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DEBRIS MODEL RESEARCH WITH BUILDING DAMAGE, FIRE SPREAD, AND DEBRIS PREDICTIONS FOR FIVE-CITY STUDY

Final Report
March 1967

Prepared for

OFFICE OF CIVIL DEFENSE
Office of the Secretary of the Army
Department of the Army
Washington, D.C. 20301
Contract Number B-70924(4949A-20)-US
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Summary
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Summary Report

of

DEBRIS MODEL RESEARCH WITH BUILDING DAMAGE, FIRE SPREAD, AND DEBRIS PREDICTIONS FOR FIVE-CITY STUDY

Final Report
March 1967

by

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Burlingame, California

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Summary Report

of

DEBRIS MODEL RESEARCH WITH BUILDING DAMAGE,

This report is divided into two parts. Part I reports on research work directed toward improvement of the debris prediction model. Part II reports on applications type work in support of the Five-City Study.

The research portion was primarily concerned with the development of multi-yield debris charts and improvement of debris distribution procedures.

MULTI-YIELD DEBRIS CHARTS

The construction of the multiyield debris charts is dependent on plotting a pair of isodamage curves for each structure. One curve defines the onset of structural collapse or dismemberment, and the other defines total collapse. These curves are plotted as a function of overpressure vs yield and, once plotted, enable the construction of the terminal limb* of the debris charts for different yields. The basic information defining the onset of structural collapse and damage parameters was obtained from TM 23-200.** When these data were plotted (overpressure vs yield for severe damage), the points exhibited a wide scatter for many of the structure types. It was not possible, within the scope of this work, to determine the reasons for this scatter, which precluded plotting the multiyield vs damage curves for all structure types. Multiyield curves were, however, plotted for structure types (mostly the steel-frame industrial buildings) not exhibiting this scattering characteristic, which enabled construction of some multiyield debris charts.

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* The terminal limb defines the region between initiation and completion of structure collapse and is yield dependent.

** Capabilities of Nuclear Weapons, Part II, Damage Criteria, TM 23-200, Defense Atomic Support Agency, 1962 (CONFIDENTIAL)

OVERTURNING

The possibility of overturning being a primary failure mechanism was hypothesized during the construction of the isodamage curves. A preliminary investigation indicates that this failure mode is likely to be the dominant one in the case of tall (and more substantial) buildings acted upon by a long-duration pulse (Fig. 1) in that overturning is shown to occur at lower overpressures than those required to cause severe damage.

DEBRIS DISTRIBUTION

Debris distribution is discussed in qualitative terms. A precise prediction scheme for debris distribution would require knowledge of building breakup, blast wave—city complex interaction, blast wave—building interior interaction, and particle trajectory from breakup through ejection from the building to final resting place, including collisions with other debris particles and/or buildings. Distribution of debris from building contents is likewise quite complex. At present, not enough is known about these complexities to justify altering the present debris distribution techniques.

FIVE-CITY STUDY: VEGETATION EFFECTS

Predictions of debris quantities resulting from damage (air blast and fire) to vegetation (primarily trees) caused by the Five-City Study attack on San Jose (5 Mt at 14,500 ft) were made. A composite tree debris chart was constructed which gives the percentage (by volume) of a particular stand of trees (forest or orchard) becoming debris as a result of brand and stem breakage or blowdown (Fig. 2). The tree or forest types covered are identified as follows:

1. Conifer - cultivated
2. Conifer - unimproved - unfavorable growing conditions
3. Conifer - unimproved - favorable growing conditions
4. Deciduous - temperate zone (like live oak or cloud forest - above 3500 ft elevations)
5. Deciduous - rain forest - very dense

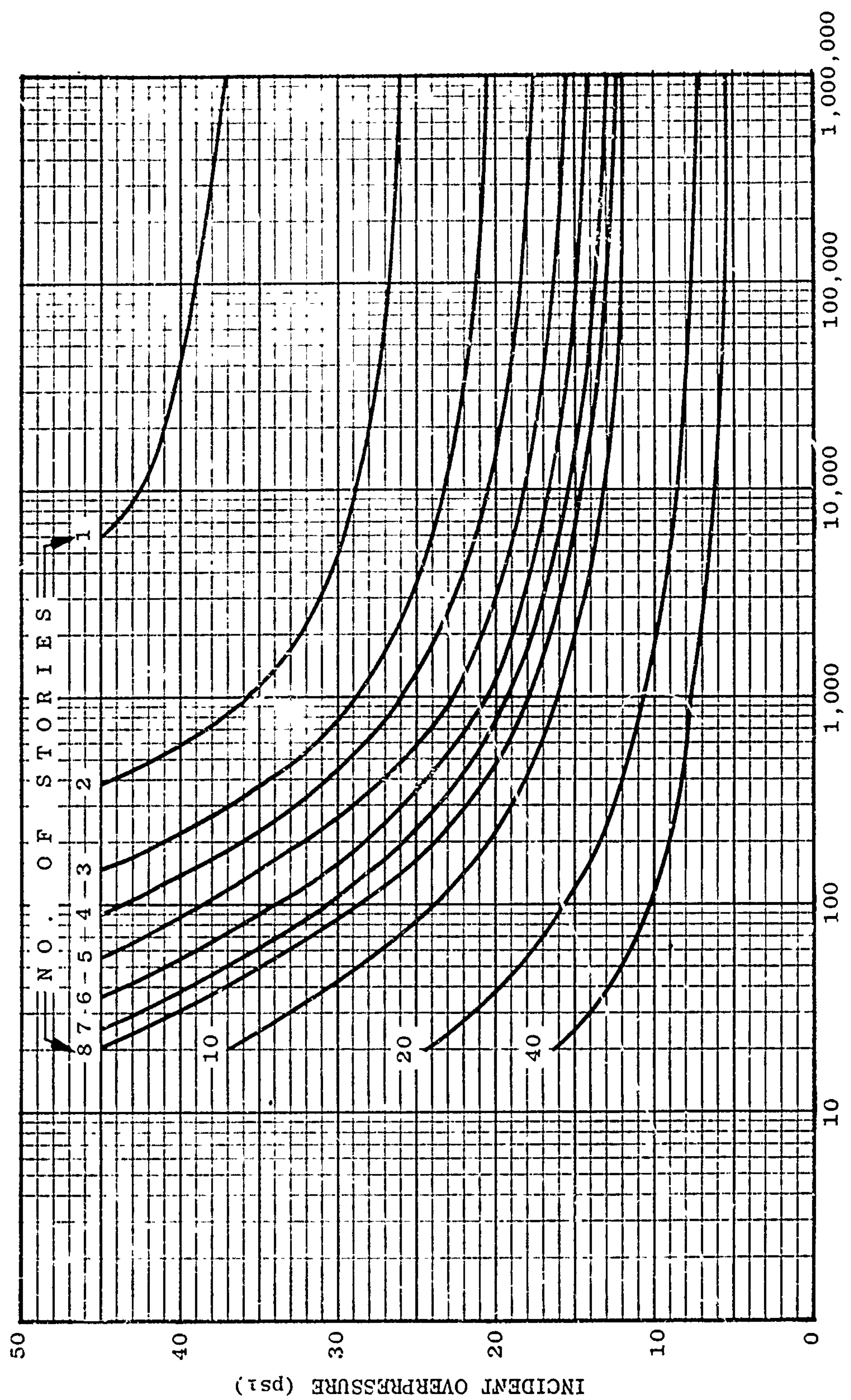

Fig. 1. Threshold of Overturning Curves for Various Story Heights as a Function of Incident Overpressure and Weapon Yield

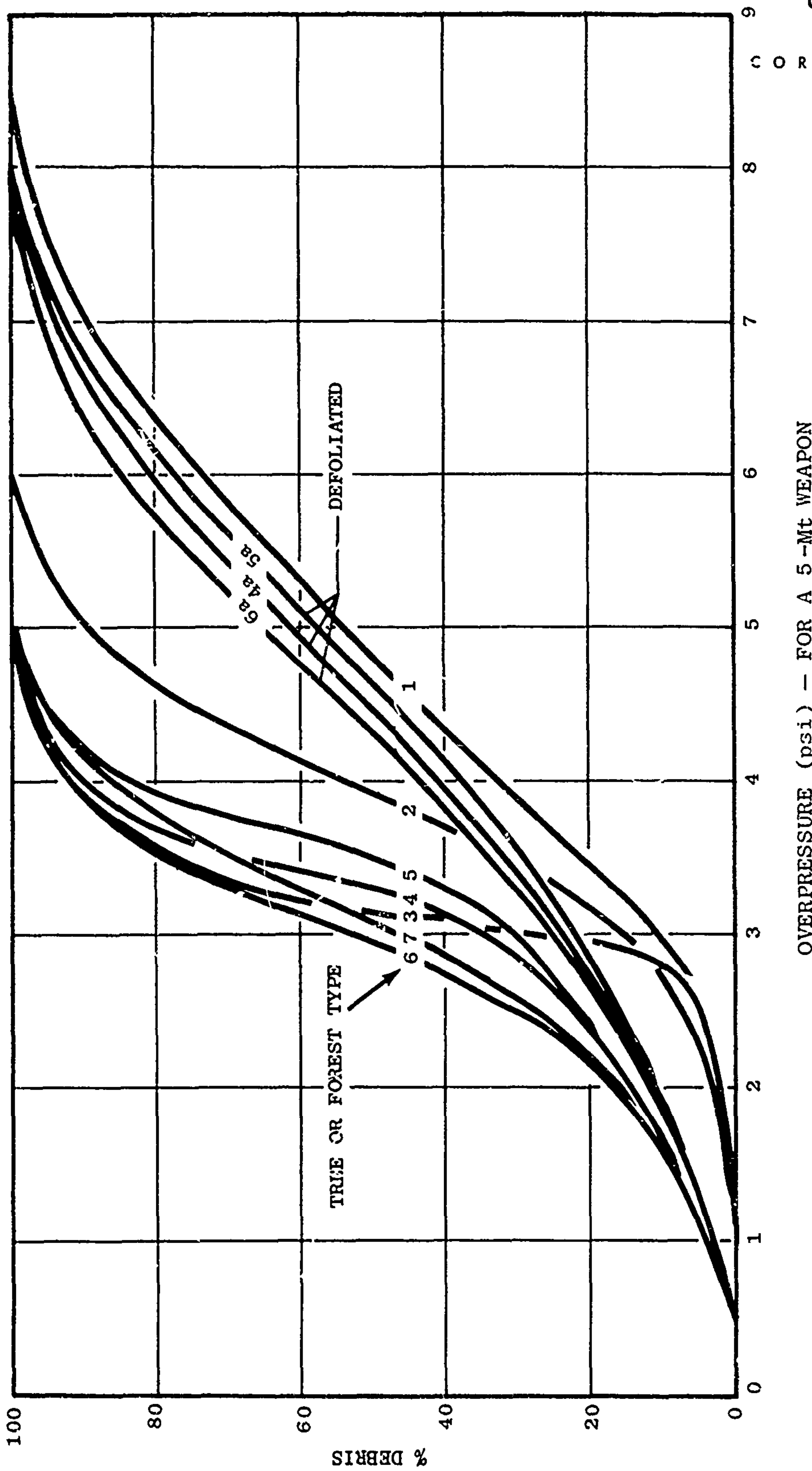

Fig. 2. Tree Debris Chart

6. Deciduous - temperate zone scattered - also orchards

7. Rubber plantation - very little underbrush and dense overlapping crowns

The wooded areas of interest in and around San Jose are virtually all orchards. Aerial maps and USGS quadrangle sheets enabled location and identification of wooded areas. For verification, an on-site reconnaisance was conducted which provided additional information as to tree sizes, densities, etc. Thermal effects (fire) were evaluated by estimating initial ignitions from thermal exposure intensities, calculating fire spread (using an existing fire spread model), and adjusting debris quantities to account for that consumed by fire.

The resulting amount of tree debris, in tons per acre, (including a reduction for fire) was plotted for selected points and debris contours drawn on an overlay to the scale of 1:24000 for submission to the Five-City Study Data Bank. A reduced version of this overlay is included in the report.

FIVE-CITY STUDY: SAN JOSE BUILDING DAMAGE

A 1:24000 scale overlay* was constructed showing the ranges corresponding to the Five-City Study attack on San Jose for different damage levels (light, moderate, and severe) for several structure categories along with a tabulation of corresponding descriptions of each damage level. Detailed damage descriptions were also furnished in a separate document submitted to the Five-City Study Data Bank for 53 specific buildings. Three samples of this output are contained in this report.

FIVE-CITY STUDY: SAN JOSE DEBRIS PREDICTIONS

The debris prediction model is described in some detail. The necessary inputs are listed and the method of operation is explained.

Debris depths for San Jose, both for air blast alone and for air blast and fire, were calculated and presented in the form of overlays showing the debris

* Presented in reduced form in the report.

depths and debris depth contours for both of these cases.

Also included is a tabulation of the typical debris composition for the categories of light, medium, and heavy debris in industrial, commercial, and residential areas. The debris sample areas are categorized as being one or a combination of these, and the debris described as light, medium, or heavy. This classification, in conjunction with the typical composition tabulation, enables a general description of debris characteristics and composition.

ACKNOWLEDGMENTS

The author gratefully acknowledges the assistance, effort and/or guidance of the many persons at OCD, SRI and URS who have contributed to this work. Specifically I wish to thank Mike Pachuta and George Sisson of OCD for their efforts in attempting to resolve the overturning and damage function problem; R. Bothun of SRI (Project Monitor) for his guidance during the course of this work; Peter Phung for his assistance in making fire spread predictions; J. E. Edmunds for diligent work in the many phases of this project, especially in the making of damage and debris predictions and overlays; Ken Kaplan for helpful program guidance and valuable review comments and recommendations, and to Allen Saltzman for his editorial services and publication advice.

FOREWORD

This report is divided into two parts: Part I reports on research work directed toward improvement of the debris prediction model: Part II reports on applications type work in support of the Five-City study. The research work was primarily concerned with the development of multiyield debris charts and improvement of debris distribution procedures. During work on the multi-yield debris charts, significant inconsistencies in present building damage functions for many building types were discovered. These inconsistencies could not be resolved within the scope of the present study, and therefore charts were prepared only for those building types whose damage functions displayed little or no irregularities. While preparing the charts, it was ascertained that overturning can be a significant mode of building damage, especially for tall buildings acted upon by blast from large-yield weapons. This damage mode has not previously been studied in detail, and no damage functions accounting for such failures are available.

Supporting information on debris distribution, scheduled to be developed concurrently by others during this period, has not been made available. This lack precluded a quantitative treatment of the debris distribution problem. A qualitative discussion, however, is included.

The Five-City study work was primarily concerned with prediction of target damage for the city of San Jose resulting from the Five-City study attack on that city.

Predictions were made of initial ignitions and fire spread in wildland fuels, and of debris resulting from the destruction of trees and buildings by the coupled effects of air blast and fire, and detailed descriptions of building damage were provided. These predictions are on file in the Five-City Study data bank and are presented for reader convenience only in scaled-down and abbreviated form herein.

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PART I

DEBRIS MODEL RESEARCH

Section 1
INTRODUCTION

This research work is primarily directed toward the development of a model for prediction of the amount, characteristics, and areal distribution of debris resulting from the destruction of buildings and their contents by the individual or coupled effects of air blast and fire associated with nuclear weapon attacks. This report is the fourth in a series covering the development of the model. In the first report (Ref. 1) the basic approach to prediction of debris was established. Also in that report, debris production as a scalable phenomenon with respect to weapon size was verified. In the second report (Ref. 2) methods and procedures were established for predicting the coupled effects of air blast and fire. The third report (Ref. 3) was primarily concerned with increasing the number of building types for which predictions can be made and developing procedures and data for prediction of debris resulting from the destruction or transport of building contents.

The first (research) part of the present report is concerned with increasing the number of weapon sizes from the two (20 kt and 20 Mt) previously considered, to a multiplicity of sizes ranging from 3 kt to 300 Mt, and with improving capabilities of predicting the distribution of debris.

The objectives of this phase of the work were only partially satisfied due, first, to discovery of differences in the presently available damage functions (Ref. 4) used in construction of debris charts which could not, within the scope of the study, be resolved and, second, to lack of debris distribution information from other contractors.

In spite of these difficulties, multiyield debris charts were produced for some (but not all) structure types, overturning (a mode of failure previously ignored) was isolated as a dominant damage mode, and a qualitative treatment of debris distribution is presented.

Section 2
DEBRIS CHART CONSTRUCTION

The basic tool used in the operation of the debris model is the debris chart. These charts show the amount of debris (as a percentage of total volume of structural material in a building) produced from destruction of various types of buildings as functions of air blast overpressure and weapon size. For convenience of discussion, a schematic debris chart typical of those for many ductile structures with frangible elements is shown in Fig. 1.

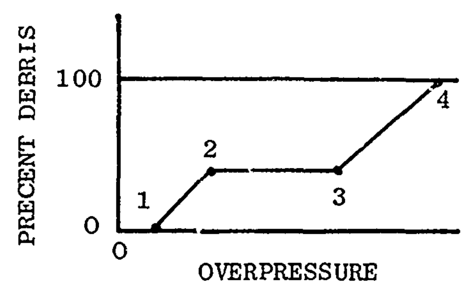

Fig. 1. Schematic of Typical Debris Chart for a Ductile Structure Containing Frangible Elements

The location of points 1 and 2, the initiation and completion, respectively, of failure of frangible or diffraction-phase-sensitive elements (panels, doors, suspended ceilings, etc.), and the amount of debris produced by these elements (expressed as a percentage of total structural material), tend to have small dependence on weapon yield (in the yield range considered here), but are strongly dependent on the types of elements present and the type and configuration of the building containing these elements. The overpressure range spanned by points 1 and 2 is partly dependent on variations of strength of like elements and variations of inherent strengths of the different types of elements in the building, but is much more strongly dependent on the position and location sensitivity of these elements (orientation to the blast, clearing times, partial shielding, etc). For the same reasons, this overpressure range will vary considerably between building types and will generally increase with plan area of the building and the density of elements within the building. The blast shielding afforded by city complexes would also affect this range (would tend to lengthen it). It is unfortunate that this factor has not been investigated in sufficient detail (see Ref. 5) to provide a quantitative appraisal of its effect on panel failures (or ultimately on overall building failure). The overpressure failure range (overpressure difference between points 1 and 2) used on debris charts constructed to date is for isolated buildings and neglects any city-complex effects.

