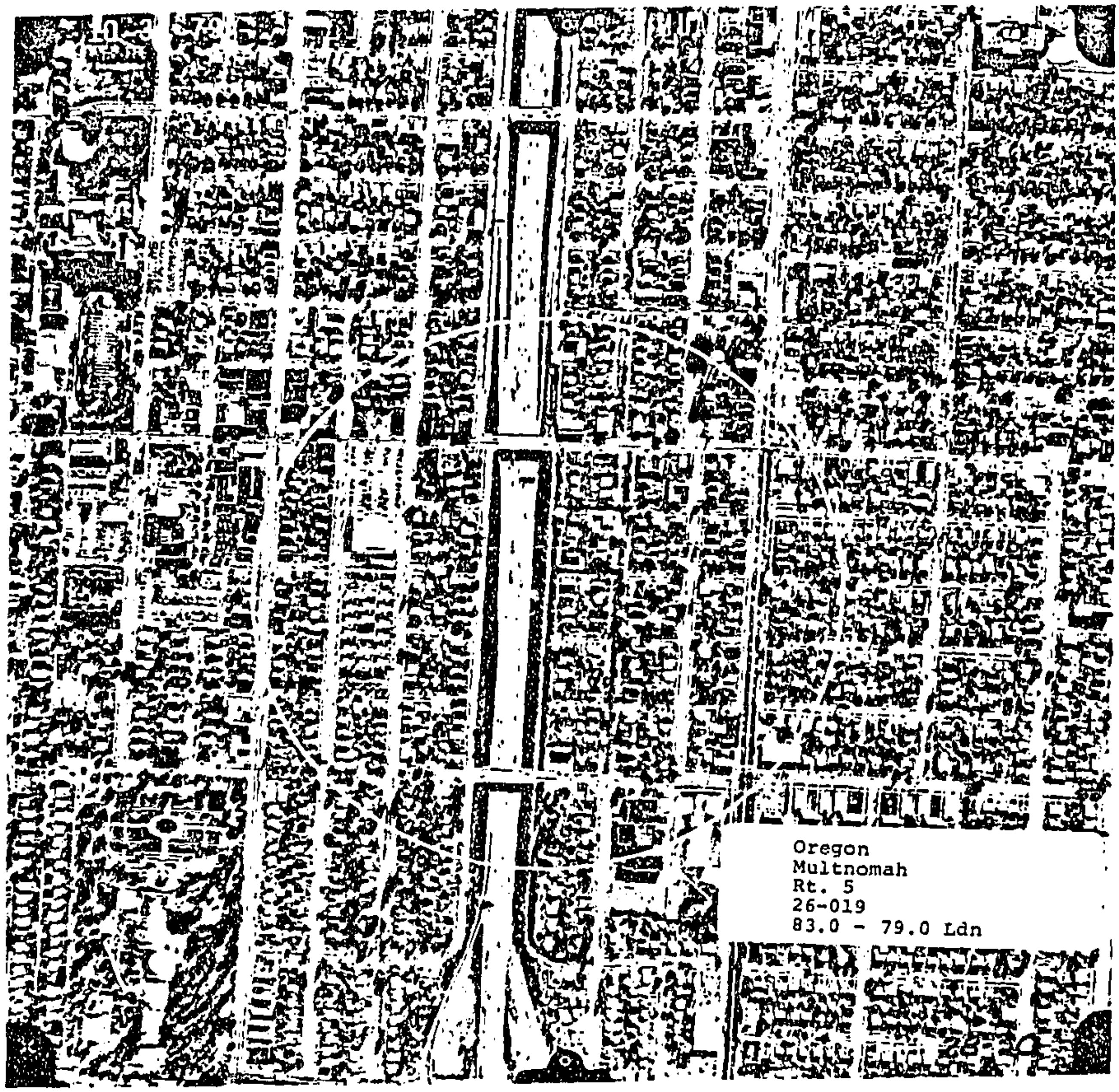

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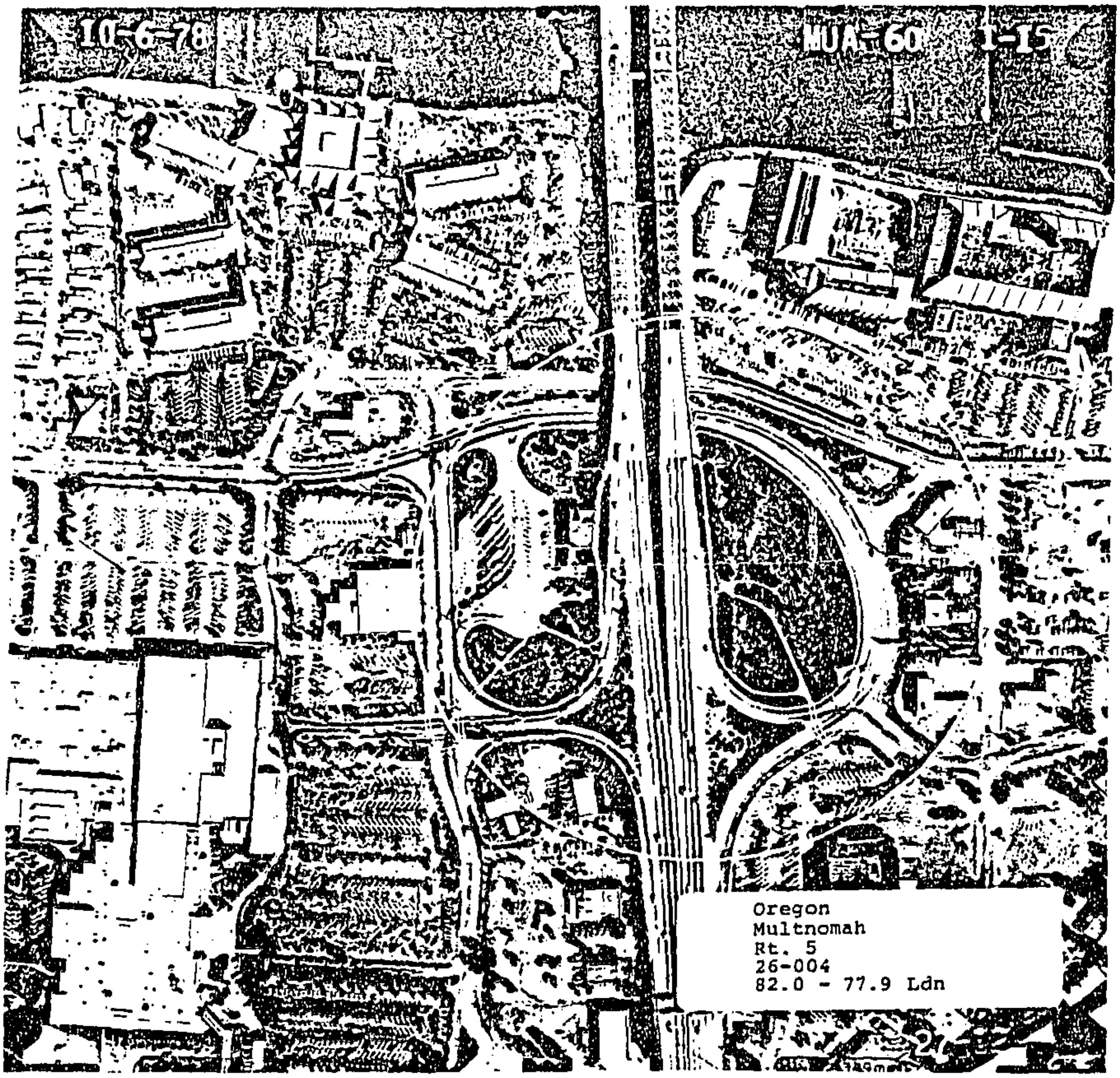