A plateau (Fig. 1, points 2 to 3) is found on charts for most buildings and reflects that overpressure range in which additional structural failures are not likely to occur. Permanent deformations of structural elements progressively increasing with overpressure would, however, be taking place. Debris charts may also contain more than one plateau.*

The location of points 3 and 4 is determined by the failure characteristics of the main structural system, point 3 representing the overpressure at which elements of the main structural system would start departing the structure (generally similar to overpressures for severe damage or threshold of collapse), point 4 representing the overpressure for complete destruction (100 percent debris). Again, the percent debris range between points 3 and 4 indicates the relative volume of material in the main structural system.

For drag-sensitive structures, such as that on which Fig. 1 is based, values of incident overpressures at points 3 and 4 are dependent on: the dynamic response characteristics of the structure at the start of failure; the structure's ability to absorb additional energy at various stages of failure; and, of course, the duration of the associated dynamic pressure pulse. As a consequence, the location of debris chart terminal limbs is weapon-yield dependent.

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* An example of this is the debris chart for a light reinforced concrete shear-wall building (industrial type) with frangible interior panels and light reinforced concrete deck roof, which shows an initial rising limb for frangible panel failure, a plateau, an intermediate rising limb for roof slab failure, a second plateau, and a terminal rising limb depicting beam and girder buckling and shear-wall diaphragm failure. (See Fig. A-13, Ref. 3).

For each structure type debris charts covering a large range of weapon yields are relatively easy to construct. Generally, only the terminal limb of a debris chart is yield sensitive, and therefore a multiplicity of yields can be covered by constructing a family of terminal limbs imposed on the non-yield-variant portions representing diffraction-phase-sensitive-element failure.

To construct multiyield debris charts, it is convenient to plot first, for each structure, a pair of isodamage curves such as that shown in Fig. 2. On that figure, curve A defines the onset of structural collapse or dismemberment, and curve B defines the completion of the process, i.e., total collapse. Thus, for any yield, the region between curve A and curve B defines the terminal limbs of the debris charts, the region between initiation and completion of structural collapse. Although it would be desirable to use empirical data to define these terminal limbs, such data although voluminous (see Section 7 of Ref. 3) are insufficient to define them. Therefore, the following procedure was adopted.

Curve A was initially obtained from the height-of-burst (HOB) curves contained in Ref. 4 (TM 23-200). These curves are essentially a family of severe isodamage lines for various weapon yields plotted as functions of HOB and ground range. Since, in the Mach reflection region, overpressures and positive-phase durations do not vary along these damage lines, the variable HOB and ground-range parameters can be replaced with a single value of overpressure for any particular yield. This, then, enabled replacement of the entire family of isodamage lines with a single curve (curve A). Each isodamage line defines one point (yield, overpressure) on this curve.

Curve B was then calculated by determining the additional amount of strain energy required to be absorbed by the structure to take the structure from threshold of collapse (severe damage) to complete collapse or dismemberment. The calculational procedures for curve B involved first estimating this additional strain energy reserve, then altering the ductility ratio (Ref. 4) to reflect this amount, and finally calculating the associated yields and overpressures for this additional structural response capability (using procedures in Refs. 6 and 7).

Certain of the "curve A" plots derived from the HOB curves of Ref. 4 showed a relatively wide scatter of derived points. In an attempt to reduce this scatter these curves were recalculated utilizing the same procedures and the same structural response parameters (tabulated in Ref. 4) as had been used in preparing the HOB charts. Differences between the two sources were still apparent and for some structure types, a third source, tabulated overpressures for severe damage from 20-kt and 20-Mt weapon yields, was employed.*

For some of the structural types considered, all sources were consistent and for these, isodamage curves were first constructed (Fig. 2-4) from which multiyield debris charts were derived (Figs. 5-10).

For the remainder of the structure types, the differences noted were too large to be resolved without additional study, which, it was believed, could not be carried out without penalizing completion of the remaining portions of work on the project — especially those directly related to the application of debris- and damage-estimating techniques to Five-City Study needs. With a few exceptions it is believed that resolution of the observed differences will not be difficult since the basic sources indicate similar and logical trends. For two types of structures, the trends observed do not appear to be consistent with known structural behavior; the resolution of differences for these structures may be more difficult.

The types of differences observed are tabulated in Table 1. As can be seen, the first two of these indicate trends that are difficult to explain (the third does too for very high yields). The remainder of the structural types are arranged in general order of decreasing degree of differences.

Figure 11 shows a plot of the "A" curves (those for initiation of structural collapse) for one of the structural types. As can be seen, HOB and calculated sources differ by some 40% in overpressure for medium yields.

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* Dynamic response and damage parameters can be obtained from these values by employing a reverse calculational procedure.

Table 1

DESCRIPTION OF TRENDS FOR THE INITIATION OF SEVERE DAMAGE

STRUCTURE DESCRIPTION	REMARKS
Wall-bearing masonry, apartment house type (up to 3 stories).	HOB curves indicate higher pressure (~5 psi required for onset of severe damage from high yield weapons than from low yield weapons.
Wood-frame residential (1 or 2 stories).	HOB curves indicate increase in overpressure required for onset of severe damage with yield. Three sources disagree by over 30% in pressure required for onset of severe damage.
Wall-bearing masonry, monumental (up to 4 stories).	Considerable scatter of points from HOB curves about meanline. Megaton range data indicate increase in overpressure required for onset of severe damage with yield.
Multi-story steel frame with lightweight, low-strength walls, earthquake design (3 to 10 stories)	For medium yields, calculated and HOB sources differ by more than 40% in overpressure required for severe damage onset.
Multi-story reinforced-concrete frame with lightweight, low-strength walls, earthquake design (3 to 10 stories).	For medium yields, calculated and HOB sources differ by 25-30% in overpressure required for severe damage onset.
Multi-story reinforced-concrete, blast resistant to 30 psi Mach-region from 1 Mt, no windows.	Analysis indicates height of building critical. Overpressure differences of 25-30% at a given yield required for onset of severe damage.
Multi-story reinforced-concrete shear wall (3 to 8 stories).	For high yields, yield to onset of failure at a particular overpressure difficult to determine for overpressures <11 psi. Building height appears critical; overpressure differences (at given yield) up to 20-30%.

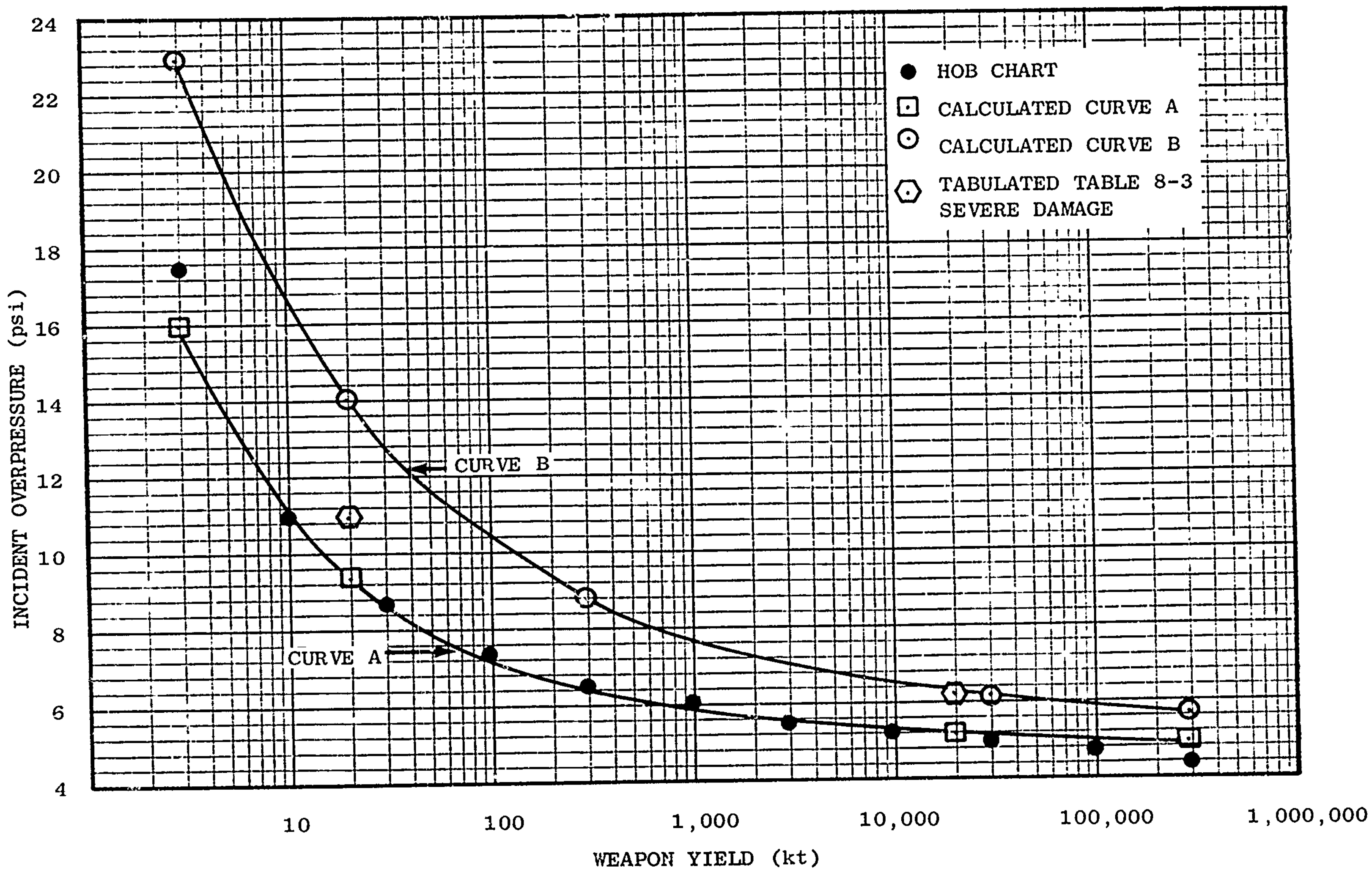

Fig. 2. Isodamage curves — Yield vs Overpressure. Light steel frame industrial building. (Up to 25-ton crane.)

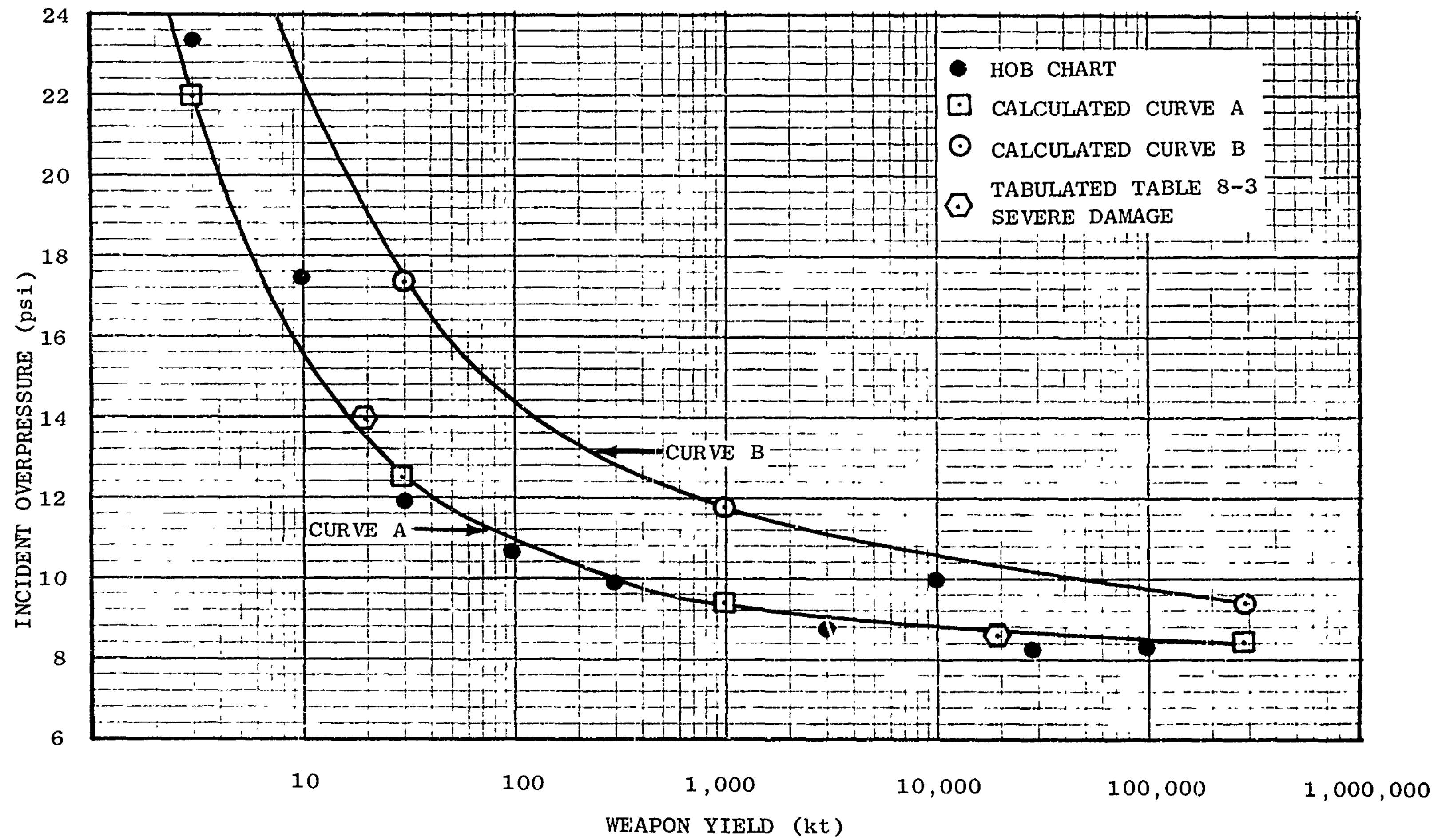

Fig. 3. Isodamage curves — Yield vs Overpressure. Medium steel frame industrial building. (25- to 50-ton crane.)

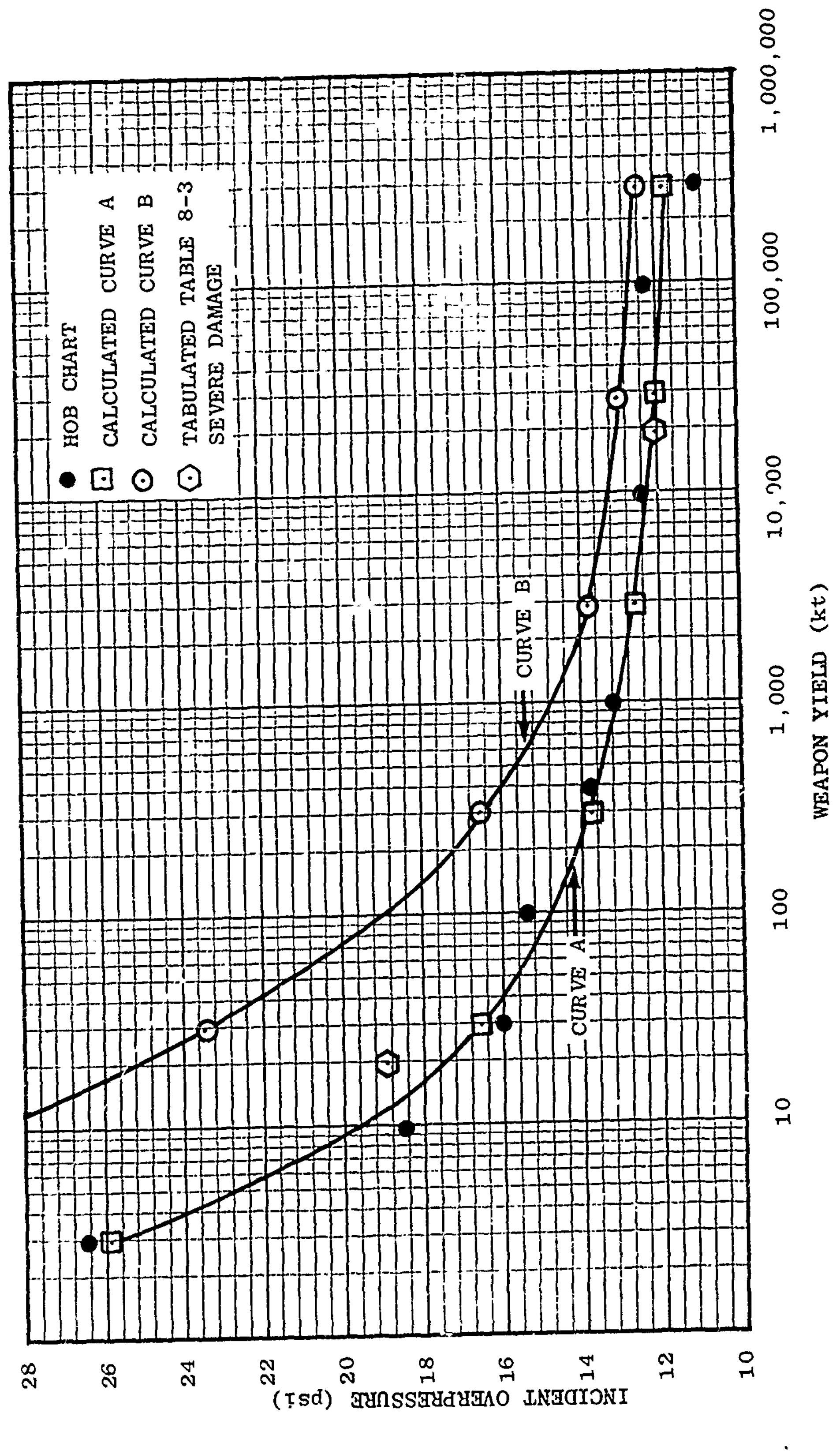

Fig. 4. Isodamage curves – Yield vs Overpressure. Heavy steel frame industrial building. (60-to 100-ton crane.)

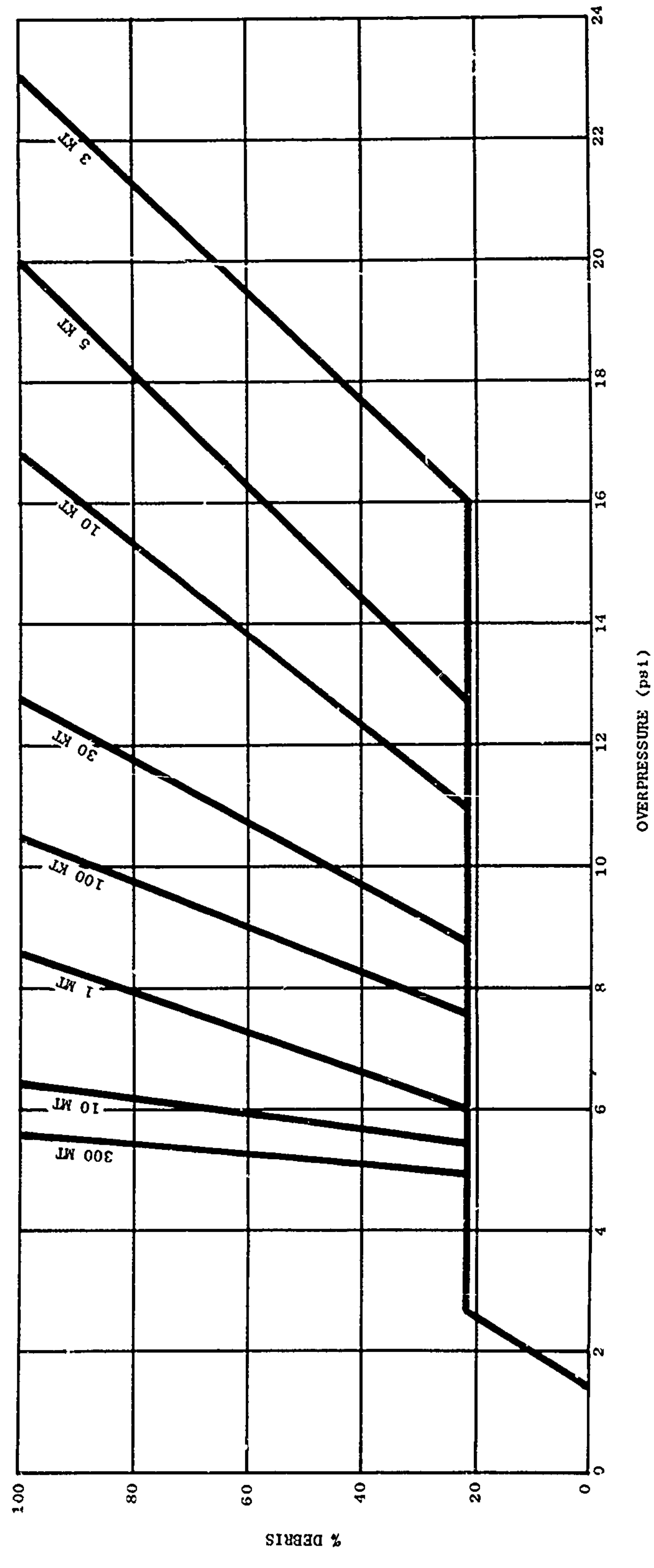

Fig. 5. Multiyield Debris Chart — Light Steel Frame Industrial Building (up to 25-ton crane) with Corrugated Iron Sheathing

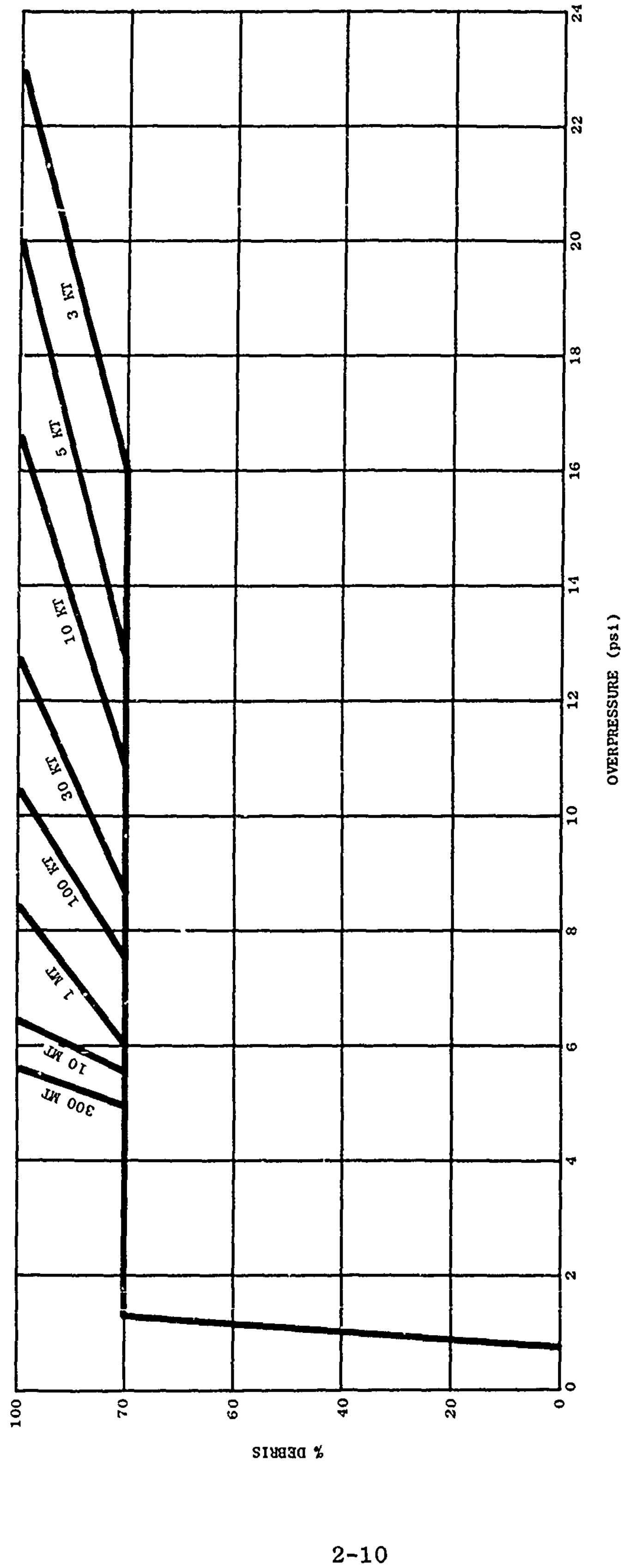

Fig. 6. Multiyield Debris Chart — Light Steel Frame Industrial Building (up to 25-ton crane) with Corrugated Asbestos Sheathing

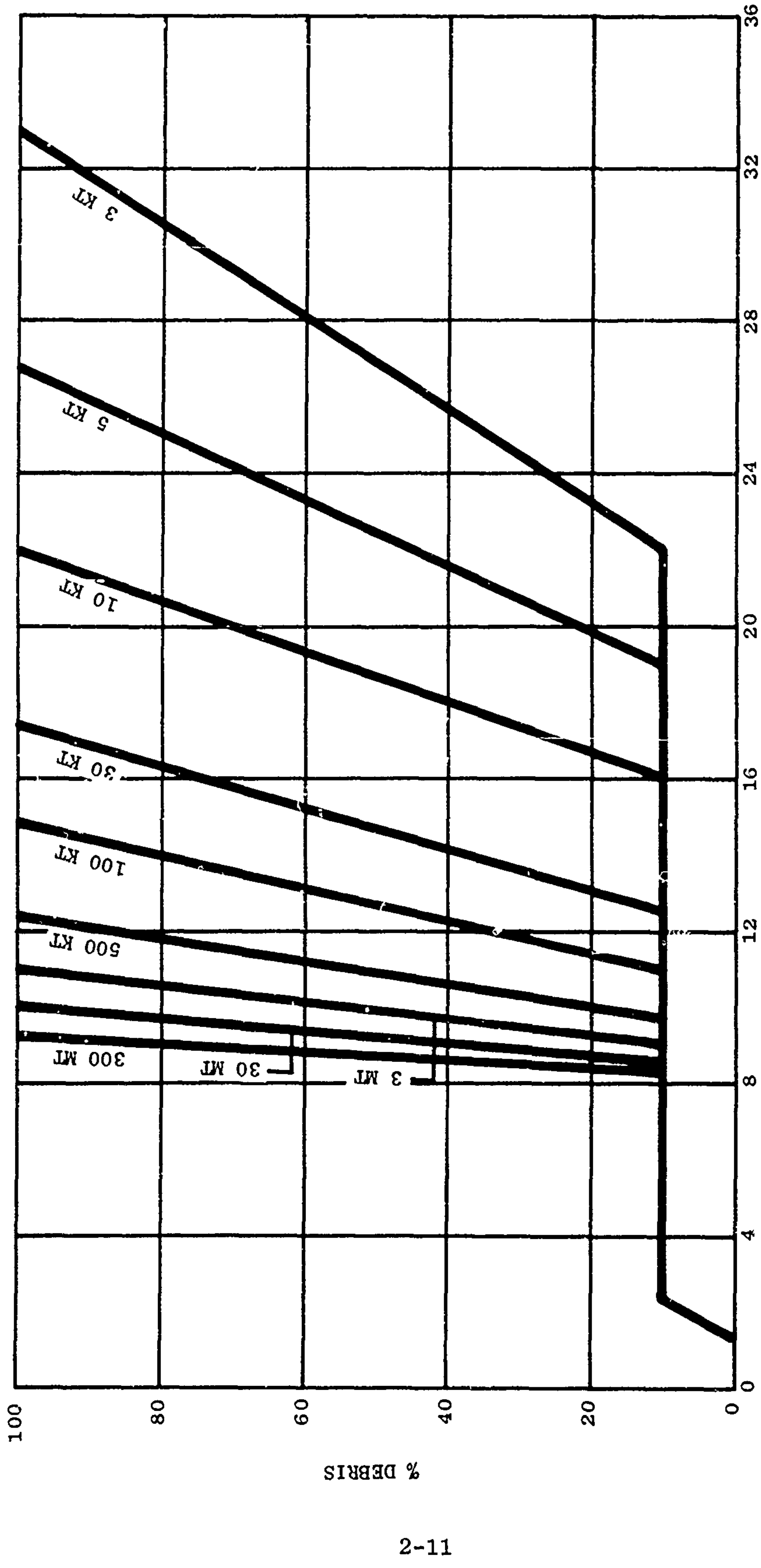

Fig. 7. Multiyield Debris Chart — Medium Steel Frame Industrial Building (25- to 50-ton crane) with Corrugated Iron Sheathing

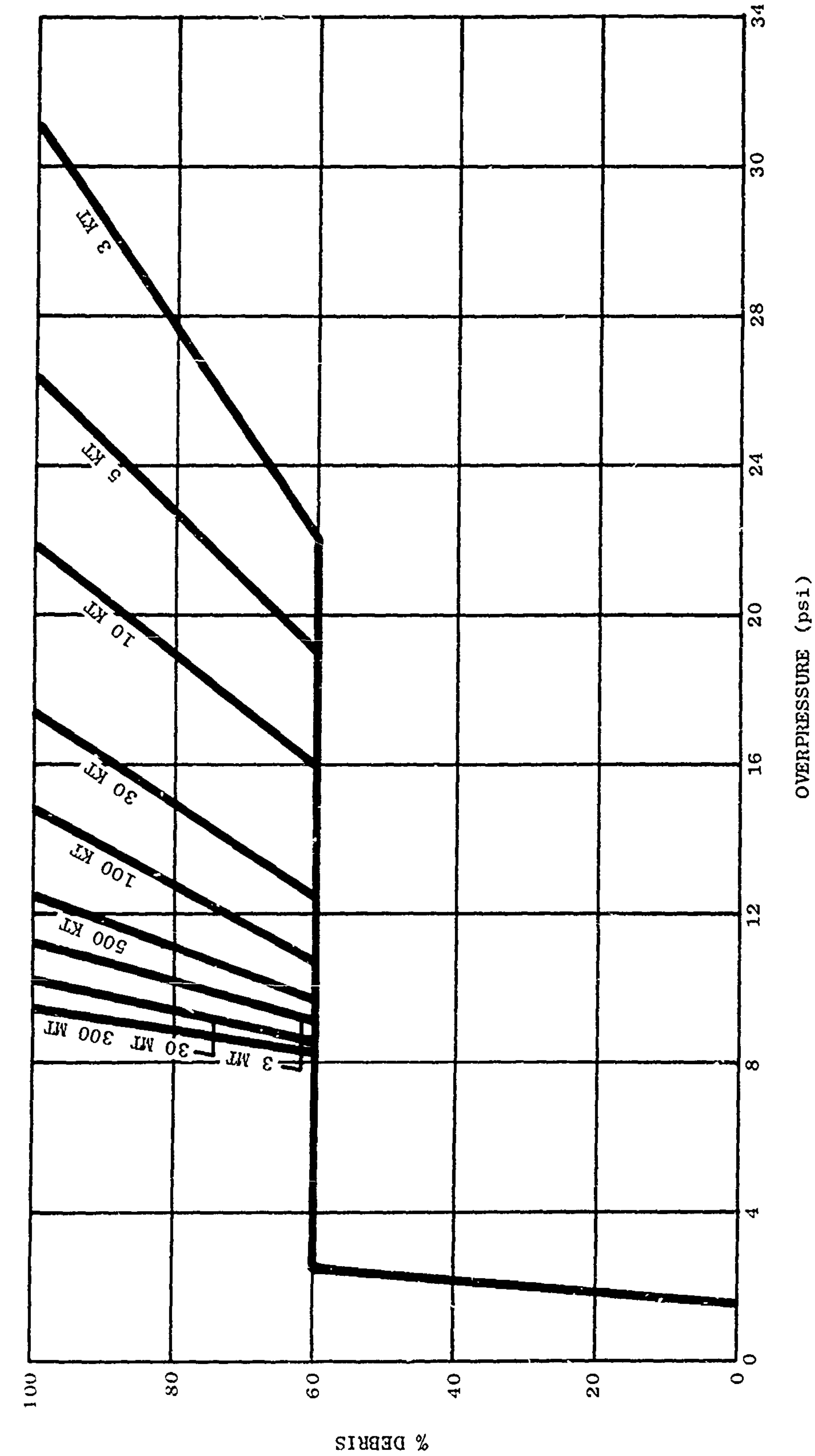

Fig. 8. Multiyield Debris Chart – Medium Steel Frame Industrial Building (25- to 50-ton crane) with Corrugated Asbestos Sheathing

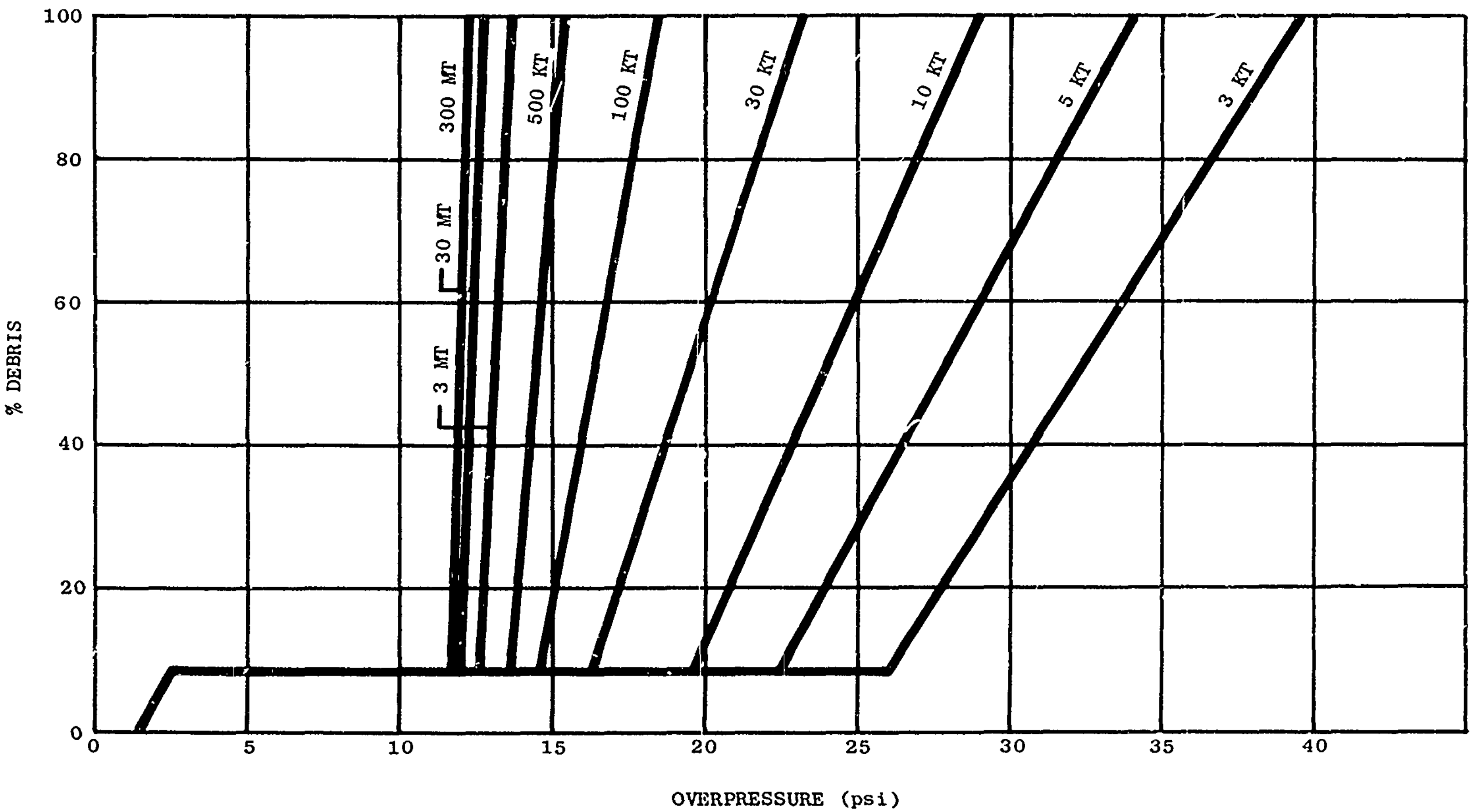

Fig. 9. Multiyield Debris Chart — Heavy Steel Frame Industrial Building (60- to 100-ton crane) with Corrugated Iron Sheathing