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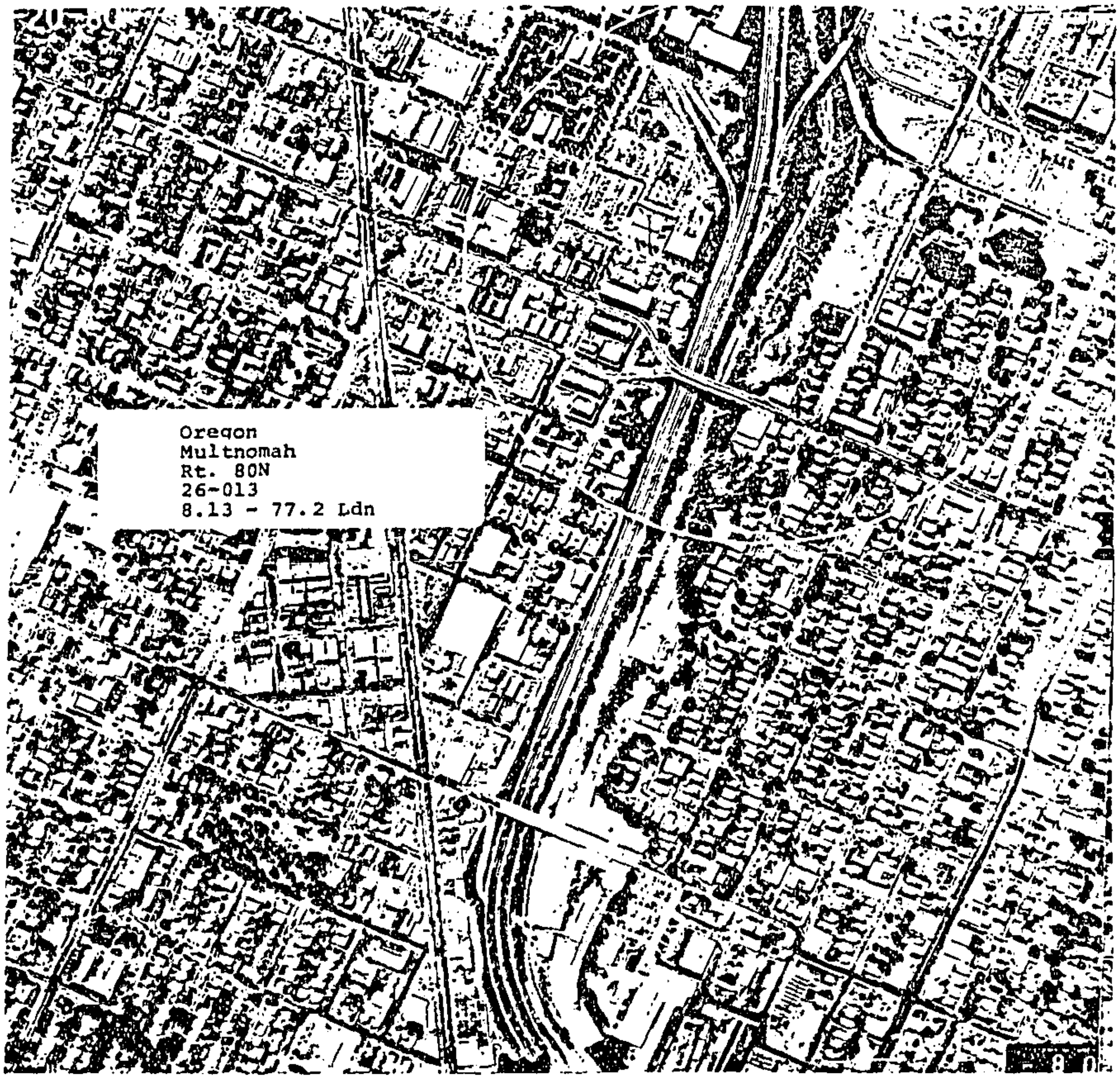

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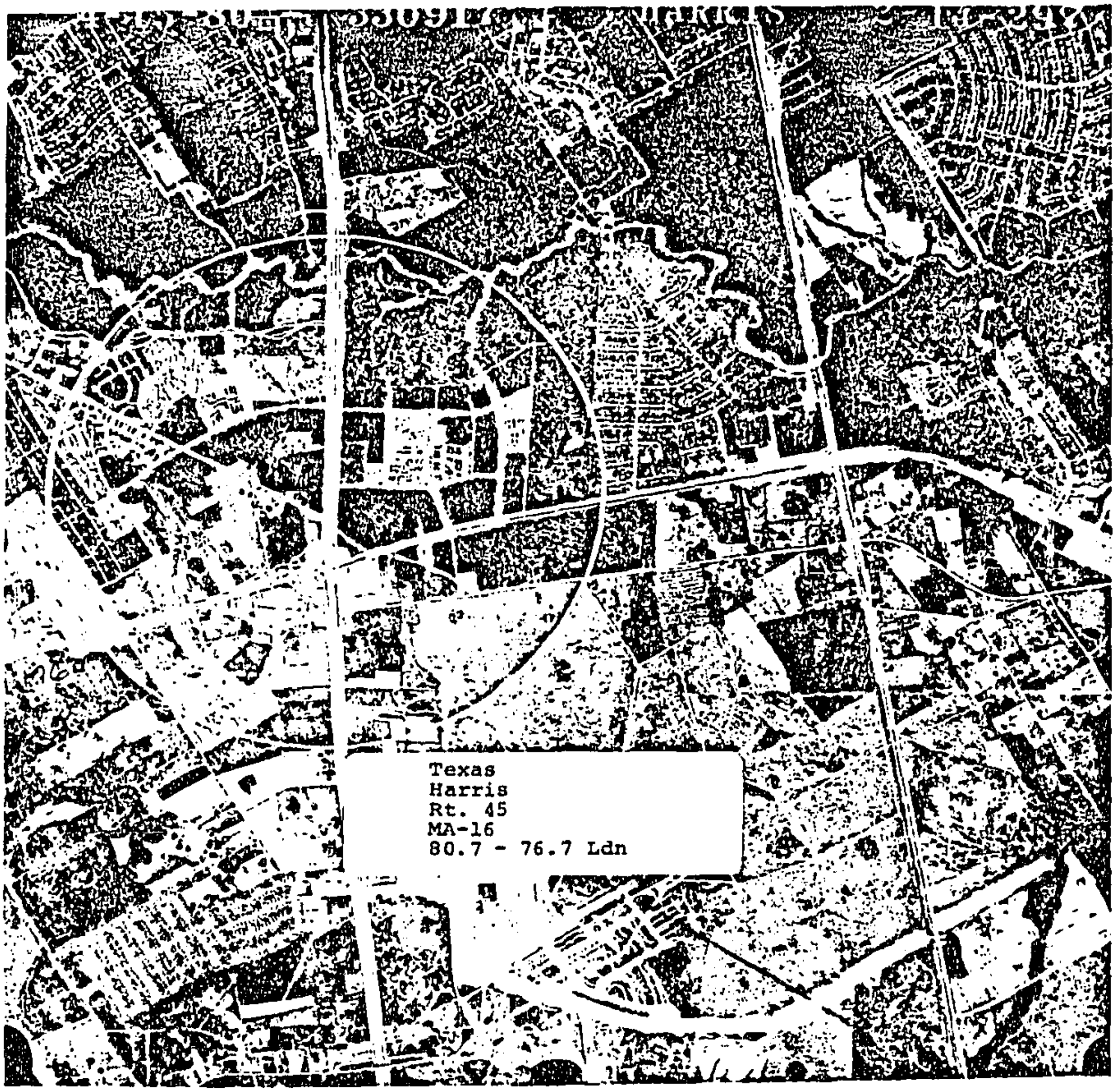

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WASHINGTON

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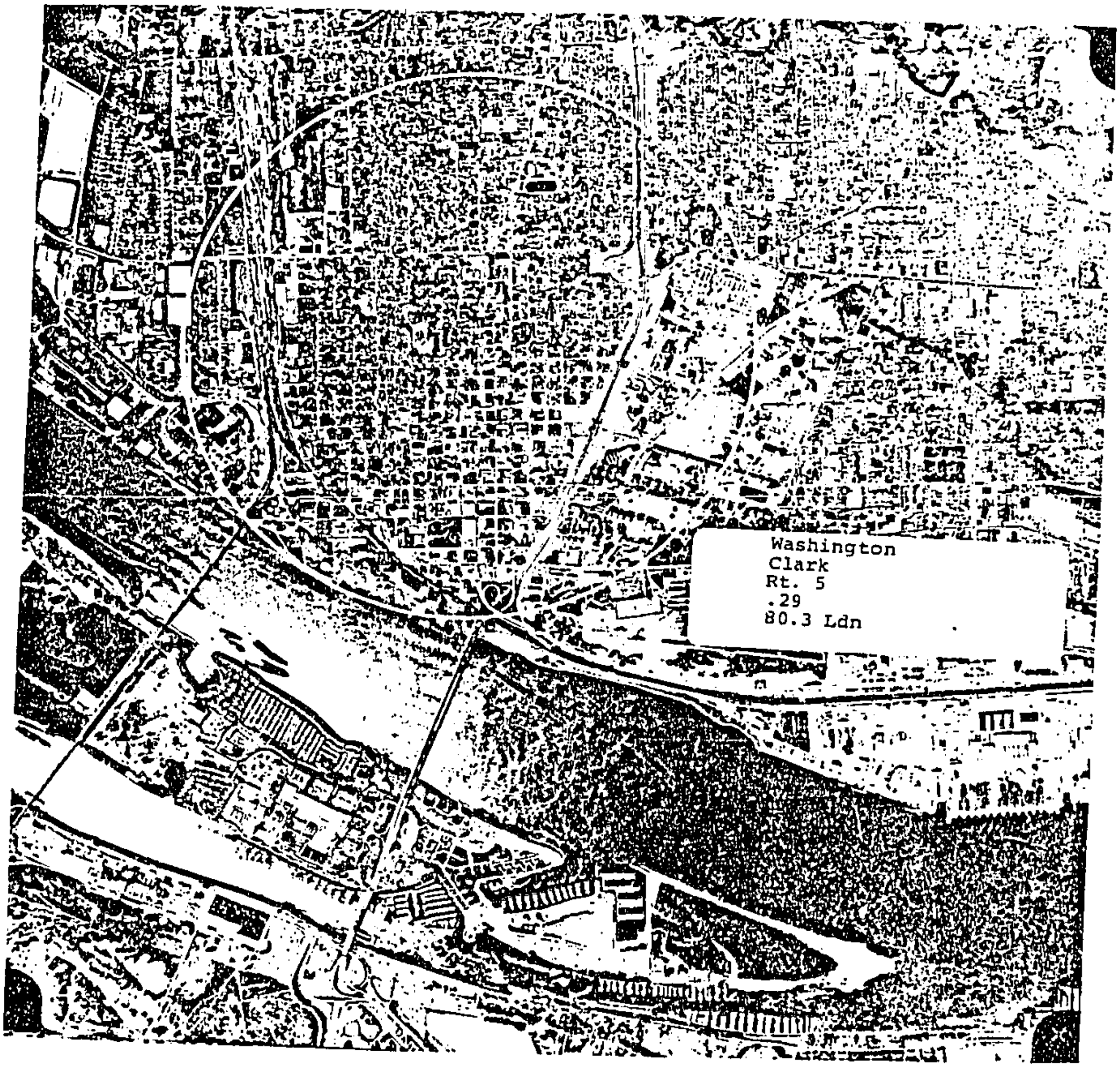