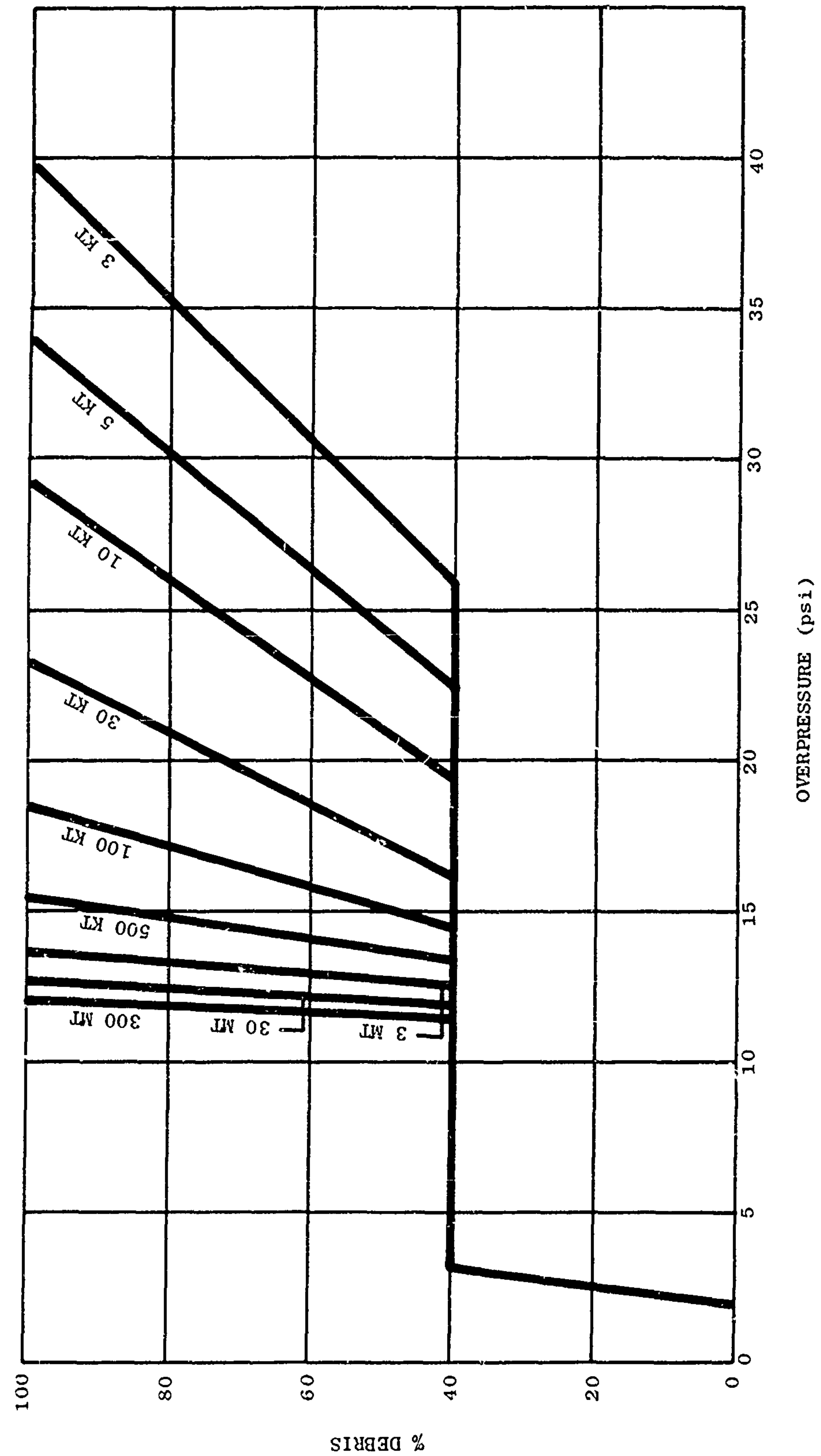

Fig. 10. Multiyield Debris Chart – Heavy Steel Frame Industrial Building (60- to 100-ton crane) with Corrugated Asbestos Sheathing

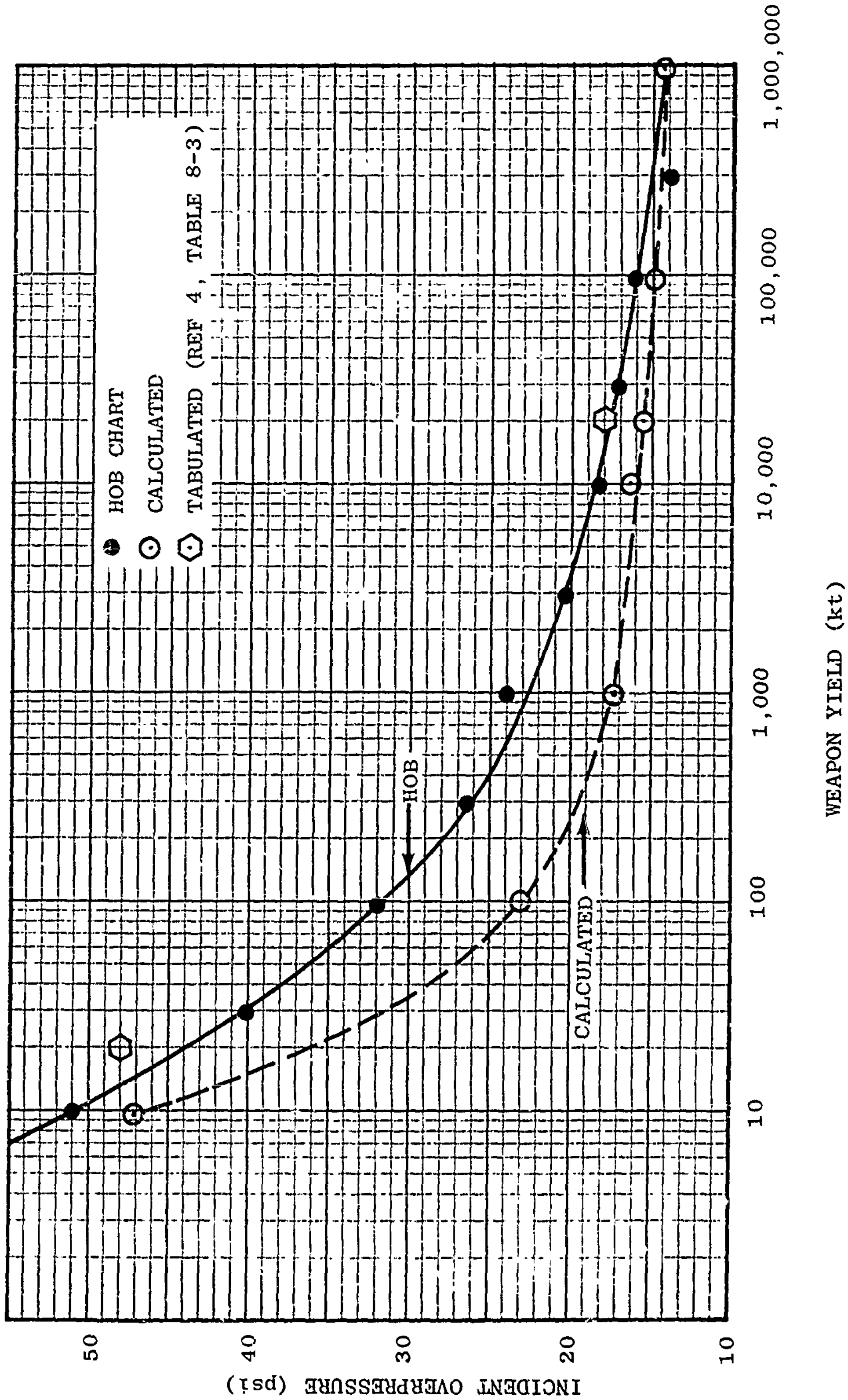

Fig. 11. Comparison of Data for Severe Damage. Multistory steel frame building with earthquake design (3 to 10 stories tall)

For this particular structural type an attempt was made to adjust the "calculated" curve to better agreement with the "HOB" curve by varying structural and dynamic damage parameters over the complete range of those tabulated, but the differences were not substantially lessened.

As a byproduct, while constructing yield-vs-overpressure isodamage curves, note was taken of the long positive-phase duration of drag pressure associated with the large-yield weapons, which prompted checking overturning as a possible damage mode.

Section 3
OVERTURNING

Recognition of overturning as a possible damage or failure mode is not new. It has been included in design and analyses of structures for blast hazards and has been considered in the design of structures used in nuclear tests. In one particular test (Ref. 8), the existence of overturning as a failure mode was vividly displayed by the tumbling of a closed structure brought about by formation of a precursor which increased the drag loading many times. Overturning was not experienced in the Hiroshima and Nagasaki attacks, but none should have been expected because of the relatively squat structures in these cities, and the small weapon yields.

Overturning as a damage mode was not discussed in Ref. 4, from which most information on damage functions was extracted. In order to obtain insight into the possible importance of overturning as opposed to other damage mechanisms, a relatively simplified analysis of conditions that might cause a structure to overturn was performed, and the results of the analysis were compared with conditions that would lead to severe damage (by other mechanisms) to multistory buildings.

A structure can fail by overturning if the magnitude of the applied forcing function is insufficient to cause gross structural element failure (buckling of columns, failure of shear walls, etc.), but sufficient to reduce the stability ratio* below unity for a time long enough to allow the structure to rotate beyond the point of stable equilibrium.**

To estimate whether or not this failure could frequently occur for multistory buildings acted upon by blast waves with long positive-phase

* Ratio of moments resisting overturning to applied overturning moments.

** Angle of rotation beyond which the structure will no longer return to an upright position.

durations of dynamic (drag) pressure, the following conditions were examined.

1. an average building depth of 50 ft (horizontal)
2. an average story height of 10 ft
3. a nonyielding point of rotation at ground level on the leeward side of the building (see Fig. 12)
4. a clearing distance of 10 ft for diffraction-phase loading
5. a drag coefficient of unity
6. an equivalent (impulse) triangular loading function, and a rectangular (instead of a trigonometrical) resistance function

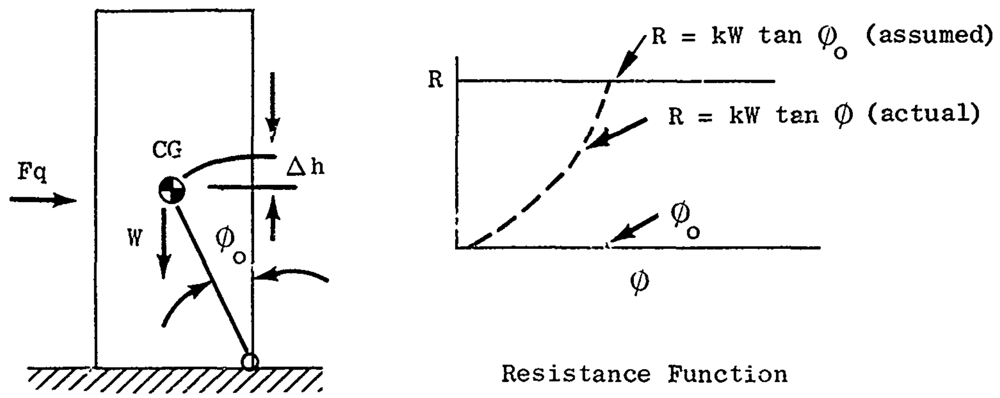

Fig. 12. Schematic Overturning Structure with Actual and Assumed Resistance Functions

These conditions reflect a substantial simplification of the actual problem, but do enable a preliminary investigation of a complex problem by relatively simple hand calculations.

The fictitious maximum work E_m, done on a mass M by an impulse (integrated force time function) H, is

$$E_m = \frac{H^2}{2M}$$

The amount of this "available" energy absorbed into a particular plastic system during any time interval is a direct function of the difference between the average value of the applied load and the plastic resistance to motion during that time interval. The conservative assumption of a constant, i.e., rectangular, resistance function instead of a more correct trigonometrical function enabled Fig. 13 (from Ref. 9) to be used for determination of the amount of energy absorbed into the system.

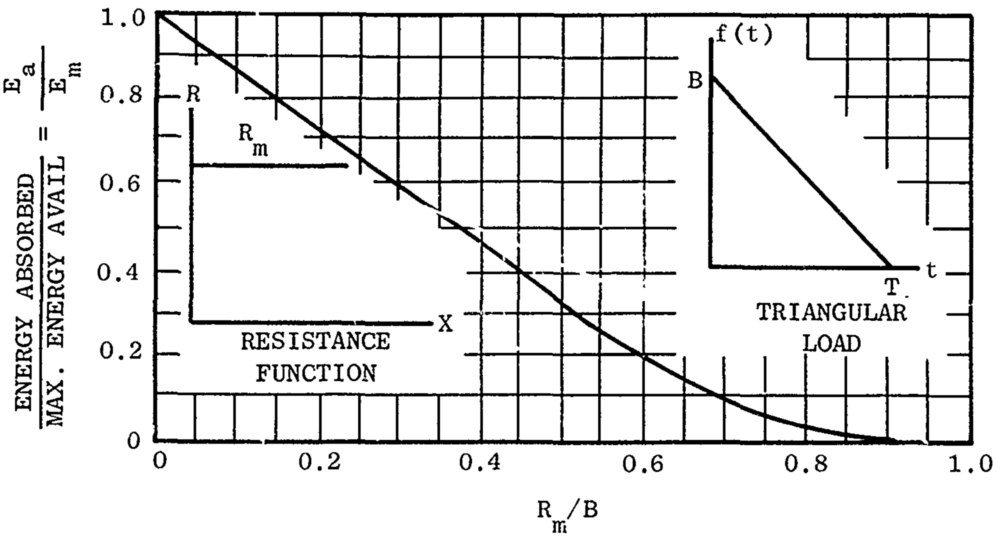

Fig. 13. Absorbed-Energy Ratio vs Load-Resistance Ratio for Triangular Load and Rectangular Resistance Function (from Ref. 9)

If it is assumed that there is no vertical deflection at the point of rotation, the amount of energy absorbed to bring the structure to the point of unstable equilibrium ($\theta = 0$) would be equal to $W(\Delta h)$.

The threshold of overturning would then be passed when the energy absorbed E_a exceeds $W(\Delta h)$, i.e.,

$$E_a = \left(\frac{E_a}{E_m} \right) \times \frac{H^2}{2M} \geq W(\Delta h)$$

Higher overpressure levels for overturning are obtained by assuming resistance constant since the energy absorbed would increase as resistance to motion decreases.

A plot of these overpressure values for threshold of overturning as a function yield is shown in Fig. 14. In Fig. 15, the overpressure-vs-yield functions for severe damage to multistory structures (from HOB charts, Ref. 4), are superimposed on the curves for overturning.

As can be seen, for the taller buildings acted upon by the larger yield weapons and especially for the more substantial structures, overturning would take place at a lower overpressure level than that required to produce severe damage. For these structures, therefore, overturning could well be the controlling damage mode.

A more precise solution of this problem (which could not be executed under the present contract), would include the following:

1. consideration of strain energy absorbed and relinquished in the structural system
2. evaluation of all motion instead of just solid-body rotation
3. evaluation of foundation effects
   a. punching
   b. shear
   c. point of rotation locations for structures with basements
4. evaluation of aerodynamic lift and drag coefficients for damaged structures (which damage can vary from window breakage to denuded decks)
5. consideration of "angle of attack" changes in the forcing function as denuded or semi-denuded decks rotate
6. solution of the actual equations of motion for rotation

The basic equation of motion of overturning (see Fig. 16) would be:

$$J_{o-o}\ddot{\Theta} + F_{hd}d' + Wr\cos(\Theta + B) = M_o(\Theta, t)$$

J_{o-o} = polar moment of inertia about point of rotation

$\ddot{\Theta}$ = angular acceleration

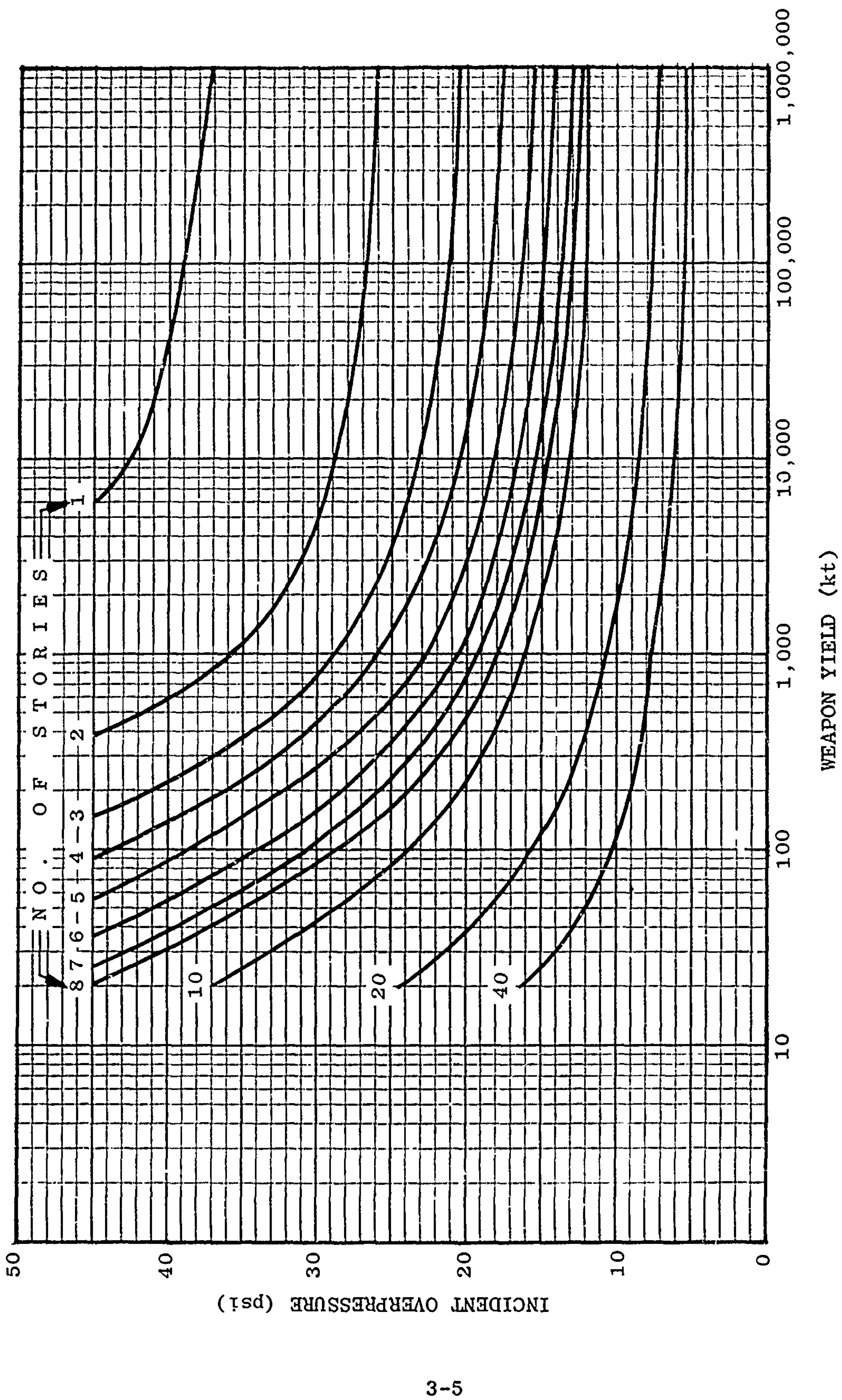

Fig. 14. Threshold of Overturning Curves for Various Story Heights as a Function of Incident Overpressure and Weapon Yield

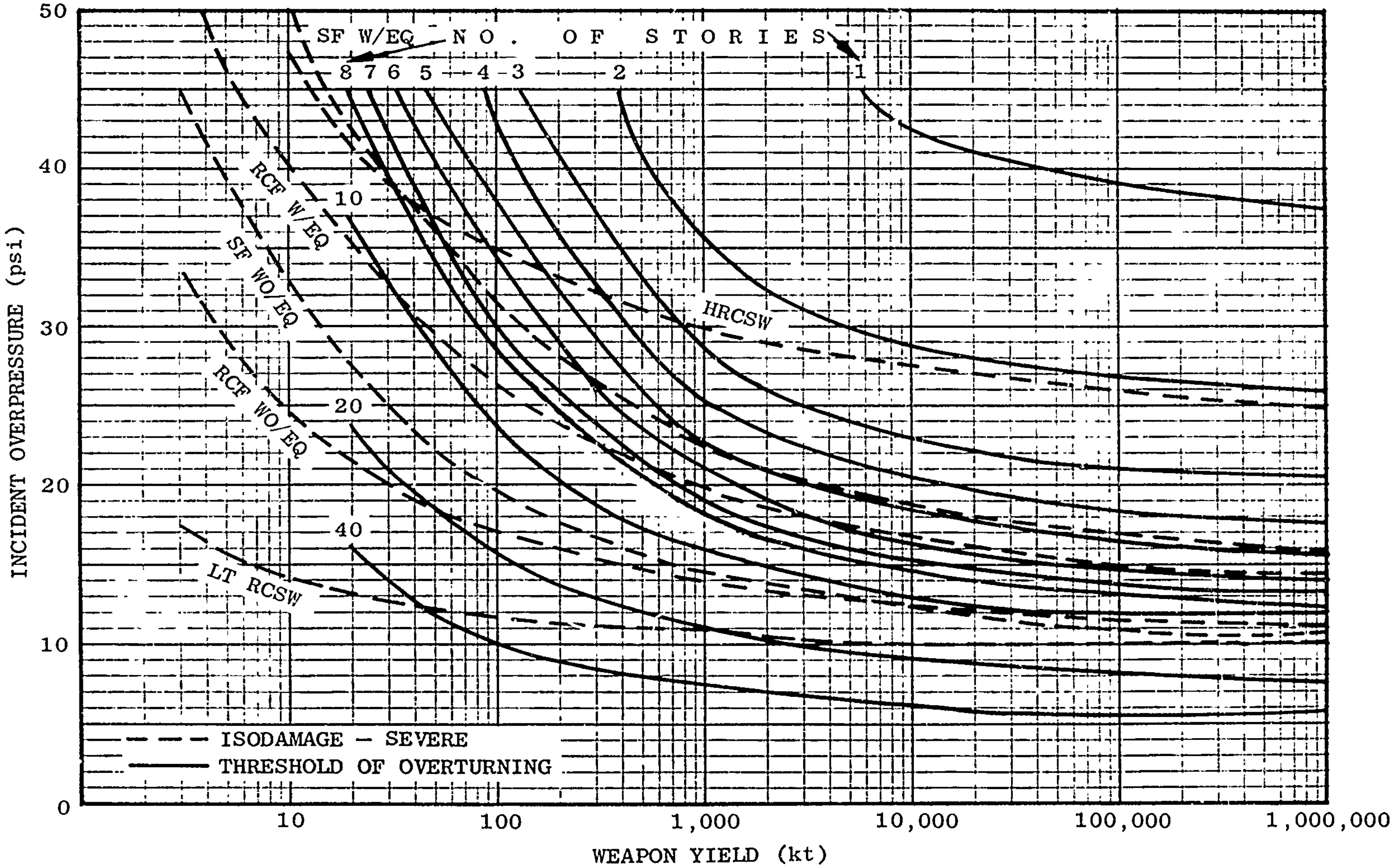

Fig. 15. Threshold of Overturning Curves (Fig. 14) Superimposed on Isodamage Curves (from Ref. 4 - HOB Charts,. NOTE: Abbreviations of structure types are explained in Table A-1 and Fig. A-5.

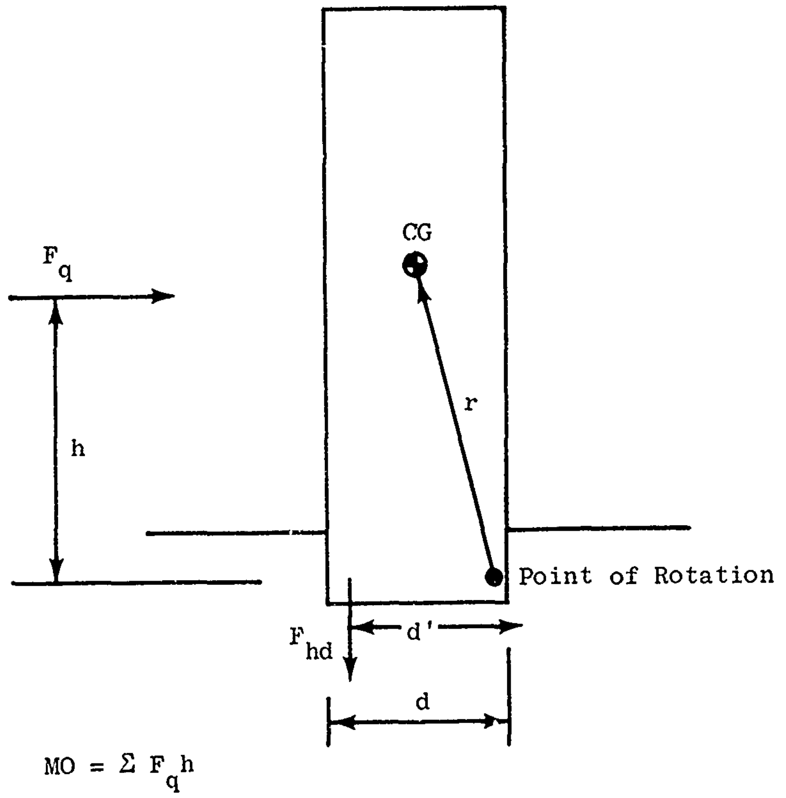

Fig. 16. Schematic Overturning Model

F_{hd} = any hold-down force that may be present (such as uplift resistance of piling)

d' = distance between line of action of hold-down force and point of rotation

W = weight of building

r = radius of gyration of building

Θ = angle of rotation

B = angle between the horizon and a line joining the center of mass with the point of rotation (angular location of mass center)

M_o = moment couple of applied forces about point of rotation

$M_o(\Theta,t)$ = moment couple as a function of angle of rotation and time

Should the hold-down force be discontinued, the term $F_{hd}d'$ would become zero and the equation of motion subsequent to that event would become:

$$J_{o-o}\ddot{\Theta} + Wr\cos(\Theta + B) = M_o(\Theta,t)$$

Subsequent to passage of the blast wave, the term $M_o(\Theta,t)$ also becomes zero and the equation of motion reduces to:

$$J_{o-o}\ddot{\Theta} + Wr\cos(\Theta + B) = 0$$

or if a hold-down force is still acting

$$J_{o-o}\ddot{\Theta} + F_{hd}d' + Wr\cos(\Theta + B) = 0$$

Section 4
DEBRIS DISTRIBUTION

Debris has been classified with respect to location into two categories – on-site debris and off-site debris – depending on whether the debris stays within the confines of the building site or is transported from the building by virtue of failure processes (e.g., falling walls) or ejection by the blast wave.

Methods were derived and general rules established (in Ref. 2) to estimate the distribution of debris formed by fire effects on undamaged and blast damaged structures. In some of these cases (for fire damage) it was relatively easy to predict whether the debris would fall on-site or off-site, but in others it was quite difficult, if not impossible. In these more difficult situations, probabalistic approaches were employed.

The prediction of the final resting place of air-blast-formed debris is an even more complex problem. Many factors are involved, some of which can be evaluated within the present state-of-the-art and others which can be evaluated only by statistical appraisal. In the first category are such factors as the physical dimensions and characteristics of a building and its contents, the weapon size and location, pertinent target conditions and environment, and idealized weapon phenomenology, from which overpressure, drag pressure, positive-phase duration, etc., can be predicted.

In the second category are such factors as the modification of the blast wave by city complexes; the behavior of the blast wave within the building itself; the time taken for an element to fail or an object to be separated from the structure; the size and shape of particles resulting from fractured elements; the path of the debris particles within the structure; the partitioning of energy between, and further fracturing of, colliding particles, and the amount of damage done by these particles in colliding with other elements; time lapse between arrival of the shock wave and ejection of the particle; and particle velocity vectors at time of ejection.

Once a particle is formed and out of a building with some initial velocity, its initial path can be predicted (if the ambient blast environment is predictable) by consideration of transport via blast winds. This return to predictability is relatively short-lived, however, since present knowledge does not permit calculation of trajectory history beyond the time of collision with another particle, building, ground surface, street surface, or pile of previously deposited debris. At that time the particle would take on a new velocity and direction or might break up into several smaller particles, each with its own characteristic motion. Debris previously at rest could also be further broken up and set in motion by these subsequent collisions.

It is quite evident that these complexities would preclude precise analytical treatment and that an empirical, or at best a semi-empirical, approach should be employed in assessing debris distribution.

Consideration can be given separately to transport of building contents, nonstructural building components, and structural components. Contents, not being firmly attached to a building, will require little time to begin transport. Nonstructural walls, partitions, and appendages will require a longer time to be separated from the building, and thus their initial velocities should be lower and their transport distances shorter. A still longer time will be required to separate elements of the main frame and structural components, or to fail the main frame and main structural components and produce debris without separation.

The drag pressure at the start of transport and the transport capability associated with each weapon size can be considered along with height and type of building, builtupness of area, width of street, adjacent vacant spaces, etc., in formulating interim techniques for debris distribution prediction. Information from bombing surveys, weapon tests, and specially devised tests can provide considerable insight into the problem.

It was planned during this phase of work to utilize trajectories for particles starting at various time delay increments from time of arrival of the shock wave. At the time of this writing, however, only information on brittle-fracture materials (zero time delay) was available.* As a consequence, the procedures presently being used to predict debris distribution were not altered. When these data do become available, in conjunction with other information, they might well enable sufficient improvements to be made in the procedures to merit their general revision.

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* D.I. Feinstein, Debris Distribution, Contract No. OCD-PS-64-50, OCD Work Unit 3322B, IIT Research Institute, March 1966

PART II
APPLICATIONS

Section 5
GENERAL

The applications of research described in this section are primarily in support of the Five-City Study recently initiated by the Office of Civil Defense. This study has as its purpose the accomplishment of three main objectives (Ref.10):

1. To accomplish a detailed exposition of the effects of various attack conditions on five selected localities; to evaluate and measure the performance of current and alternative future civil defense capabilities; and to apply the results of these point-by-point analyses to the development of improved generalized assessment methods.

2. To provide an orderly framework and a set of high-quality specific nuclear attack situations for use in the prosecution of the OCD Research program.

3. To provide a vehicle for the evaluation of research results, preparation of studies for operational use, and the improved definition of program objectives and research requirements.

The first iteration of this program is primarily concerned with evaluation of the integrated present state of the art in assessment methods. Since this involves a large number of specialists in the various technical areas and phases, it becomes imperative that all those involved use a common data base, especially in light of the common occurence of the output of one phase or portion of the study becoming the input to one or more others. Although some portions of the data base may be produced through judiciously selecting one of the five cities as the geographic area to be used in the normal course of research work of this nature, in order to avoid redundant synthesis or production by each user, much of this basic information would have to be developed as a service to the study by specialists in the particular areas involved. As part of this service, URS Corporation in conjunction with their research under Work Unit 3312B was selected to furnish the following predictions:

1. Vegetation effects

2. Building damage

3. Debris production and characterization

These predictions are confined primarily to the city of San Jose, the first city to be studied.*

The basic input data used in making these predictions were obtained from the following sources:

Target Data

Aerial photo mosiacs

flown July 17, 1963 – U.S. Department of Agriculture

Quadrangle sheets

U.S. Geological Survey 1953, 1955 and 1961 issue dates

Land Use Map, 1963

Santa Clara Planning Commission

Climatological records, June through September 1963

U.S. Department of Commerce Weather Bureau

On-site reconnaisance, Jan 18 and August 23, 1966

URS Corporation

Sanborn Maps

Weapon Data (Ref. 10)

Size	5 Mt
Location	lat. 37°27'35" N., long.122°03'29" W
HOB	14,500 ft
Time	8:52 pm PDT, August 24, 1965

* Damage descriptions for a few structures in Detroit were, however, also prepared by special request of Research Triangle Institute (RTI), who were concerned with damaged-structure protection factor (PF) studies – Work Unit 3233B.

Attack Environment

Overpressure-vs-Distance plot

Stanford Research Institute (Ref. 11)

Thermal Flux vs Distance

Naval Radiation Defense Laboratory (Ref. 12)

Technical Data predictions include reports, plans, special photographs, etc.

Presently developed prediction models, were used as much as possible, but further effort was required to assemble and digest information for making damage predictions for specific buildings and for development of charts for prediction of debris as a result of destruction of trees.

Section 6
VEGETATION EFFECTS

The vulnerability of vegetation to nuclear attack is dependent on two primary effects — air blast and fire. The magnitude of destruction by air blast is dependent on the structural and dynamic response characteristics of the vegetation and, of course, the characteristics of the blast wave. Fire vulnerability is associated with the areal distribution fuels and ignitions, the burning and spreading characteristics of these fuels, and, to a limited extent, the amount of blast damage sustained.

AIR BLAST EFFECTS

For this study (Five-City Study attack on San Jose) prediction of air blast effects on vegetation were directed toward determining debris production associated with air blast damage to trees. Air blast damage to trees is generally (in order of increasing severity) in the form of removal of foliage, breakage and removal of branches (crown breakage in the case of deciduous trees), and breakage of the trunk or stump and uprooting (see Figs. 17 through 19).

Air blast damage to forests has been found to correlate with tree size, type, and density and the growing conditions associated with the wooded area. Reference 4, (TM-23-200) which contains a digest of current forest vulnerability information,* groups the various forest types into the following vulnerability categories:

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* Due to typographical errors in Ref. 4, the intended meaning in some instances was unclear. Clarifications were obtained through reference to source material (Refs. 13 through 18) and through conversations with Mr. Fred Sauer, who was instrumental in the development of much of this information.

Fig. 17. Conifer Stand Subjected to 9 psi from Subkiloton Blast

Fig. 18. Deciduous Forest Subjected to 2.4 psi from a Megaton-Range Weapon (Ref. 18). Note extensive crown breakage

Fig. 19. Deciduous Forest Subjected to 4.1 psi from a Kiloton-Range Weapon (Ref. 18). Note extensive destruction

Type	Description
1	conifer – cultivated
2	conifer – unimproved – unfavorable growing conditions
3	conifer – unimproved – favorable growing conditions
4	deciduous – temperature zone (like live oak or cloud forest – above 3,500 ft elevations)
4a	type 4 – defoliated
5	deciduous – rainforest – very dense
5a	type 5 – defoliated
6	deciduous – temperature zone scattered – also orchards
6a	type 6 – defoliated
7	rubber plantation – very little underbrush and dense overlapping crowns

Vulnerability of each of these categories to air blast is presented in the form of isodamage HOB charts using light, moderate, severe, and total as damage descriptors. These descriptors are further defined in terms of percent crown breakage or length of stem down per acre, and percent blowdown as tabulated below:

	Conifer	Deciduous
Light	Not used	50% crown breakage
Moderate	1,500 ft of stem down/acre	750 ft of stem down/acre
Severe	9,000 ft of stem down/acre	7,500 ft of stem down/acre
Total	Over 90% blowdown	Over 90% blowdown

It should be noted that these descriptors do not pertain to any one particular average tree but indicate damage to a population of trees. This agrees with observations of damage to forested areas by wind storms as well as from nuclear tests in that the number of trees blown down correlates with the severity of the windstorm or the magnitude of the drag overpressure and duration; but whether a particular tree will be blown down cannot be predicted.

The reduction of these data to a common base (the percentage of tree breakage or blow down in a forest stand or orchard) required converting length of stem down per acre to percentage of stems down through use of average tree heights and densities for the forest types represented. The data in this form were used to construct the composite tree debris chart (Fig. 20) relating percent debris to overpressure for the various types of forest.

Although some of the forest categories included are not common in this country, the data for all categories were processed and debris charts drawn. This provided further comparisons, and produced charts that could possibly be useful in other studies.

Figure 20 reflects the percentage (by volume) of a particular forest stand or orchard converted to debris as a result of branch and stem breakage or blowdown. In its construction, account was taken of statistical differences of the trees in the particular forest stand (size, shape, strength, fundamental frequencies, rot, knots, roots, fire scars, etc.) and as a consequence, it should be applied to a group of trees, such as a forest stand or orchard (instead of a single tree or average tree), where the tree population is sufficient to encompass and represent average statistical differences. Figure 20 also reflects debris produced by one weapon size (5 Mt) and should not be used for other weapon sizes since trees are drag sensitive (as can be seen from the difference in curves for foliated and defoliated deciduous trees) and the amount of damage (debris) produced at a given overpressure will depend on the positive-phase duration of the dynamic drag pressure, which — in turn — is dependent on weapon size.*

* A single-degree-of-freedom, one-mass, elastoplastic model was used to interpret test results and extrapolate them to various other sizes of weapon (Ref. 4). Although this is the simplest approach, since trees are composed of two separable and dynamically dissimilar elements, i.e., branches and stems, more reliable results could probably be obtained by use of an idealized two-mass system for scaling to other weapon sizes. It may be argued that statistical variations in trees would mask such a refinement, but if the effects of these variations are relatively constant with respect to weapon size, the merits of refinement are apparent.