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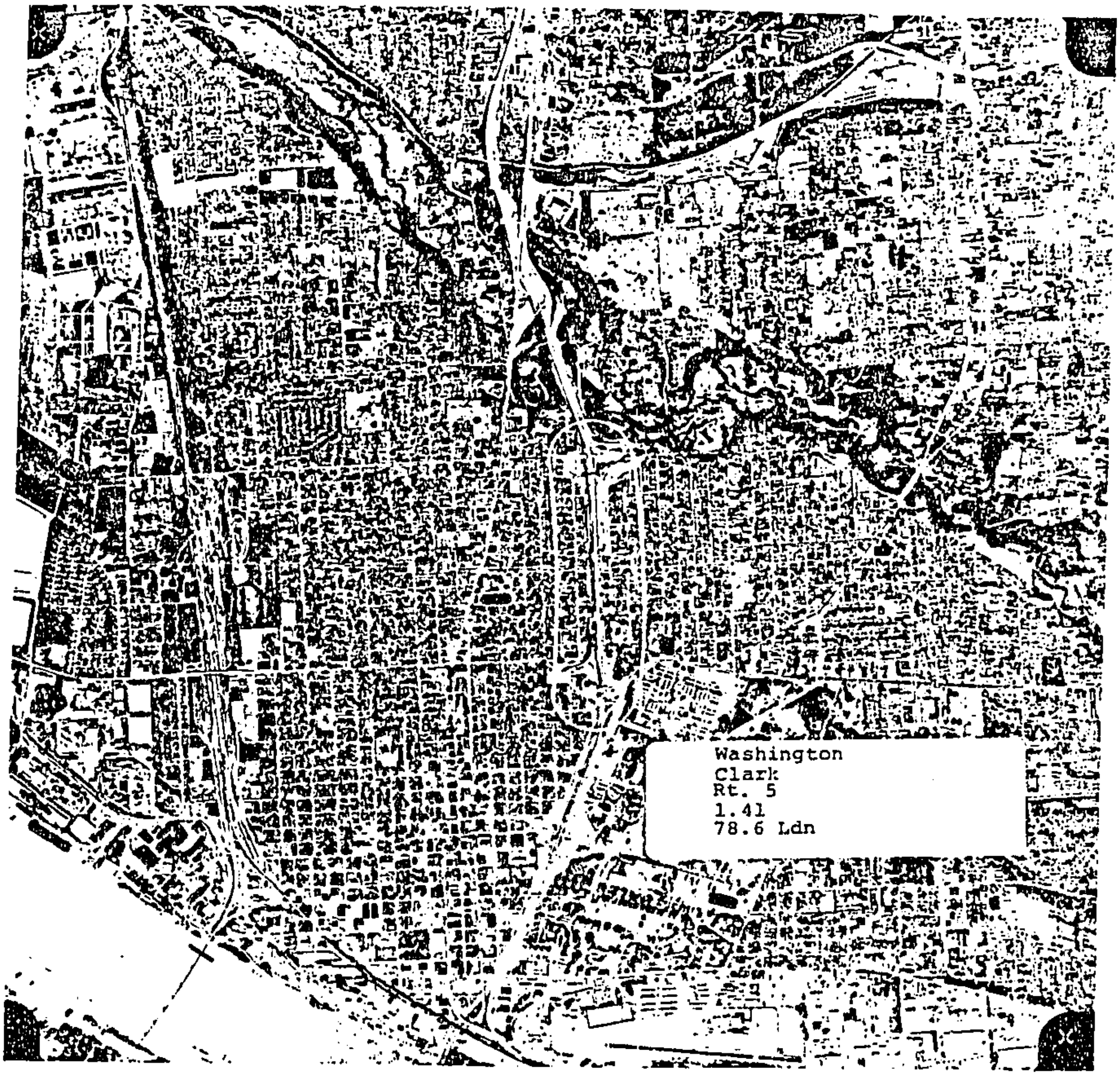

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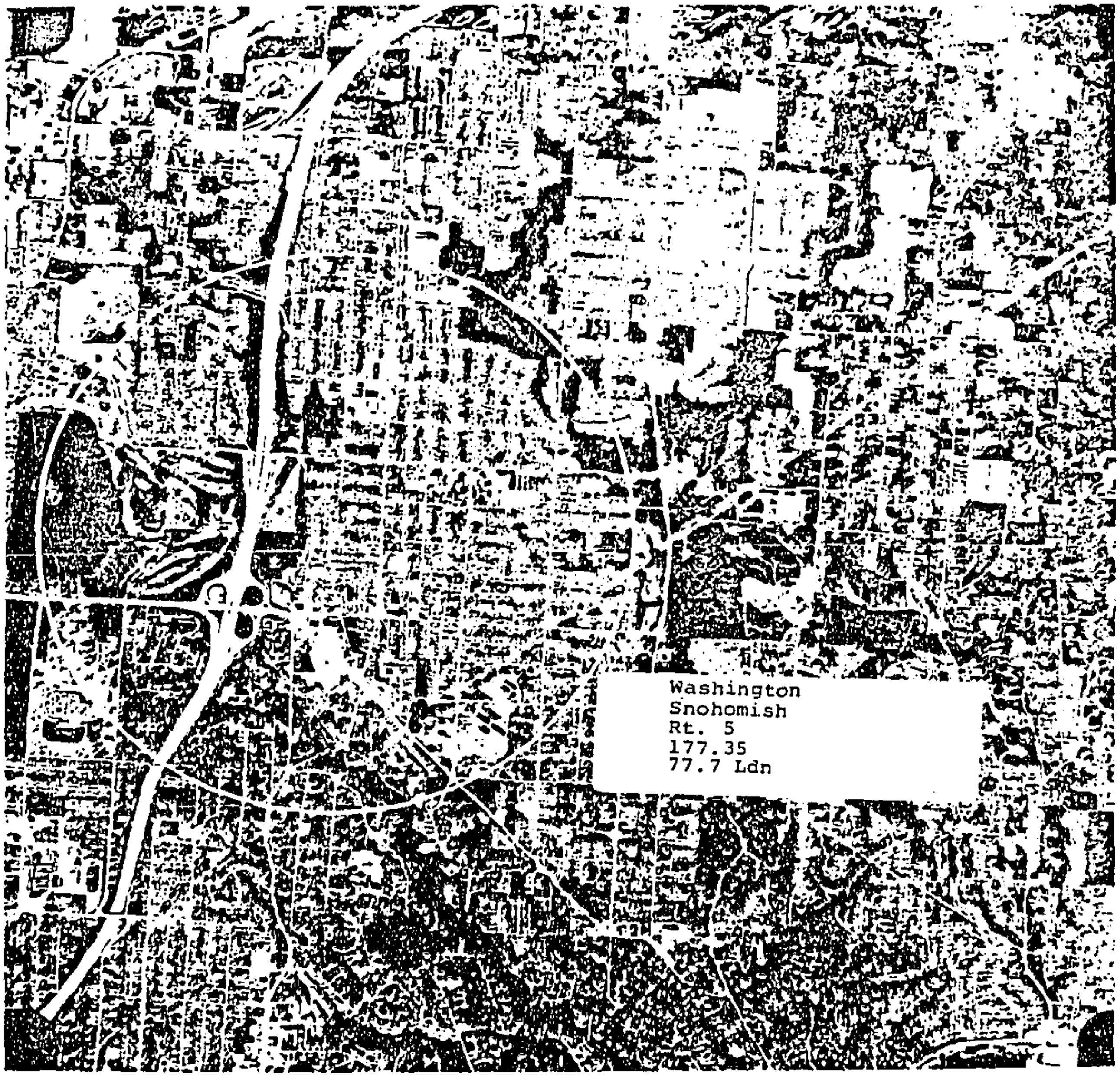

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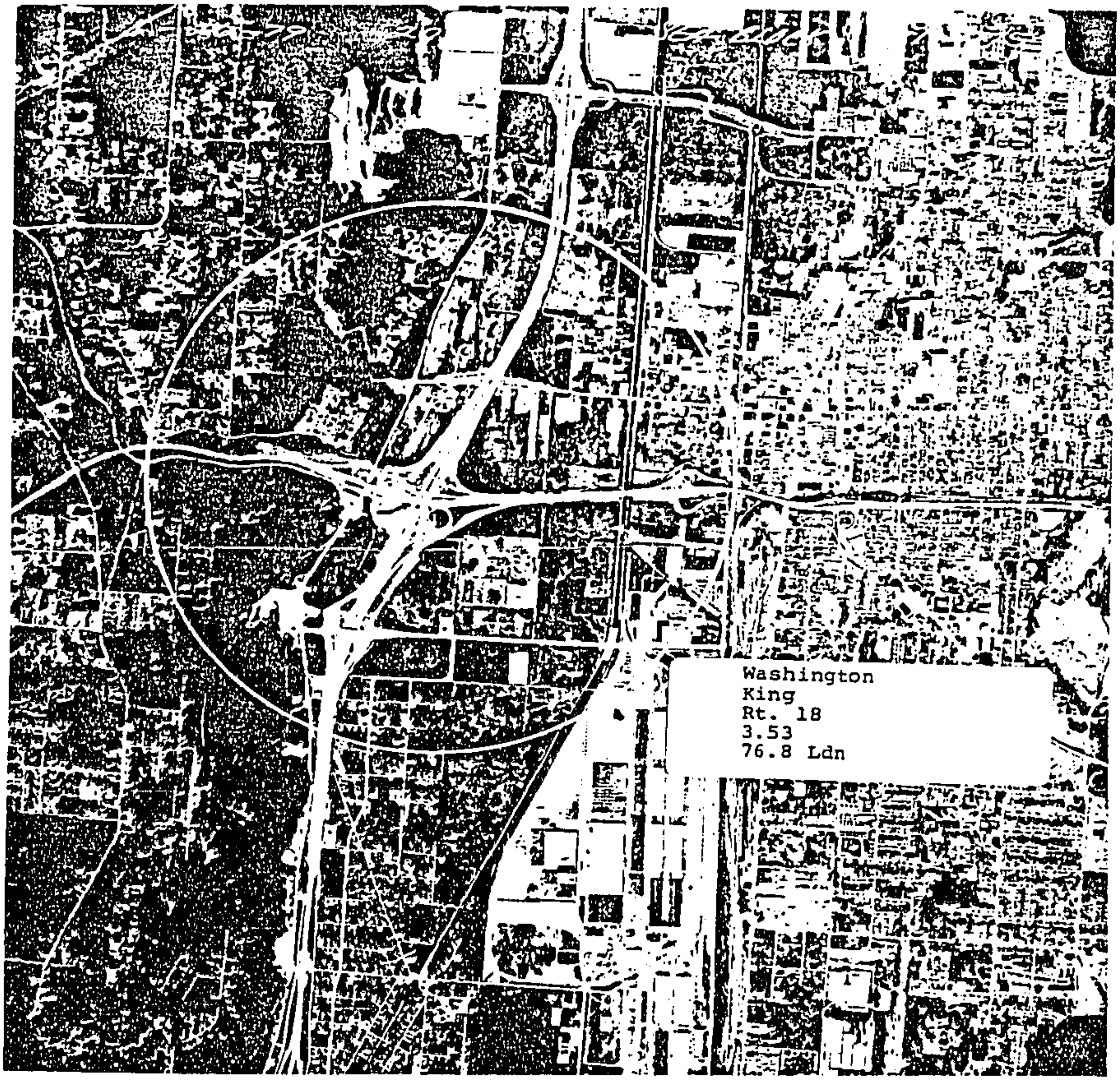

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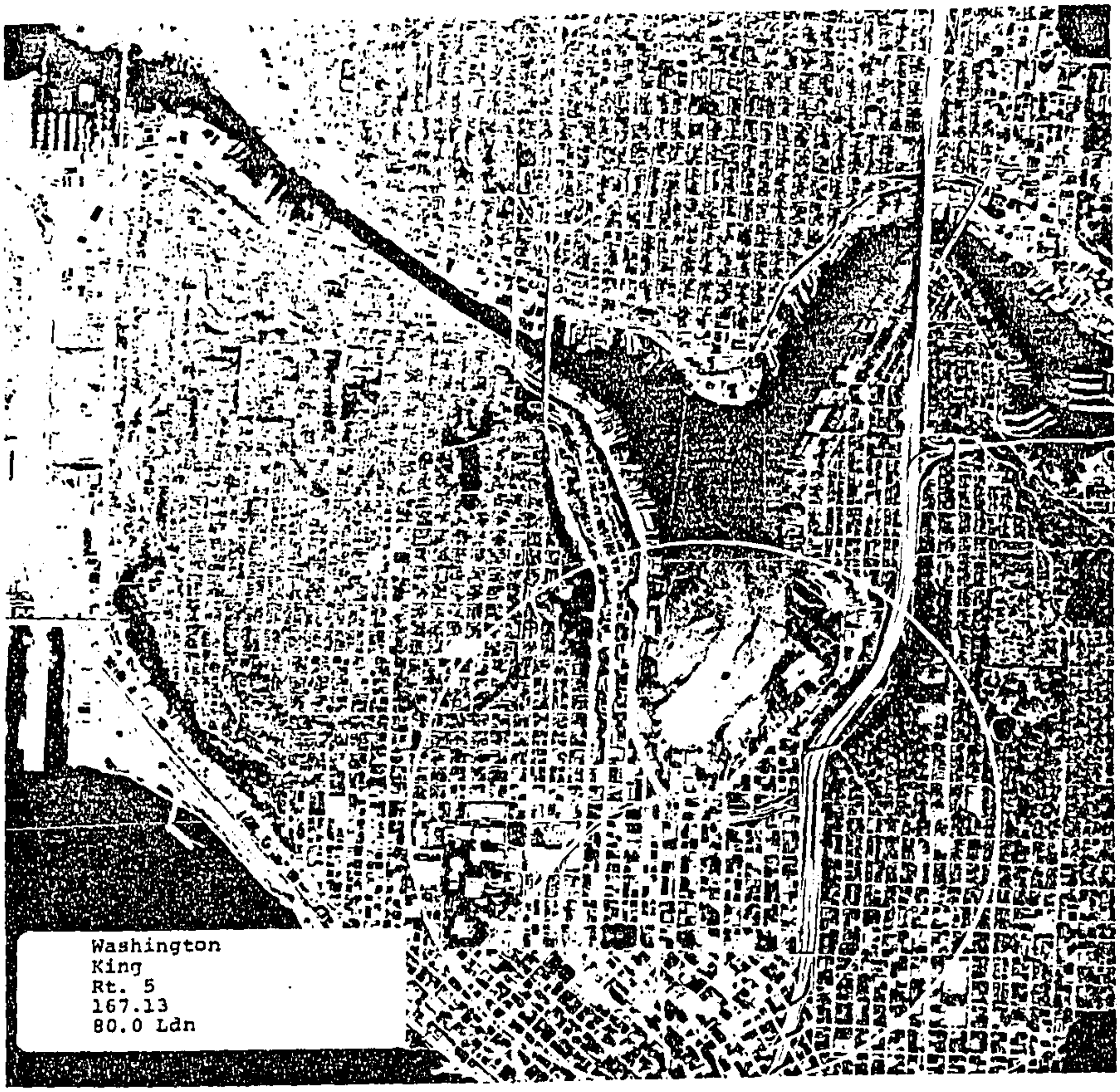