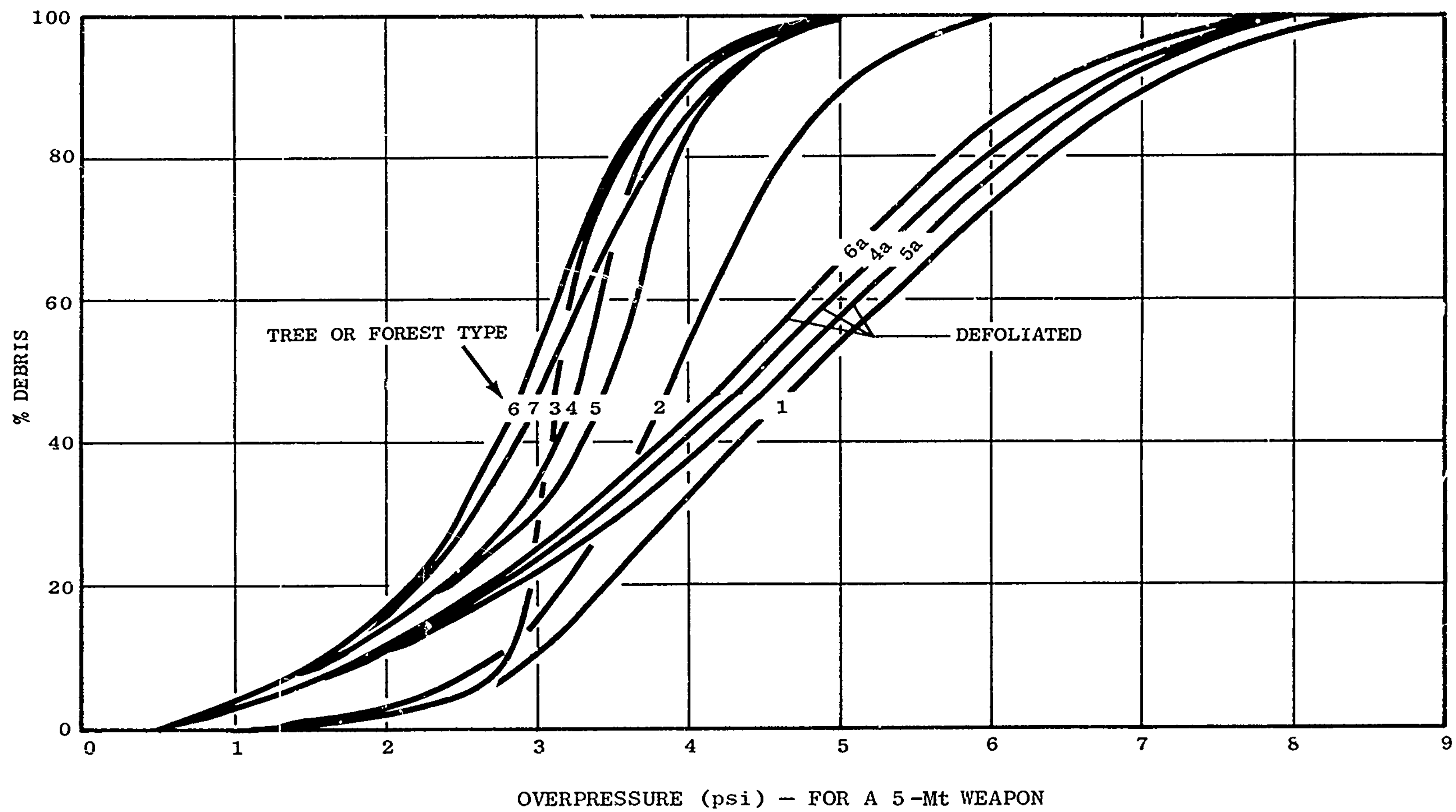

Fig. 20. Tree Debris Chart

PREDICTIONS

Predictions of effects on vegetation, utilizing the tree chart and an existing fire spread model (Ref. 19), satisfied the Five-City Study requirements (Ref. 20) for prediction of initial ignitions and fire spread in the wildland fuels and prediction of the net amount and areal distribution of debris produced from destruction of trees, with the coupled effects of air blast and fire considered.

The land use map, aerial photographs and quadrangle sheets* were used to identify the various wooded, open, and urban areas and provided an excellent cross check of accuracy. Further information on the characteristics of the wildland fuels and tree size, type, and density were obtained from on-site reconnoitering, which also provided an additional accuracy check and served to indicate the changes that had occured during the period of time between issue of source information and the present.

The quadrangle sheets issued in 1961 covering the major portions of San Jose and vicinity were deemed to be sufficiently accurate for use in this study. The quadrangle sheets issued in 1953 and 1955 covering areas to the south and the southern extremity of San Jose were found, however, to be grossly out of date and unusable for this study. This was of minor consequence since only a small portion of the city was involved, and this area is, for the most part, out of range of significant weapon effects.

Initial Ignitions and Fire Spread Predictions

Fuel type, fuel location and weather data provided the basic target information for thermal effects predictions. Weather data prior to, at the time of, and subsequent to the time of attack were used for prediction of initial ignitions and fire spread. Since the ignition of fine kindling fuels depends on moisture content, which is closely associated with the ambient relative humidity, weather conditions at the time of attack were used for prediction

* These maps used coded symbols to indicate vegetation, urban areas, and topography (See Fig. A-2).

of initial ignitions (Ref. 21 and 22). These ignitions were predicted to occur in timber brush and open high-grass areas at about the 10-cal/cm^2 exposure level (for a 5-Mt weapon). This corresponds to an ignition radius of approximately 15.5 miles (from Ref. 12). No ignitions were predicted to occur in the high grass under orchard trees since, in these locations, ignitions would be much less frequent (because of the higher moisture content of the grass and the partial shielding afforded by foliage). Such ignitions would probably be of little importance, in any case, because of much higher ignition densities in adjacent, open, grass-covered areas.

Data on rate of spread (as a function of wind velocity, wind direction and relative humidity given in Ref. 19) were used to predict the rate of spread (in four principal directions) of fire from each ignited patch of fuel.

For the average weather conditions following the attack, the fire was predicted to spread windward at an average rate of 0.042 mph: laterally (to the direction of the wind) at 0.033 mph, and against the wind at 0.028 mph. The fire fronts were expanded by distances corresponding to these rates at 1-hour intervals for the first 6 hours, and at 6-hour intervals thereafter. The spread was continued until the fire front either reached a firebreak,* was in contact with an urban areas,** or was heading away from the city.

The initial ignition radius, location of initially ignited areas, and total burn are shown in Fig. A-3.***

These fires would generally be low ground fires like that shown in Fig. 21 consuming low-lying dry leaves, brush, grass and a portion of the air-blast-formed tree debris. The tree debris likely to be consumed would be small

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* Barren strips, 30 ft wide and 100 ft wide, were considered to constitute firebreaks for grassland and brush-timber fires, respectively.

** Fire spread from urban areas into vegetation was not included in this study.

*** Overlays (drawn to 1:24000 scale) showing the progress of fire at the intervals cited above are on file at the Five-City Study data bank (document No. 5S-11101-3312B-2).

branches, bark, and leaves. The heavier portions (larger diameter branches and tree stems) would probably remain, since fires of this type (see Fig. 22) would have insufficient intensity to consume these high-moisture-content, freshly broken, heavier fuels.

Tree Debris Prediction

Tree type, size, spacing and location constituted the basic target information necessary for prediction of debris depths associated with the destruction of trees.

The location and type of wooded areas were determined primarily from quadrangle sheets. Variations in size and spacing of trees within these areas were determined through inspection of aerial photographs. Categories depicting these variations were established and actual sizes and densities determined by onsite reconnaissance. This information enabled calculation of the solid volume of material (in cubic feet per acre) contained in the trees in each area.

The amount of this material resulting in debris was determined by entering the debris chart (Fig. 20) with the overpressure on the area (from Ref. 11) to obtain the percentage debris production.

In burned areas, these percentages were reduced 5 percent in areas of total destruction to 15 percent in the more lightly damaged areas to reflect estimated* amount of material consumed by fire. The final percentages were applied to the total volume of material to obtain the net volume of debris produced. Using an average density (40 pounds per cubic foot), these values were converted to units of tons per acre** and plotted on a map of the area for construction of debris contours (as shown in Fig. A-4).***

* These estimates were based on review of information dealing with wildland fires and by consulation with persons experienced in this type of fire.

** Tons per acre is considered a more meaningful unit of measure for defining tree debris than debris depth, especially when used with respect to clearance and trafficability problems. If depth is preferred, 72.5 tons per acre is equivalent to 1 in. of solid depth.

*** The original overlay drawn to 1:24,000 scale is on file at the Five-City Study Data Bank, Doc. No. 5S-11101-3312B-2.

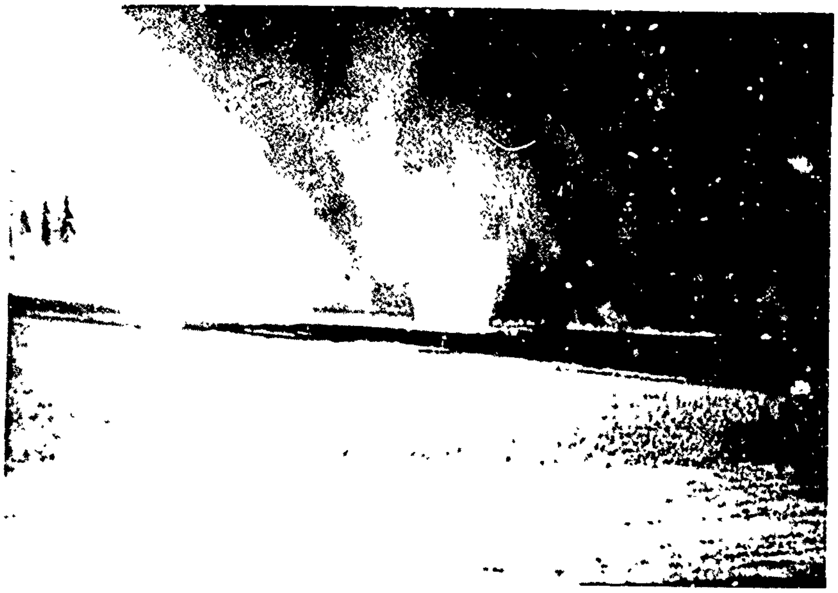

Fig. 21. Typical Grass Fire

Fig. 22. Edge of Grass Burn Under Young Orchard — Outskirts of San Jose. Note unburned stems and larger branches of small trees.

To check seasonal-change predictions based on the January 1966 reconnaissance and to determine more closely what conditions may have existed on August 24, 1965, a subsequent duplicate on-site reconnaissance was conducted on August 23, 1966, which indicated the following:

- All wildland areas would burn and support fire spread. The initial ignition limit taken for these areas is probably on the conservative side, considering the extremely dry conditions observed throughout, especially on the forest floor.

- Foliage on trees in the wildland areas appeared somewhat shriveled in some species and greasy in others, which would indicate that crown fires could be possible during this season.

- Some orchard trees (specially unirrigated) were beginning to turn color and loose leaves.

- Most ground cover in the foothills would burn (open grassland, orchard undergrowth, scrub brush, forest floor materials, etc.).

- At least 90 percent of the open areas assumed to be initially ignited contained highly combustible dry grass or mown stubble that would, in all likelihood, ignite and support fire spread. (See Fig. 23). Those portions that would not ignite were either recently plowed, used for growing crops such as tomatoes and lettuce, or used for floricultural purposes.

- All untilled areas contained abundant dry grass and weeds that would burn easily (see Fig. 23a).

- About 75 to 80 percent of the orchards were recently disced and harrowed (See Fig. 24). This operation was observed in progress in several of the orchards. About 15 to 20 percent of these would still support fire spread (marginally) through the unburied stubble (See Fig. 25)

- In the unharrowed orchards, the undergrowth consisted of a fresh crop of broadleaf weeds (in irrigated or high water table areas), and dry grass and scrawny weeds (in unirrigated areas). About 60 percent of the weeds were of the dry variety and would burn. The remaining broadleaf variety would probably not burn or support fire spread in the relatively low-heat ground fire.

From discussions with local agriculture authorities, it was indicated that the harrowing and discing operations observed in process in several of the orchards would have, all other things being equal, taken place before August 24, 1965. Therefore, it is felt that the orchard undergrowth constitutes less of

Fig. 23a. A Typical Open Area Containing Dry Grass and Weeds

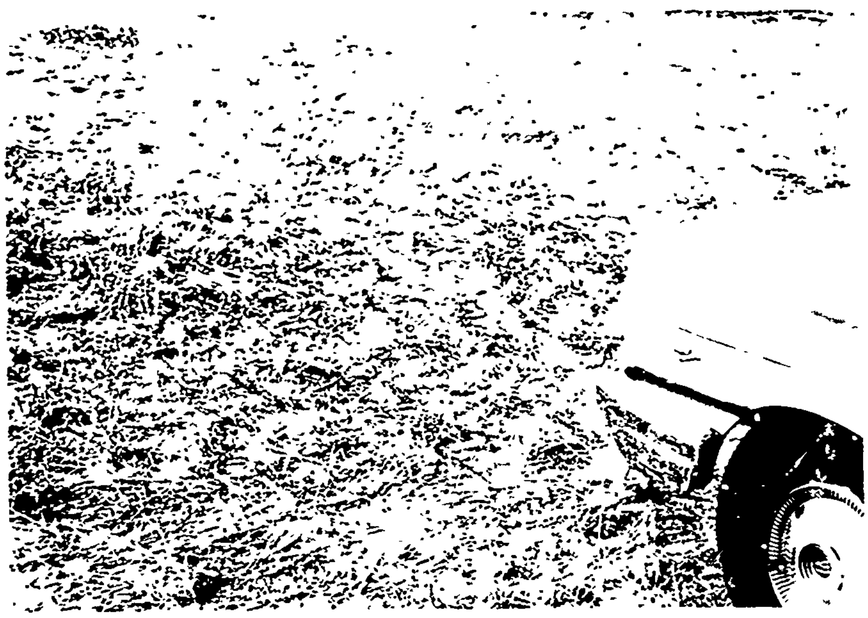

Fig. 23b. Mown Stubble

Fig. 24a. Orchard Trees in January 1966. Note grass and weeds.

Fig. 24b. View (in August 1966) of Same Area as Shown Above. Note discing operation and foliage density.

Fig. 25. Unburied Stubble — Could Support Fire Spread Marginally

a fire hazard than depicted by the overlays. On the other hand the fire hazards in wildland fuels would be more severe, especially with respect to ignition limits. Fires in open grassland areas would be about as predicted.

The net amount of debris formed would be somewhat greater (about 10 percent) in many orchard areas, considering the absence of fire (in areas recently harrowed and disced, irrigated, or containing green broadleaf weeds). In wildland areas, however, the amount of debris would likely be less than predicted since a greater percentage of material would probably burn due to the extremely dry conditions observed.

SUMMARY

It can be concluded from this study that the existing model for prediction of fire spread in urban fuels and the developed method for predicting debris from destruction of trees are relatively easy to combine and apply, and information is readily available which enables determination of vegetation type and location to a much higher level of detail then anticipated.

It is also significant to note that, in addition to seasonal changes, fire hazards in rural areas can be changed considerably in a very short period of time by human activity (plowing, harrowing, irrigation, harvesting, cleanup operations etc.).

Section 7

BUILDING DAMAGE PREDICTIONS

Building damage predictions for this study fell into two general categories; those conducted specifically to satisfy other Five-City Study contractors' needs (detail and output format coordinated with requestors), and those to satisfy requirements set forth in the specifications for damaged target model 5X-11101-4000-A (Ref. 23), which are summarized as follows:

Task Definition

Furnish detailed descriptions of damage to buildings and their mechanical equipment resulting from blast overpressure, dynamic pressure, ground shock and fire

Form and Extent of Output

1. Detailed descriptions of damage to individual buildings in samples
2. Descriptions of special situations and indications of special problems
3. Overlay identifying class of damage to class of building (e.g., severe damage to wood frame dwellings)
4. Detailed maps of sample areas showing class of damage to individual buildings

The organizations and work units for which individual building damage predictions were made are listed below:

WORK UNIT	DESCRIPTION	ORGANIZATION	NO. OF BUILDINGS	CITY
3233B	Revised PF	RTI	5	Detroit
2411H	Damage to people	Dikewood	4	San Jose
3423A	Food	SRI	12	San Jose
4000	Attack environment spec.	Five-City Study	32	San Jose
		TOTAL	53	

In an effort to supply damage predictions that would possibly be used by other contractors (other than the three who submitted damage prediction requests), and in the absence of specific requests, it was decided to select representative structures out of the sample areas chosen for debris predictions (See Fig. 30). Figures 26 through 29 are representative examples of the damage predictions for the 53 buildings studied.*

These predictions will in all likelihood not satisfy the varied requirements of the many contractors working on the Five-City Study but will provide a good basis of comparison, at least, for structural damage in San Jose (since the debris samples were chosen to be representative of the city composition). They are, however, considered adequate to satisfy the damage target model requirements 1 and 2 (see task definition).

Figure A-5 was constructed to satisfy requirement No. 3 (overlay identifying class of damage to class of building). Damage (light, moderate, and severe) is depicted in the form of damage radii for each building type. Light damage for all structures is shown extending to the 1-psi level at 32.5 km from ground zero. The damage level sustained by any of the building types represented can be obtained by determining the distance from the building to ground zero and comparing this to the damage radii.** Descriptions of the general levels of damage (light, moderate, and severe) are given in Table A-1.***

Due to the low overpressure on the city, Item 4 — to furnish maps of sample areas showing class of damage (light, moderate and severe) to individual building — can be satisfied merely by noting that all structures in San Jose will suffer only light damage out to 32.5 km from GZ except for wood frame

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* These are on file at the Five-City Study Data Bank. Document No. 5S-11101-3312 B-3.

** 1:24000 overlay available at Five-City Study Data Bank

*** These descriptions have been expanded from those contained in Refs. 4 and 24.

BUILDING ENVIRONMENT AND PHYSICAL DESCRIPTION

Building Name:	Valley Fair Shopping Center
Address:	San Jose
Incident Overpressure:	2.4 psi
Fire-resistant construction	Yes
Souce Building Information	Sanborn Map No. 248
Building Type	Mostly steel frame
Description:	1 story and basement
Exterior Walls:	Glass and metal lath and plaster
Interior Walls.	Metal lath and plaster
Roof:	Gypsum roof with compostion roofing
Floors:	Reinforced Concrete

BUILDING DAMAGE AND DEBRIS DESCRIPTION

Glass:	Out
Doors:	40 percent removed
Suspended Ceiling:	Removed
Heating and Venting	Bent and partially torn loose; insulation removed
Roof:	Some vents torn out; some composition roofing removed
Floors:	No damage
Exterior Walls:	Walls on blastward side (unshielded) 25 percent blownout; other walls bowed and distorted
Interior Walls:	Cracked and distorted, 5 percent removed
Frame:	No damage
Remarks:	Light damage; shielding reduces damage to interior shops. Fire damage, if present, would be light; combustibles would be consumed.