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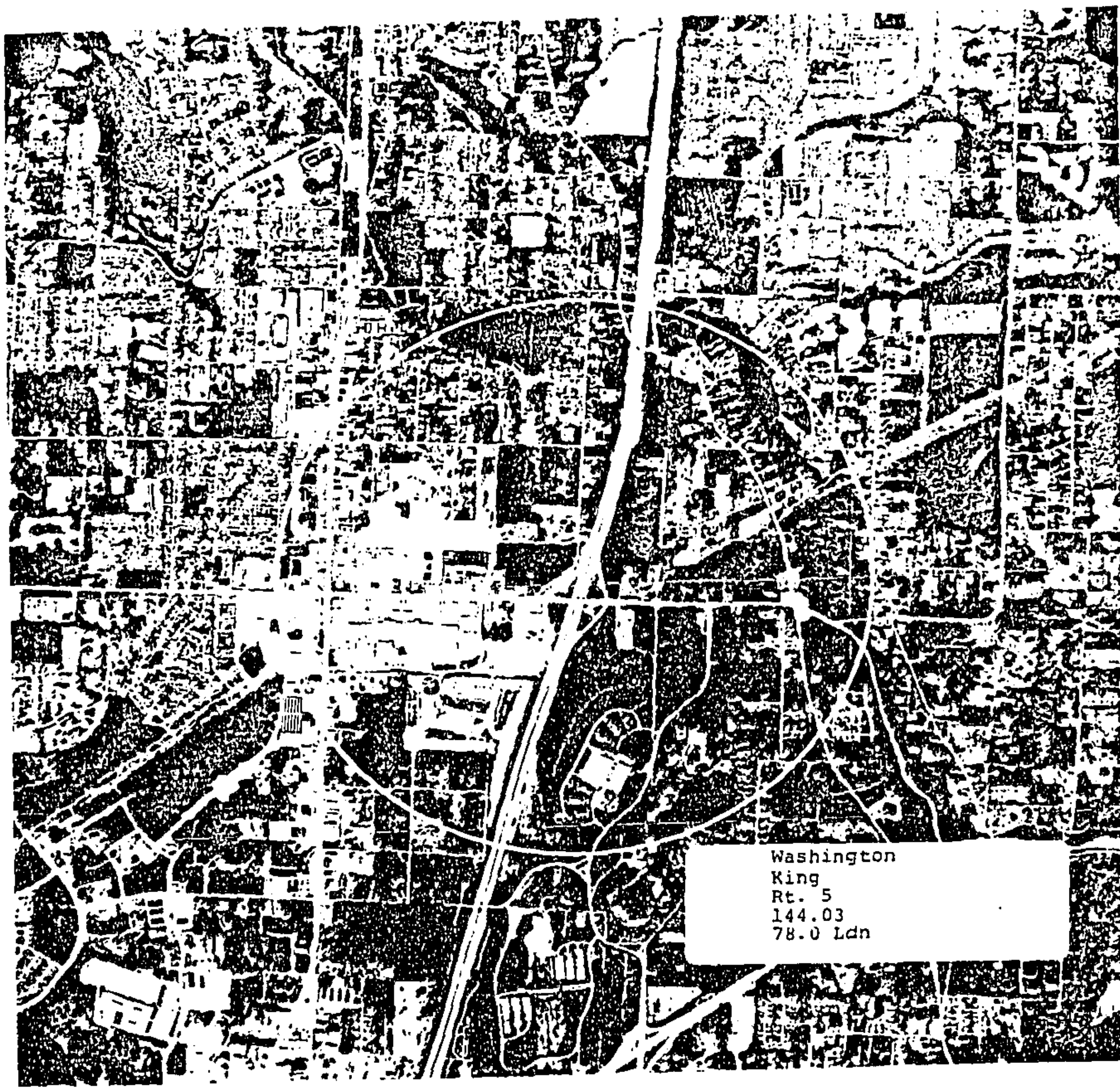

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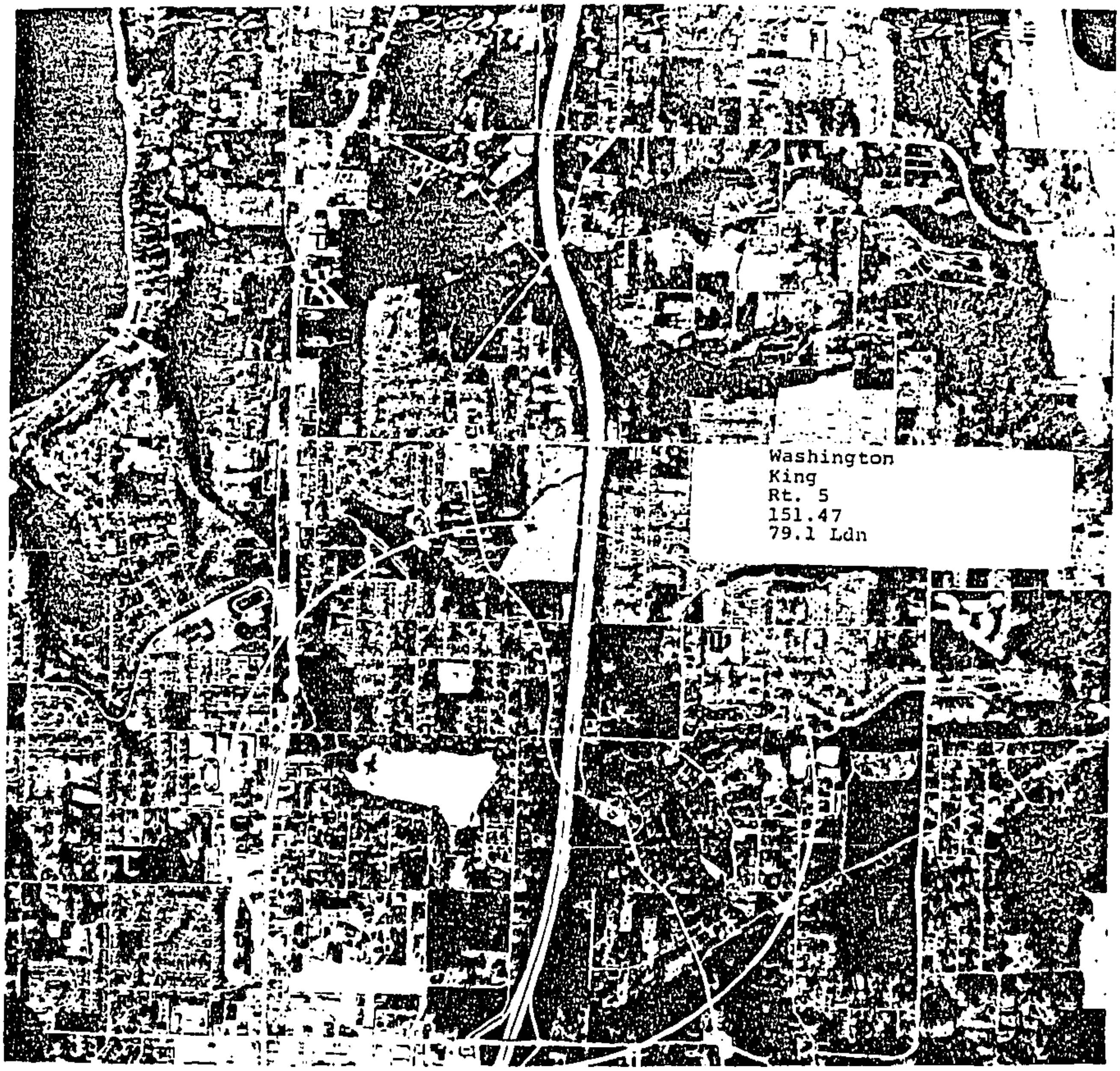

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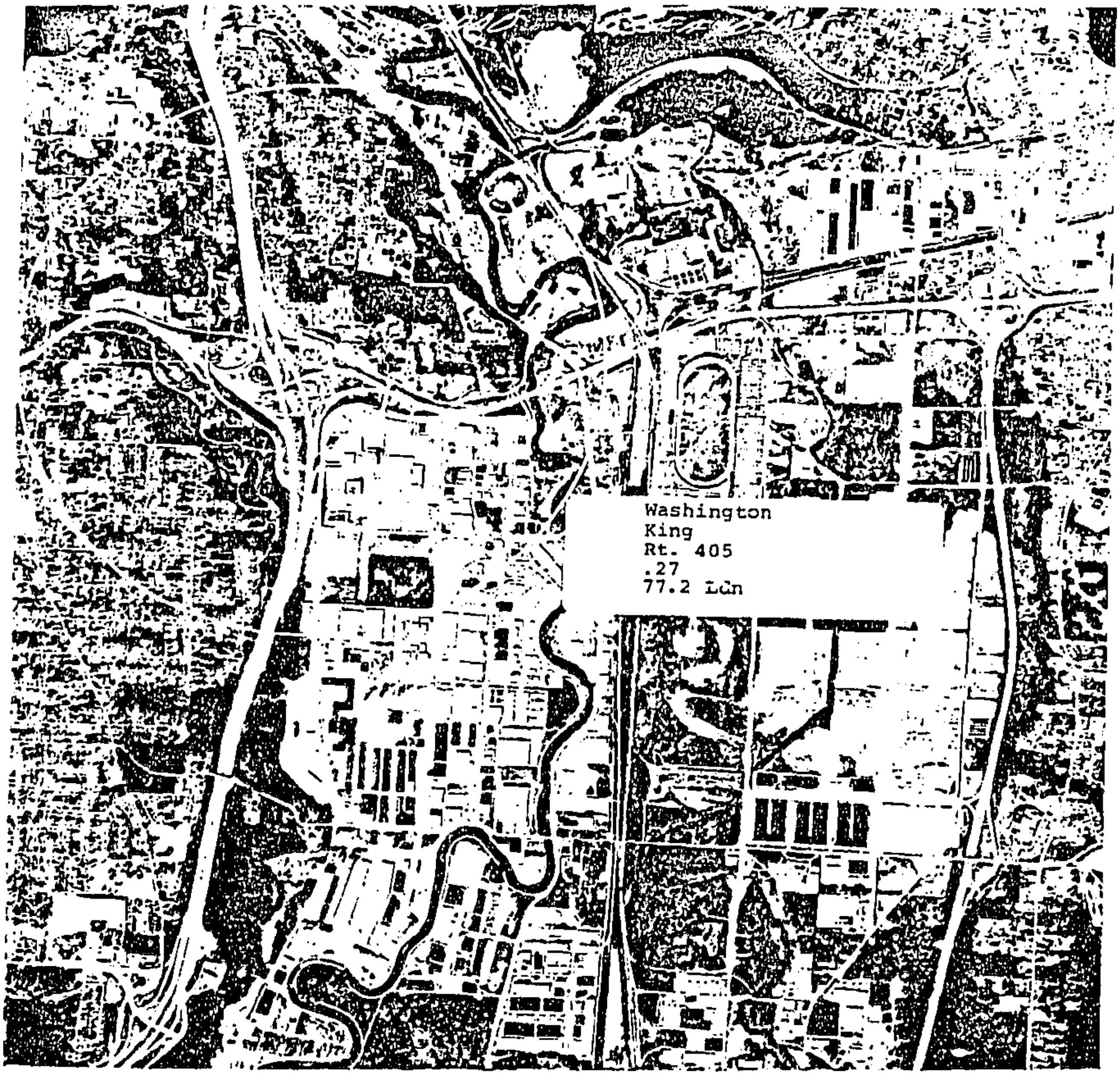

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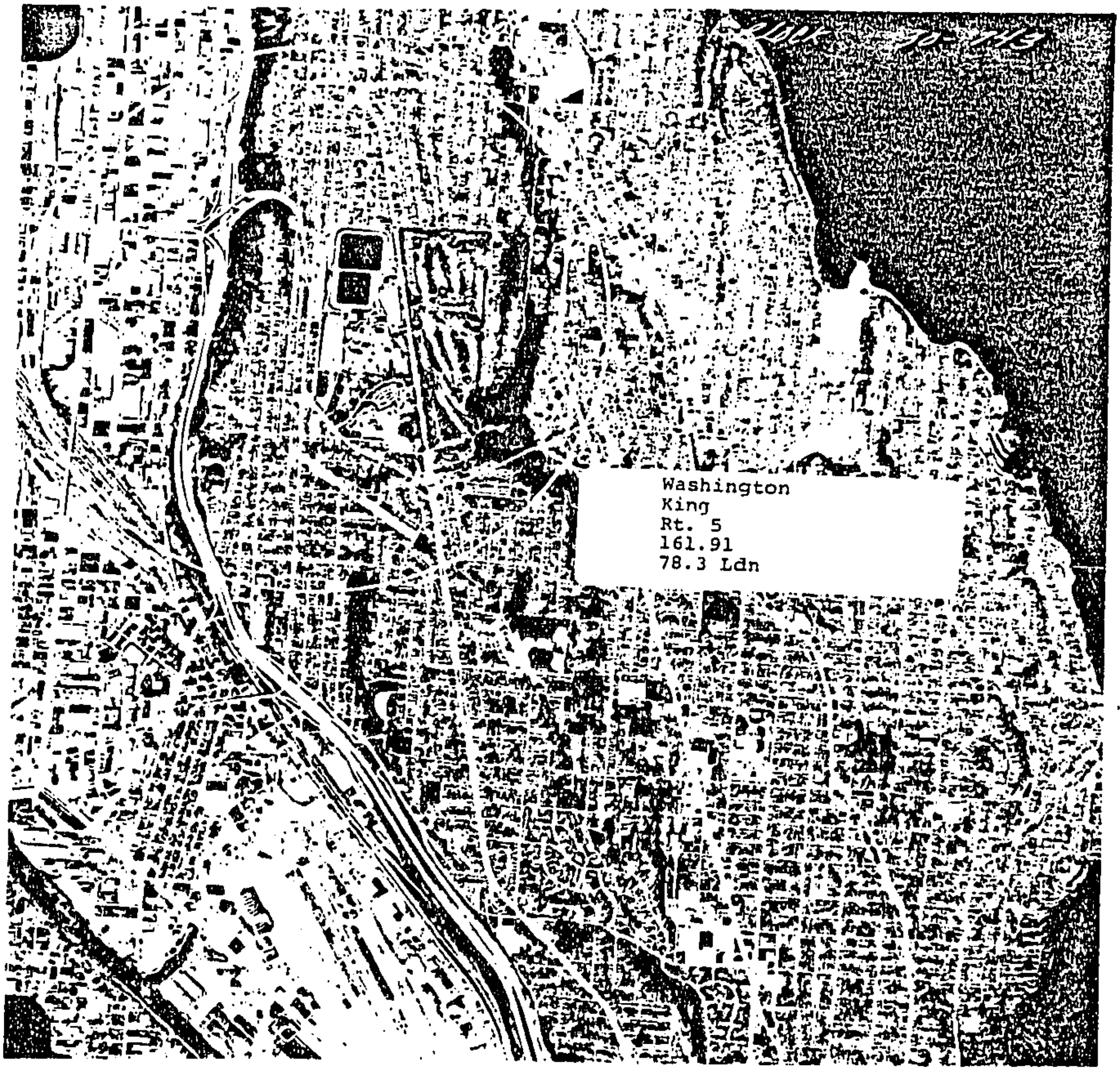

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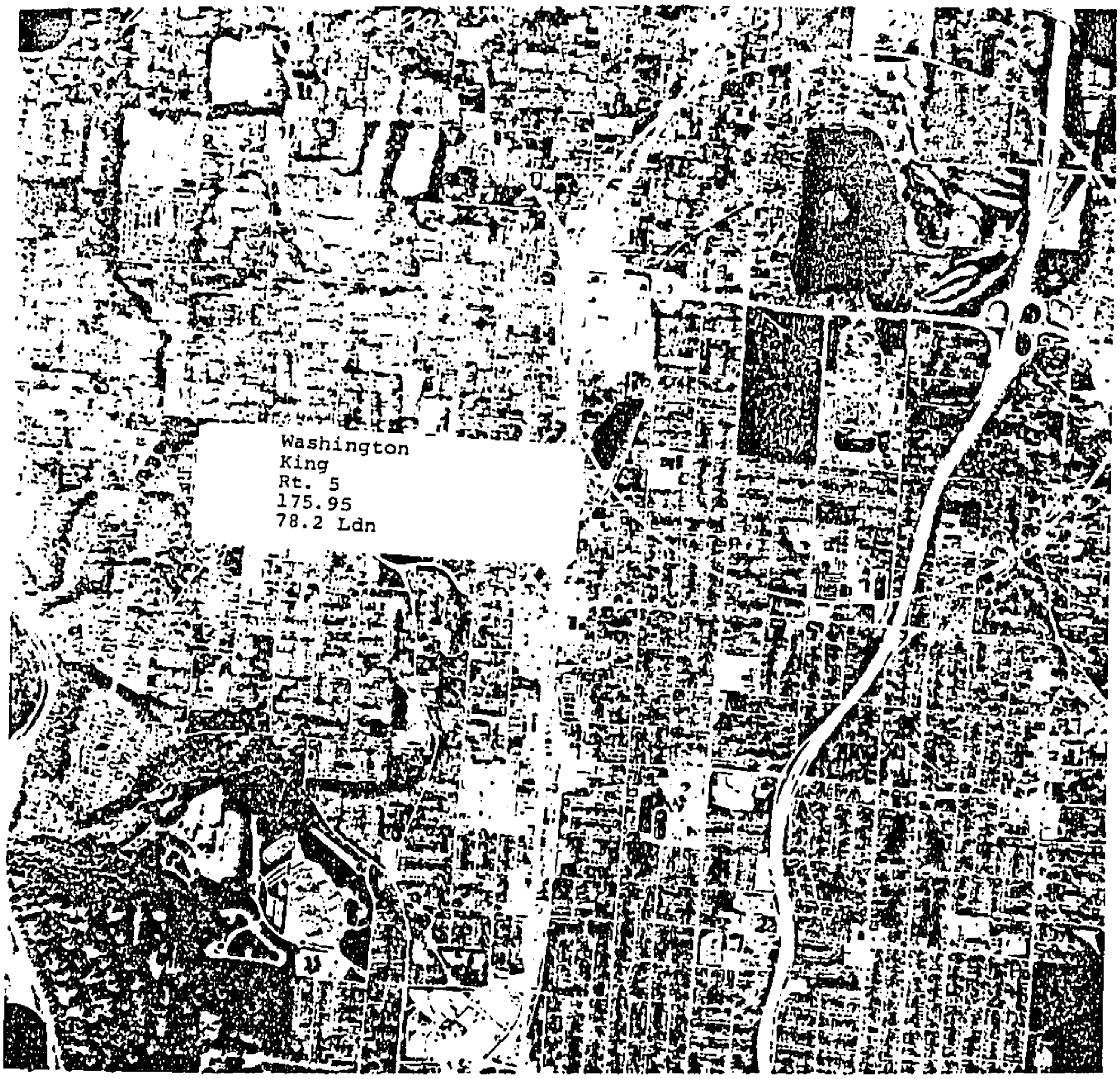