Fig. 28. Building Damage Prediction (shopping center in San Jose)

BUILDING ENVIRONMENT AND PHYSICAL DESCRIPTION

Building Name:	Mercy Hospital
Address:	Detroit
Distance From Ground Zero:	3.03 mi.
Incident Overpressure:	11.5 psi
Fire resistant constructions	Yes
Source Building Information	Building plans, photos, Sanborn Map
Building Type and Description:	Single-story, load-bearing masonry with provision for future second story
Exterior Walls:	8-in. block with 4-in. brick facing 12-in. block
Interior Walls:	4-, 8-, and 12-in. block
Roof:	6-in. Flexicor
Floors:	6-in. Flexicor with 2-in. concrete topping

BUILDING DAMAGE AND DEBRIS DESCRIPTION

This building, although more substantial (with regard to resisting blast loading) than the average load-bearing masonry building, is still past the threshold of collapse and can, therefore, be assumed destroyed.

There is good likelihood that the basement will receive a major portion of the debris from failure of overhead floors and roof and approximately 70 percent of debris from overhead panels.

Fire, if present, would consume major portion of combustible debris.

Fig. 29. Building Damage Prediction (hospital in Detroit, Michigan)

Fig. 30. Sample Areas, San Jose

buildings and that moderate and severe damage radii for all other structures fall short of the city.

In the interest of avoiding the administrative coordination and execution burden of providing damage predictions in varying number and degrees of detail to the other user organizations (some not specifically identified at this time), the numerous bits and pieces of damage information should be assembled into a coherent work and published as a state-of-the-art report so that user organizations could perform, through use of this document, all (or at least most) of their own damage predictions.

Section 8
DEBRIS PREDICTION

Debris predictions for San Jose were made in accordance (where possible) with the Five-City Study specifications for Damage Target Model (Ref. 23), which are summarized as follows:

Task Definition

Furnish predictions of the fragmentation, displacement, and disposition of structures and vehicles by overpressure, dynamic pressure, and fire

Form and Extent of Output

1. Overlays showing depth and coverage of debris (including voids and fire loss) resulting from demolition of structures and vehicles

2. Plan views showing trajectory path, velocity, and sizes of debris being translated

Note: Debris resulting from structure and vehicle demolition will be added to that from vegetation in this output.

Output requirement No. 2 was not satisfied for reasons outlined in Section 4.

The damage function problems (discussed in Section 2, Part I) did not affect the operation of the debris model in making debris predictions for the City of San Jose because attack overpressures (below 3 psi) were generally below the range of overpressure in which the difficulties were encountered.

For reader convenience, a description of this model and its operation is included (for further detail on charts, tables, and other data, refer to the consolidated information contained in the appendix of Ref. 3 (URS 651-4).

Section 9
MODEL DESCRIPTION

The debris prediction model is designed to provide a means of predicting the amount of debris that would be produced by blast and fire effects of a nuclear attack on an urban area. As such, the ouput can be in the form of general debris depth contours covering the entire city or more accurate debris depths in specific locations or along routes into or through the city. The contours can be used to gain a general picture of the debris problem over the entire city and, in addition, can be invaluable in solving specific, more detailed problems, such as selection of least-obstructed routes.

The model does not include means for determining fire spread, but it can be integrated with a fire spread model for determination of the limits of fire-affected areas. Should such fire spread information not be available, the debris estimates can be bracketed by arbitrarily including and excluding fire effects in specific portions of the city.

To facilitate the use of the model, input information required is briefly described in this section of the report, and the sources through which this information can be obtained are tabulated and discussed. The section also includes a step-by-step outline of the model's operation and indication of how each step is to be carried out.

INPUT DATA

Input data required for operation of the model include weapon size and location and city layout, with detailed information on buildings and structures within the city. In addition to these, meteorological data are required for prediction of fire effects. The meteorological data can be obtained from weather records and the attack information estimated or synthesized. The city data (which comprise the major portion of input data) can be obtained from the following sources:

1. Quadrangle maps
2. City street maps
3. Land-use maps
4. Buying-power maps
5. Aerial mosaics
6. Sanborn maps
7. On-site reconnaissance
8. Miscellaneous: panoramic photos, zoning maps, building regulations, etc.

General topographic information about the city, its prominent features and its surrounding areas, can be obtained from quadrangle maps. These maps are also useful in locating the weapon burst point, since they are accurate as to scale and detail and are referenced in both Geodetic and Universal Transverse Mercator Coordinate Systems.

The street maps provide detailed information on roads, streets, and general layout of the city.

A more detailed concept of the composition of the city can be obtained from land-use and buying-power maps. The land-use maps identify residential, industrial, and commercial districts, and the buying-power maps serve to identify and bound the major subsections of residential areas. These maps are useful in the interpretation of aerial photography from which current integrated information on development and extent of the various areas as well as ground cover and vegetation can be obtained. They are also useful to the planning of on-site reconnaissance, should aerial photography prove inadequate or unavailable.

Detailed knowledge of the sectional composition of the city will enable the efficient selection of Sanborn maps for sample areas in homogeneous sections and for adequate coverage in areas of changing builtupness or in heterogeneous areas. These Sanborn maps are as yet the best readily available source of detailed building information, which is essential to the operation of the debris model.

Should information from some of these sources not be available, the model can still be used, but with a lesser degree of relative accuracy and/or efficiency.

OPERATION

After determination of the objectives of the investigation and assembly of the input data required to satisfy those objectives, the debris model is ready for operation. This involves the following procedure:

1. Determine overpressure vs distance (from size and height of burst of weapon)
2. Determine occupancy, type, and size of building (usually from Sanborn maps
3. Determine overpressure at building's location
4. Enter proper curve (for type of building and size of weapon) with overpressure to obtain percentage of structure converted to debris by:
   a. Blast only
   b. Blast and fire (if in burned area) (see Figs. A-1 through A-16 of Ref. 3)
5. Refer to debris overpressure criteria for contents to determine percent of contents of the building converted to debris (Section 3 Ref. 3)
6. Calculate total structural material volume (see Table A-3, Ref. 3)
7. Calculate volume of contents (see Table A-2, Ref. 3)
8. Apply percentage figures to structural and contents volumes to determine volume of debris from building.
9. Distribute debris.*
10. Repeat for next building.
11. Sum up all contributions and apply void ratio** to obtain debris depths at specific locations.

---

* At present, simplified procedures are used for debris distribution. These can be refined and improved upon when more trajectory data are made available (see Section 4).

** The void ratio (volume of voids divided by the volume of solid material) is assumed to be unity in absence of a measured value.

These debris depths may be used for investigation of specific areas, to plot debris profiles along routes through the city, or as control points for construction of debris depth contours, etc.

OUTPUT

With the aerial photographs, land-use maps, and topographic map, sample areas — shown outlined and numbered on a street map of San Jose (Fig. 30) — typifying the composition of this city were selected. The makeup of these areas was verified by an on-site reconnaissance.

Overpressures on these areas were then determined (Ref. 11). These are plotted in the form of isobars on Fig. A-2.

Building information was obtained from Sanborn maps (see sample, Fig. A-8) and processed via procedures previously outlined (see Fig. A-9) for determination of debris depth control points for debris contour construction.

Due to lack of burn/no-burn input, duplicate calculations had to be performed (1) without fire and (2) with fire. It is significant to note that in the "downtown" section of the city, fire increased the debris depth in some areas from virtually nothing to well over 2 ft, as shown on the enlarged sections showing debris in downtown areas (Figs. 31 and 32).

Debris contours for the entire city are shown on the large sheets (Figs. A-6 and A-7) in the appendix for air blast acting alone and for air blast coupled with fire, respectively. Also shown on these sheets (in accordance) with Five-City study Specs. Ref. 23) is amount of debris (in tons per acre) produced from destruction of trees by both air blast and fire.

DEBRIS DESCRIPTION

To avoid a long and laborious description of the debris represented at each control point, the various types of debris were grouped into major categories (with respect to their origin) and described in further detail under

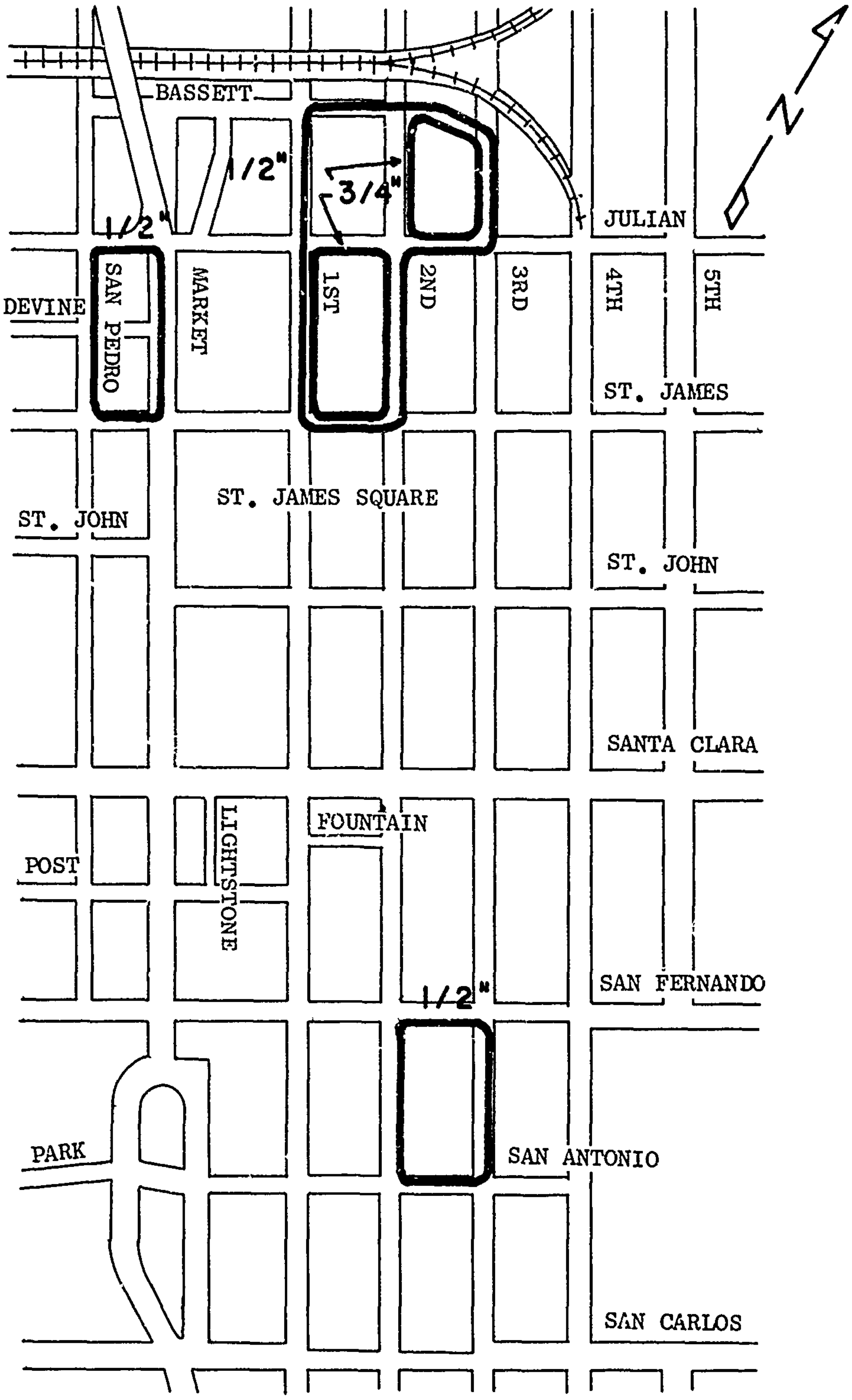

Fig. 31. Enlarged Section, Downtown San Jose Debris Contours (without fire)

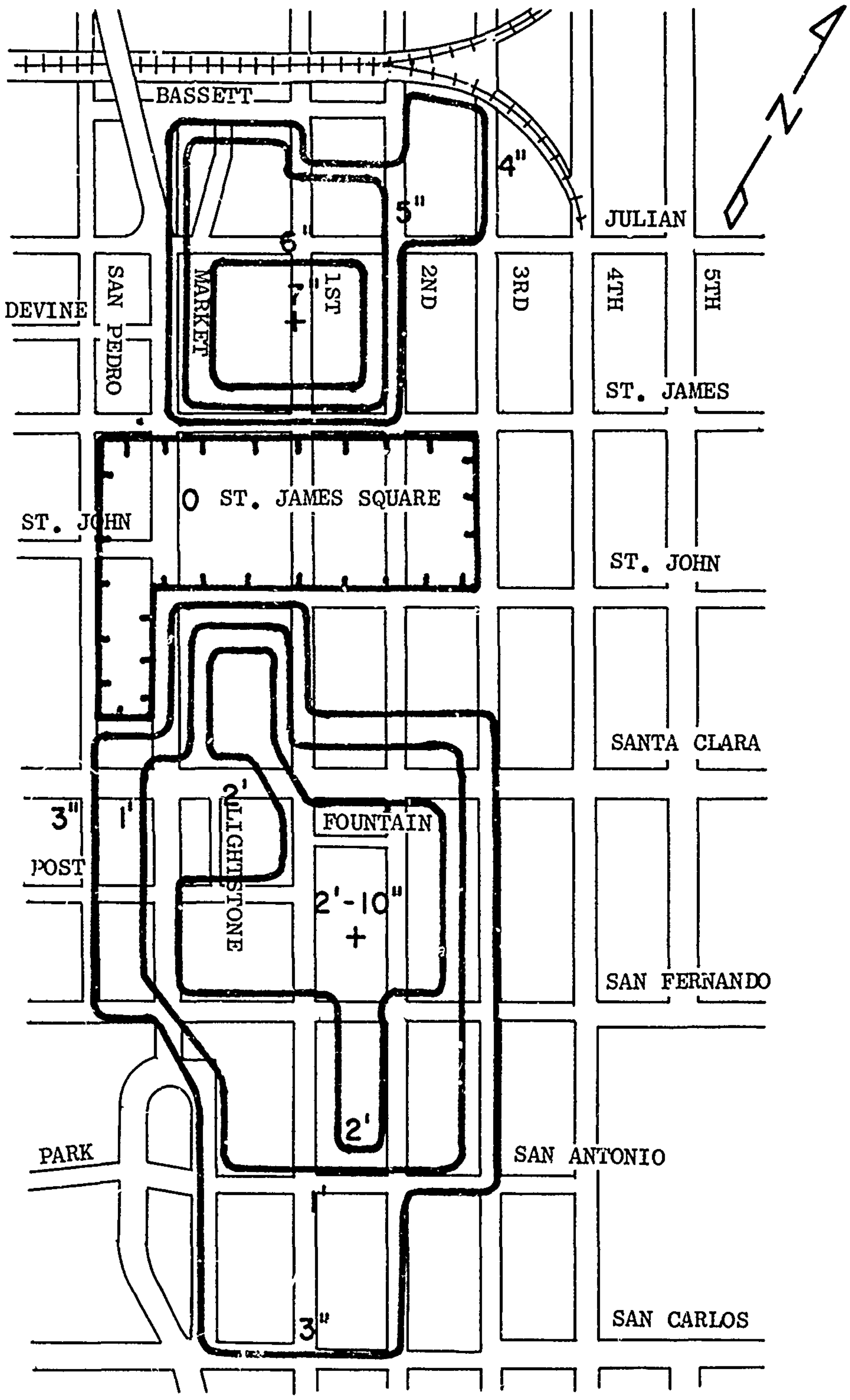

Fig. 32. Enlarged Section, Downtown San Jose Debris Contours (with fire)

subheadings in Table A-2. The debris type and description is then found through cross-referencing to the major types and subtypes by identification numerals and letters contained in Table A-3. The points referred to are identified as to sample area numbers (See Fig. 30), Sanborn map numbers, and reference bounding streets, so that they can easily be located in Fig. 31, 32, A-6 and A-7.

The overpressure on the areas, the zone, structure types, occupancies represented (by percentages), and amplifying remarks are also given in Table A-3.

Section 10
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Appendix A

OUTPUT DATA

Fig. A-1

TOPOGRAPHIC MAP SYMBOLS

VARIATIONS WILL BE FOUND ON OLDER MAPS

Hard surface, heavy duty road, four or more lanes

Hard surface, heavy duty road, two or three lanes

Hard surface, medium duty road, four or more lanes

Hard surface, medium duty road, two or three lanes

Improved light duty road

Unimproved dirt road and trail

Dual highway, dividing strip 25 feet or less

Dual highway, dividing strip exceeding 25 feet

Road under construction

Railroad, single track and multiple track

Railroads in juxtaposition

Narrow gage, single track and multiple track

Railroad in street and carline

Bridge, road and railroad

Drawbridge, road and railroad

Footbridge

Tunnel, road and railroad

Overpass and underpass

Important small masonry or earth dam

Dam with lock

Dam with road

Canal with lock

Buildings (dwelling, place of employment, etc.)

School, church, and cemetery — Cem

Buildings (barn, warehouse, etc.)

Power transmission line

Telephone line, pipeline, etc. (labeled as to type)

Wells other than water (labeled as to type) — o Oil o Gas

Tanks, oil, water, etc. (labeled as to type) — Water

Located or landmark object; windmill

Open pit, mine, or quarry, prospect

Shaft and tunnel entrance

Horizontal and vertical control station:

- Tablet, spirit level elevation — BM △5653
- Other recoverable mark, spirit level elevation — △5455

Horizontal control station: tablet, vertical angle elevation — VABM △9519

- Any recoverable mark, vertical angle or checked elevation — △3775

Vertical control station: tablet, spirit level elevation — BM X957

- Other recoverable mark, spirit level elevation — X954

Checked spot elevation — x4675

Unchecked spot elevation and water elevation — 870

Boundary, national

- State
- County, parish, municipio
- Civil township, precinct, town, barrio
- Incorporated city, village, town, hamlet
- Reservation, national or state
- Small park, cemetery, airport, etc.
- Land grant

Township or range line, United States land survey

Township or range line, approximate location

Section line, United States land survey

Section line, approximate location

Township line, not United States land survey

Section line, not United States land survey

Section corner, found and indicated

Boundary monument: land grant and other

United States mineral or location monument

Index contour	Intermediate contour
Supplementary contour	Depression contours
Fill	Cut
Levee	Levee with road
Mine dump	Wash
Tailings	Tailings pond
Strip mine	Distorted surface
Sand area	Gravel beach

Perennial streams	Intermittent streams
Elevated aqueduct	Aqueduct tunnel
Water well and spring	Disappearing stream
Small rapids	Small falls
Large rapids	Large falls
Intermittent lake	Dry lake
Foreshore flat	Rock or coral reef
Sounding, depth curve — 10	Piling or dolphin
Exposed wreck	Sunken wreck

Rock, bare or awash; dangerous to navigation

Marsh (swamp)	Submerged marsh
Wooded marsh	Mangrove
Woods or brushwood	Orchard
Vineyard	Scrub
Inundation area	Urban area

1 0 1 2 3 4 5 MILES

MILE SCALE 1:62 500

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TOPOGRAPHIC
MAP SYMBOL SHEET
NOVEMBER 1966

QUADRANGLE MAPS, AND QUADRANGLE MAP SERIES

Quadrangle maps cover four-sided areas bounded by parallels of latitude and meridians of longitude. Quadrangle size is given in minutes or degrees. The usual dimensions of quadrangles are: 7.5 by 7.5 minutes, 15 by 15 minutes, 30 by 30 minutes, and 1 degree by 1, 2, or 3 degrees.