EXHIBIT VI-2: AERIAL PHOTOGRAPHS - (Continued)

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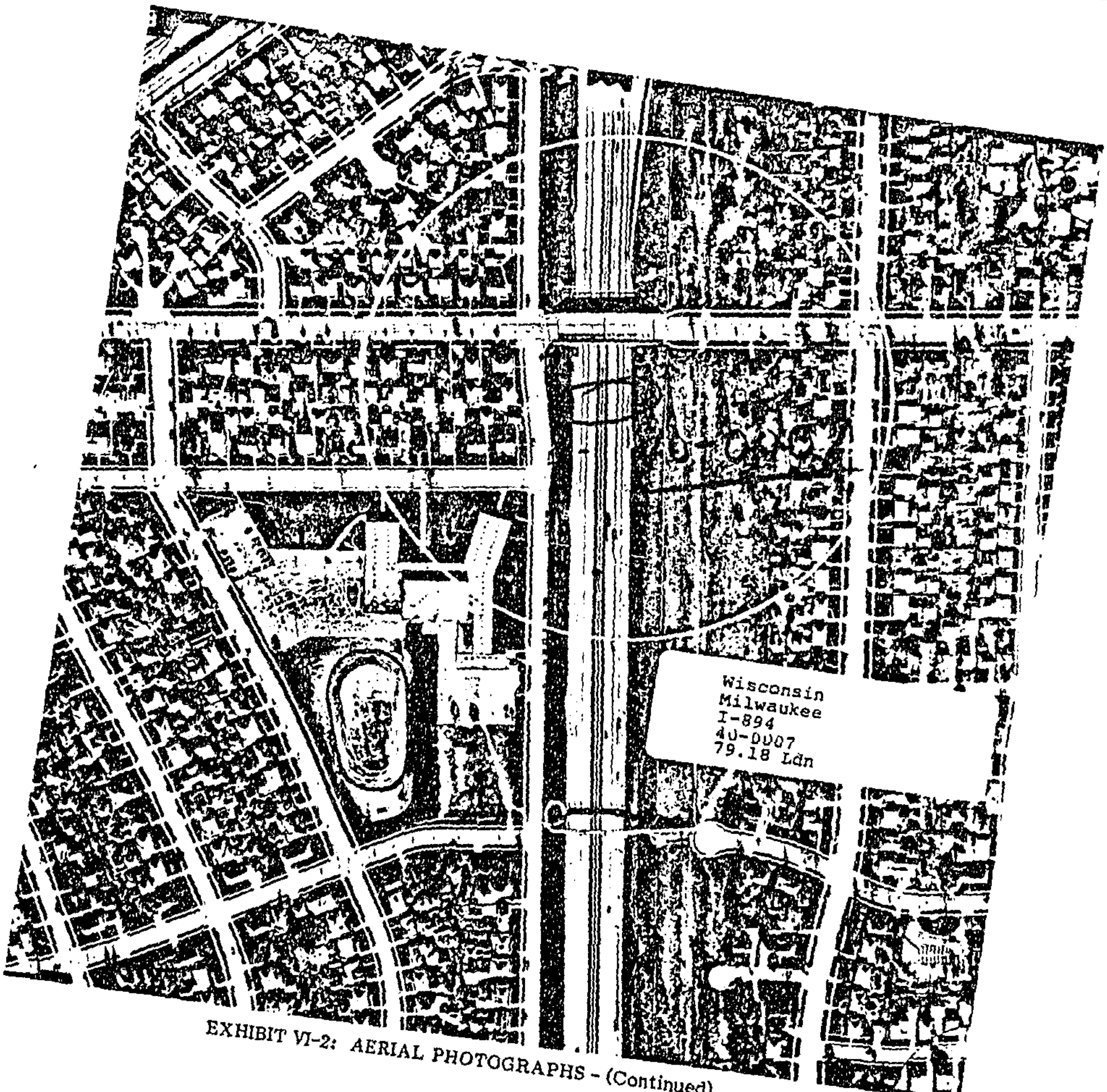

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SECTION VII

SUMMARY AND CONCLUSION

SECTION VII

SUMMARY AND CONCLUSION

This document contains information that can be used to facilitate the reduction in the number of people exposed to L_{dn} greater than 75 dB, or L_{dn} greater than 65 dB in noise sensitive areas (hot spots). The goal was to discuss the ill effects resulting from exposures to high noise levels, and, consequently, instilling concern in people affected. Some solutions were explored and the advantages and disadvantages of particular path controls were discussed. It was hoped that this would help everyone concerned with the problem — from citizens living along busy interstate highways to State highway engineers — evaluate the appropriateness of particular path controls. In addition, hot spots in Standard Metropolitan Statistical Areas (SMSA's) larger than one million were identified in order to give illustrative examples of areas that should be of concern for verification and possible treatment with path controls or compatible land use planning.

It was pointed out that the ill effects from noise exposures to high level are numerous. Among others they include possible hearing loss, stress-related increases in blood pressure, sleep interferences and speech interference. Even though people living in hot spots may learn to tolerate the high noise levels somewhat, they cannot escape many of the health consequences. Therefore, it was concluded that people living in hot spots should investigate possible remedies to their noise problem.

Initial indications as to whether or not residents annoyed by noise are living in a hot spot area can be attained without complex measuring equipment by merely following a simple nomograph (Exhibit IV-1). If results appear positive, more precise measurements may be requested. And if the initial impression is confirmed, the noise problem should be addressed.

This paper then outlined several possible avenues for seeking relief. Among them are path controls, like barriers. Citizens are given assistance by making them aware of pertinent regulations, potential benefits, and avenues for recourse. Local officials can also benefit from this information, along with information related to financing, design and economic benefits. At the state level the discussion about the availability of outside funding, economic benefits and alternatives to path controls may be of more interest.

Section VI entitled, "Hot Spot Identification and Aerial Photographs" was designed to alert State and local officials concerned with or in charge of the health and wellbeing of citizens including planners, and highway engineers, that there may be a problem or potential problem. They should verify whether or not those remotely identified hot spots are in fact areas with the high noise levels. If the findings are negative they should project the future traffic flow in order to determine if a noise problem will likely arise in the near future. If a noise problem is either expected or identified, positive steps should be taken to bring relief to those people who are adversely affected. If the hot spot and the surrounding area is not inhabited, steps would be taken to assure compatible land use. The attached aerial photographs depict examples of both conditions.

In conclusion, it should be noted that noise exposures can be unhealthy and that citizens can identify a noise hot spot and initiate actions. The solution to the problem involves not only citizens but officials of all levels of government. Enough information is available, in this paper and other publications, for everyone concerned with the problem to be relatively well prepared to become involved in solving it. The hot spots indentified and sites with aerial photographs should be verified and if there is a problem if should be properly addressed. The other hot spots identified in this paper should also be addressed before considering hot spots not identified, but existing or potential hot spots. The identification of potential hot spots is important because it reduces the possibility of a serious problem arising in the future.

APPENDIX A

METHODOLOGY

APPENDIX A
METHODOLOGY

The discussion of how highway noise levels can be estimated through the use of a simplified mathematical model can be of considerable interest to those citizens and officials involved with local noise control. Since the procedure does not necessitate the use of an acoustician with an electronic noise-measuring instrument, the estimations can be done indoors, anywhere a scientific calculator is handy.

But before beginning a how-to description, a few items must be discussed concerning the development of the mathematical mdoel, as well as its limitations.

First of all, noise is generated by every type of vehicle on a given highway, and each different vehicle emits a different amount of noise. It is obvious that a sedan in good operating condition cannot be considered as noisy as a truck, although most people would agree that a sedan can be compared to a station wagon. To simplify the equations, certain categories had to be established, according to how noisy each is. The final set of divisions for the model presented here breaks all vehicles down into three types: automobiles, medium trucks, and heavy trucks.

The sources of vehicle noise are varied. It is a combination of engine, exhaust, body, wind, and tire noise — potentially modified by the roadway or pavement type and by the dryness of the highway, although no conclusive data have been collected on these last few sources. Vehicle noise is also modified by acceleration and deceleration. None of these could be incorporated into the equations.

The different variables which affect vehicle noise emission are too great in number to list here. Instead, a list will follow which includes all the major assumptions made in deriving the mathematical model.

1. Since the model was designed to extract maximum noise levels, all traffic is assumed to be travelling at a constant 55 mph. This means an average output per vehicle of 72 dB for automobiles, 82 dB for medium trucks, and 86 dB for heavy trucks. Also important here is the concept of a constant speed. Any accelerations will, of course, increase the noise levels measured.

2. All highways are assumed to be straight and level. Curves increase tire friction against the pavement, which translates to an increase in decibel levels. An inclined surface requires the vehicle to increase its energy output, which achieves the same results as acceleration.

3. The ratio of day traffic to night traffic is assumed to be 83% to 17%. Modelling tends to assume uniform time flows of traffic. However, the measurement of Ldn levels requires that all traffic flows be divided into day (7 AM to 10 PM) traffic and night (10 PM to 7 AM) traffic. According to the widely accepted standard, it can be assumed that 83% of all traffic traversing a given highway does so between 7 AM and 10 PM. This does not take into consideration that the split may be different for different categories of vehicles.

4. All lanes are twelve feet wide. In general, this is a safe assumption.

5. The results obtained through the use of the equations are not meant to coincide with actual (instantaneous) measurements. The quantity being sought here is the overall noise level that the populace is subjected to during the span of a twenty-four hour time period. Any results obtained are expressed in A-weighted decibels.

6. No highway median strip is present on the highway. The type of strip referred to here is that which separates lanes in opposing directions by dedicating one to four lanes as unusable. This type of division is rare enough, though, to be considered negligable.

7. Topographic effects are not taken into account. Examples are: nearby hills, rocks, landmarks, and highways. There is no realistic way any model could take all these effects into account.

The very nature of an assumption implies that a potential for error exists within its boundaries. When a variable which normally fluctuates in a fairly random fashion is held constant, a certain possibility for error always exists. The more assumptions, made, the simpler the estimation can be. But too few assumptions, and the mathematical equations become unmanageable and uneconomical. An attempt was made to strike a happy medium.

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We have just discussed the assumed constants used in model. Now we must discuss the variables. There are exactly four:

1. ADT (Average Daily Traffic). This is by far the most important variable when dealing with highway noise. It measures the average number of vehicles traversing a given point on a highway every day, for all lanes in both directions.

2. Number of lanes. This usually falls between 2 and 12.

3. Fraction of medium trucks. This figure is the average number of medium trucks on a highway divided by the ADT.

4. Fraction of heavy trucks. The average number of heavy trucks divided by the ADT.

The equations used to calculate the L_{dn} of a given stretch of highway are given as follows:

Look-up Table to Determine "L"

# of lanes	value of L
1	50927
2	66650
3	72618
4	83364
5	94165
6	104970
7	118725
8	128528
9	137457
10	148230
11	158972
12	169860

Let: Fh = fraction of Heavy trucks
Fm = fraction of Medium trucks
ADT = Average Daily Traffic

Then:

$X = 2.426\,(Fh/Fm) + 0.0832/Fm + 0.9168$

$Y = L/X$ (The variable names X,Y,Z were arbitrarily chosen)

$Z = 2.5067\,(Fh/Fm)\,(Y)$

$A = L - Y - Z$ (A = equivalent number

of automobiles)

$M = Y/12.02$ (M = equiv. number of Medium trucks)

$H = Z/30.16$ (H = equiv. number of Heavy trucks)

$T = A + M + H$ (T = reference for equiv. total traffic)

$N = 75 + 10 \log_{10} (ADT/T)$ (N = noise leve, L_{dn}, in dB)

This procedure can be performed on a simple home or business computer with a simple program. It can also be performed on a scientific hand-held calculator. Examples of the procedure are shown in Exhibit A-1.

Now that the methodology itself has been discussed, it would be appropriate at this time to include a few words on the collection of the required data. All that is needed by the equations frequently can be obtained through the individual State Departments of Transportation. Usually there is a nominal charge for such information, although it is often free.

The accuracy of this model has been compared to two major computer noise models: the DOT traffic-EPA noise model and the Wyle model. The procedure produces higher noise levels than the former and lower levels than the latter, within a range for both of +4 db to -3 db.

1. Suppose we have obtained the following information about a specific highway:

ADT = 43,210
Number of Heavy trucks = 1,280
Number of Medium trucks = 3,020
Number of lanes = 8

(1) Index the appropriate number for L on the look-up table. Here, the corresponding number for 8 lanes is 128528. Thus, L = 128528.

(2) Fraction of Heavy trucks = Fh = 1280/43210 = 0.0296.
Fraction of Medium trucks = Fm = 3020/43210 = 0.0699.

(3) X = 2.426(Fh/Fm) + 0.0832/Fm + 0.9168
X = 2.426(0.0296/0.0699) + 0.0832/0.0699 + 0.9168
X = 1.0274 + 1.1903 + 0.9168
X = 3.1345

(4) Y = L/X = 128528/3.1345 = 41004

(5) Z = 2.5067(Fh/Fm)(Y)
Z = 2.5067(0.0296/0.0699)(41004)
Z = 43525

(6) A = L - Y - Z = 128528 - 41004 - 43525 = 43999

(7) M = Y/12.02 = 41004/12.02 = 3411

(8) H = Z/30.16 = 43525/30.16 = 1443

(9) T = A + M + H = 43999 + 3411 + 1443 = 48853

(10) N = 75 + 10 log (ADT/T)
N = 75 + 10 log (43210/48853)
N = 75 + 10 log (0.8845)
N = 75 + 10 (-0.0533)
N = 75 - 0.533
N = 74.5

N is the equivalent noise level, measured in decibels. Here, the result is 74.5 decibels, a fraction of a decibel below the 75 dB cut-off point.

EXHIBIT A-1: SAMPLE PROBLEMS

2. Suppose that this time, the following data was obtained:

Vehicle Type		Number Observed
# Axles	# Wheels	
2	2	23
2	4	44502
2	6	1721
2	8	17
3	8	1763
3	10	72
4	any	835
5	any	909
6+	any	34

(Number of lanes = 4 at this counting location)

What should be done first is to add up all vehicle types above to get a figure for the ADT. Here, ADT = 49,876.

The next step is to seperate the vehicles by the categories required by the equations. Heavy trucks are those vehicles with 3 or more axles. Here, we have the number of Heavy trucks = 1763 + 72 + 835 + 909 + 34 = 3613.
Thus, Fh = 3613/49876 = 0.0724. Note that since buses were not explicitly included in the table above, they could not have been taken into consideration here.

Now, for Medium trucks, which have two axles and six wheels, we get 4911. Therefore, Fm = 1721/49876 = 0.0345.

It should be added that the 2-axle, 2-wheel vehicles, as well as the 2-axle, 8-wheel ones, were not accounted for by the equations. They did not fit any of the categories, so they had to be discarded.

From the look-up table, we get L = 83364.

$X = 2.426(0.0724/0.0345) + 0.0832/0.0345 + 0.9168$
$X = 5.0911 + 2.4116 + 0.9168$
$X = 8.4195$

$Y = 83364/8.4195 = 9901$
$Z = 2.5067(0.0724/0.0345)(9901) = 52084$

$A = 83364 - 9901 - 52084 = 21379$
$M = 9901/12.02 = 824$
$H = 52084/30.16 = 1727$

$T = 21379 + 824 + 1727 = 23930$

$N = 75 + 10 \log (ADT/T)$
$N = 75 + 10 \log (49876/23930)$
$N = 75 + 3.2$
$N = 78.2$ dB

EXHIBIT A-1 - (Continued)

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