Quadrangle map series are map groups of the same size quadrangles. In each series the maps follow a systematic quadrangle pattern, they have a uniform format, and they usually have the same scale.

MAP SCALE DEPENDS ON QUADRANGLE SIZE

The scale of a map is the ratio between a map distance and the same distance measured on the ground.
Map scale is given as a numerical ratio, and by bars marked in feet, miles, and kilometers.

STANDARD SCALES AND PRICES OF THE NATIONAL TOPOGRAPHIC MAP SERIES

SERIES	SCALE		PRICE
7.5 minute	1:24,000	1 inch equals 2,000 feet	$0.50
15 minute	1:62,500	1 inch equals about one mile	.50
1:63,360 (Alaska)	1:63,360	1 inch equals one mile	.50
30 minute	1:125,000	1 inch equals about two miles	.50
1:250,000	1:250,000	1 inch equals about four miles	.75
1:1,000,000	1:1,000,000	1 inch equals about sixteen miles	1.00

CONTOURS SHOW LAND SHAPES AND ELEVATION

The shape of the land, portrayed by contours, is the distinctive characteristic of topographic maps.
Contours are imaginary lines following the ground surface at a constant elevation above sea level.
The contour interval is the regular elevation difference separating adjacent contour lines on maps.
Contour intervals depend on ground slope and map scale; they vary from 5 to 200 feet. Small contour intervals are used for flat terrain; larger intervals for rugged mountain areas.
Supplementary dashed or dotted contours, at less than the regular interval, are used in flat areas.
Index contours, every fourth or fifth line, are heavier than others, and have elevation figures.
Hachures, form lines, and symbol patterns are also used to show some kinds of topographic forms.
Relief shading, an overprint giving a three-dimensional effect, is used on some quadrangle maps.

COLORS DISTINGUISH CLASSES OF MAP FEATURES

Black is used for man-made or cultural features, such as roads, buildings, names, and boundaries.
Blue is used for water or hydrographic features, such as lakes, rivers, canals, and glaciers.
Brown is used for relief or hypsographic features—land shapes portrayed by contours or hachures.
Green is used for woodland cover, with typical patterns to show scrub, vineyards, or orchards.
Red emphasizes important roads, shows built-up urban areas, and public-land subdivision lines.

STATE TOPOGRAPHIC INDEXES SHOW MAPS PUBLISHED

For each State, and for Puerto Rico and the Virgin Islands, indexes show all maps distributed. Index maps give quadrangle location and name, and survey date. Listed also are: special maps and sheets with prices, map dealers and Federal distribution centers, map reference libraries, and detailed instructions for ordering topographic maps.

HOW MAPS MAY BE OBTAINED

Mail orders for maps west of the Mississippi River should be addressed to the Geological Survey, Distribution Section, Federal Center, Denver, Colo., 80225, and for maps east of the Mississippi River to the Geological Survey, Distribution Section, Washington, D.C. 20242. Maps of Alaska may also be ordered from the Geological Survey, 520 Illinois Street, Fairbanks, Alaska 99701. Order by map name, State, and series. Maps without woodland overprint are furnished on request. A 20% discount is allowed on an order amounting to $20 or more, and 40% discount is allowed on an order amounting to $100 or more. Each order for maps should be accompanied by exact payment in cash, or by money order or check made payable to the Geological Survey. Your ZIP code is required.

Sales counters are maintained in the following Geological Survey offices where maps of the area may be purchased in person: 1200 South Eads Street, Arlington, Virginia; 1028 General Services Administration Building, Washington, D.C.; 1109 North Highland Street, Arlington, Va.; 345 Middlefield Road, Menlo Park, Calif.; 7638 Federal Building, 300 North Los Angeles Street, Los Angeles, Calif.; 504 Custom House, 555 Battery Street, San Francisco, Calif.; Federal Center, Denver, Colo.; 15426 Federal Building, Denver, Colo.; 602 Thomas Building, 1314 Wood Street, Dallas, Texas; 8102 Federal Office Building, 125 South State Street, Salt Lake City, Utah; South 157 Howard Street, Spokane, Wash.; 108 Skyline Building, 508 Second Avenue, Anchorage, Alaska; 203 Simpson Building, Juneau, Alaska; and 310 First Avenue, Fairbanks, Alaska.

State indexes and a folder describing topographic maps are furnished free on request.

Private dealers sell quadrangle maps at their own prices. Names and addresses of such dealers are listed in each State index.

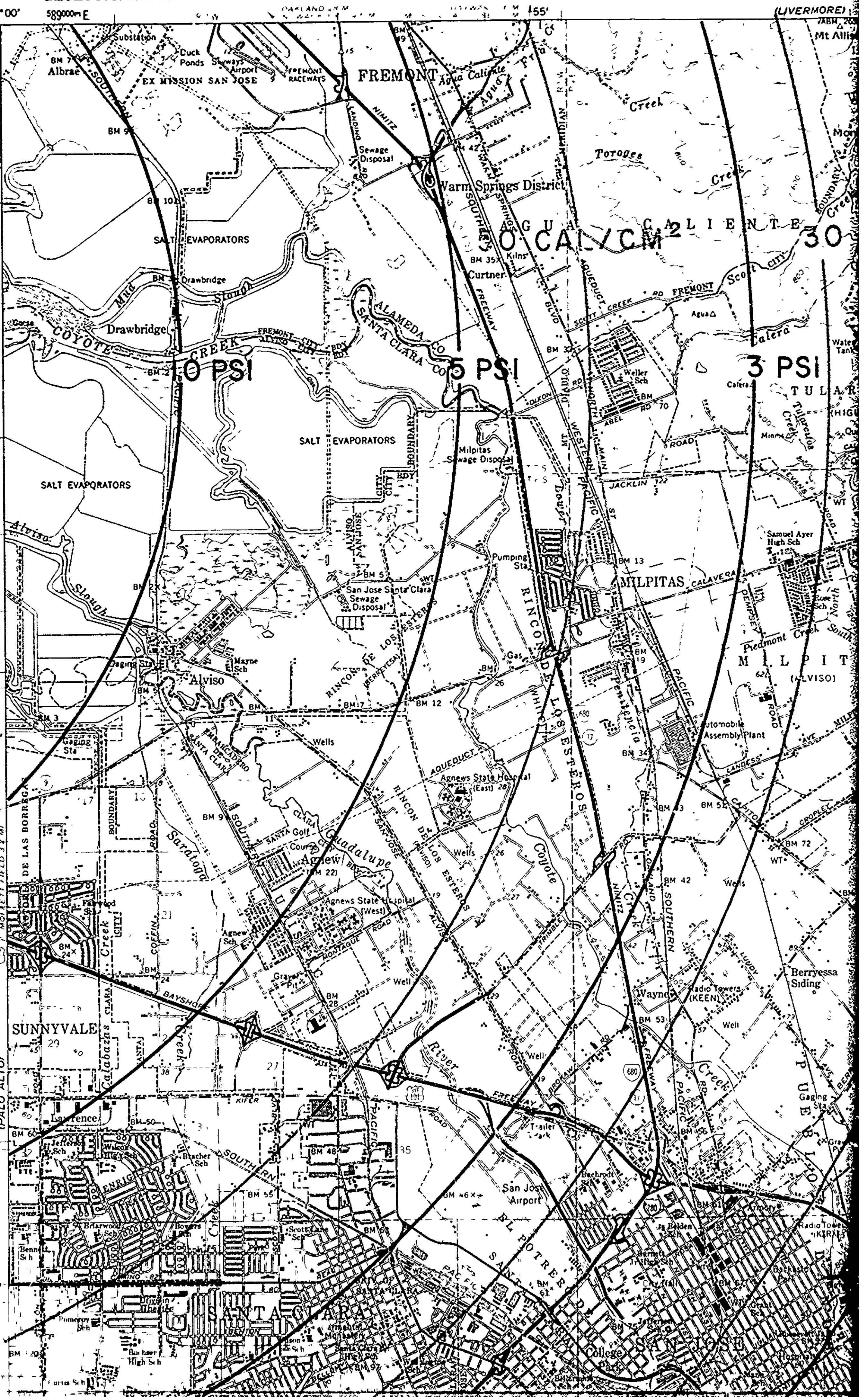
MILE SCALE 1:24 000 — 2 MILES, 1, 0, 5

FOOT SCALE 1:24 000 — 1000, 0, 5000, 10 000, 15 000 FEET

FOOT SCALE 1:62 500 — 5000, 0, 5000, 10 000, 15 000, 20 000, 25 000 FEET

1

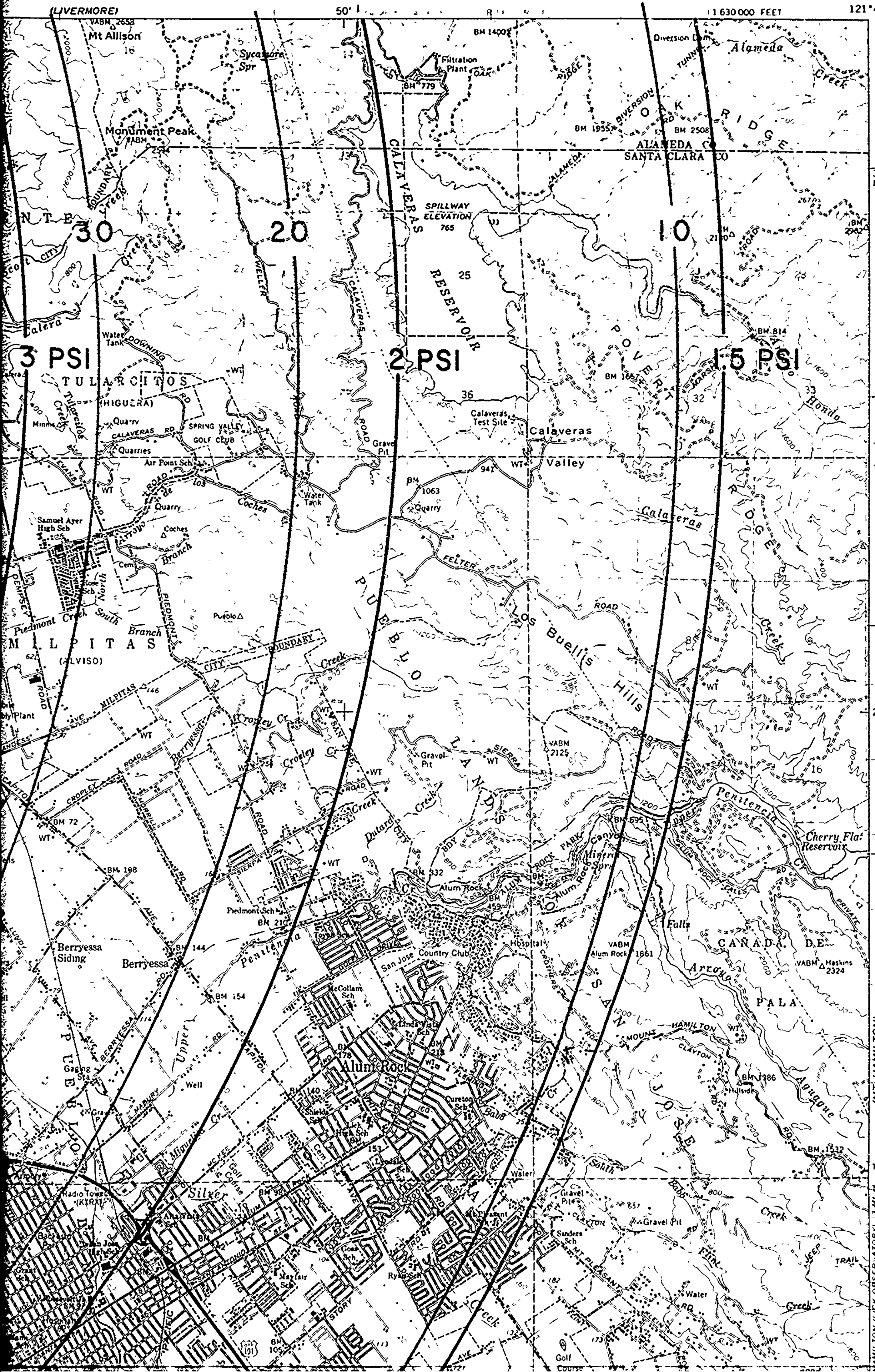
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

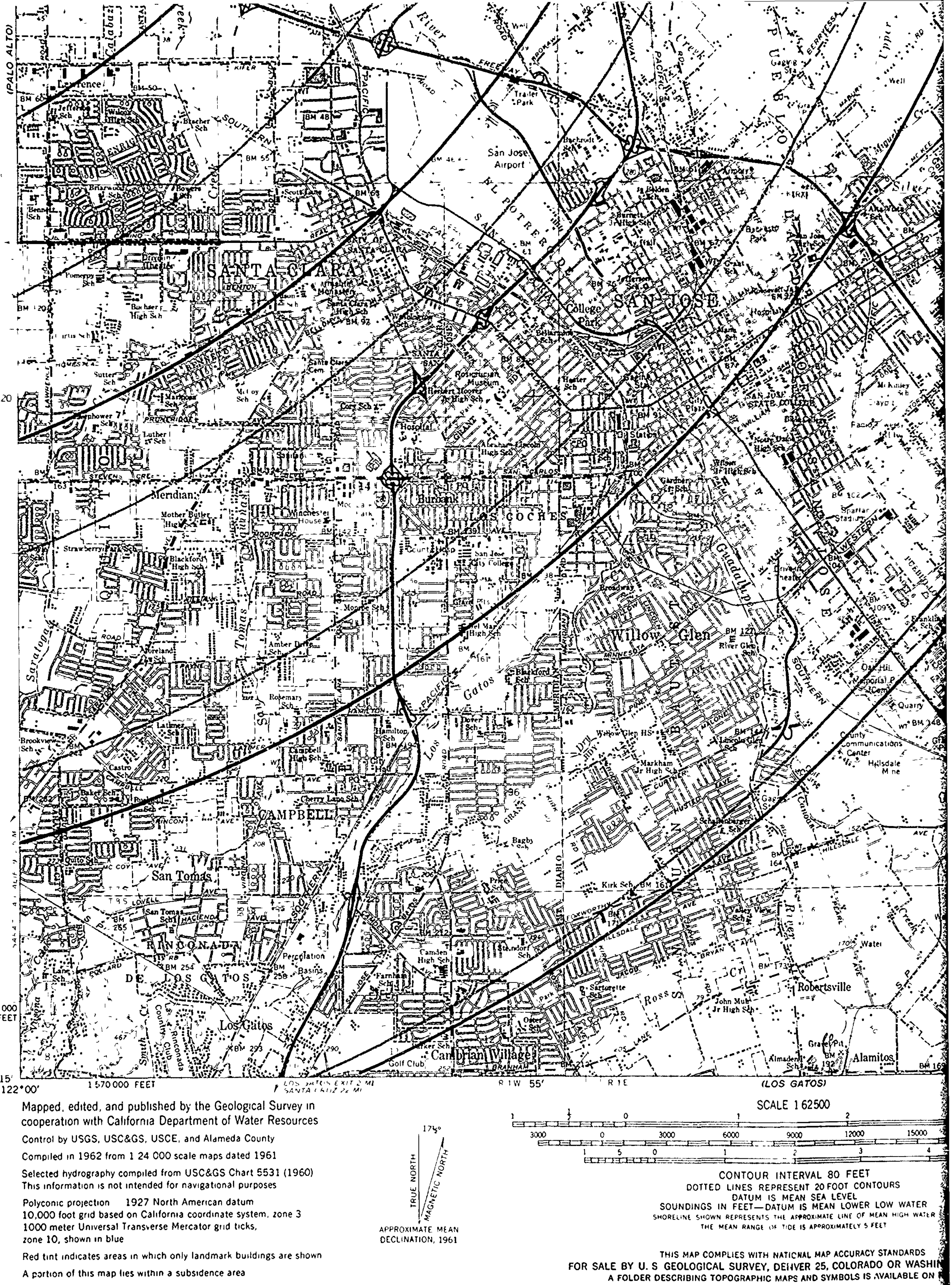


SAN JOSE QUADRANGLE
CALIFORNIA
15 MINUTE SERIES (TOPOGRAPHIC)

A-2

2





Mapped, edited, and published by the Geological Survey in cooperation with California Department of Water Resources

Control by USGS, USC&GS, USCE, and Alameda County

Compiled in 1962 from 1 24 000 scale maps dated 1961

Selected hydrography compiled from USC&GS Chart 5531 (1960)
This information is not intended for navigational purposes

Polyconic projection 1927 North American datum
10,000 foot grid based on California coordinate system, zone 3
1000 meter Universal Transverse Mercator grid ticks, zone 10, shown in blue

Red tint indicates areas in which only landmark buildings are shown

A portion of this map lies within a subsidence area

Areas covered by dashed light-blue pattern are subject to controlled inundation

TRUE NORTH
MAGNETIC NORTH
17½°
APPROXIMATE MEAN DECLINATION, 1961

SCALE 1 62500

1 ½ 0 1 2
3000 0 3000 6000 9000 12000 15000
1 .5 0 1 2 3 4

CONTOUR INTERVAL 80 FEET
DOTTED LINES REPRESENT 20 FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
SOUNDINGS IN FEET—DATUM IS MEAN LOWER LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
THE MEAN RANGE OF TIDE IS APPROXIMATELY 5 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U S GEOLOGICAL SURVEY, DENVER 25, COLORADO OR WASHI
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON R

2

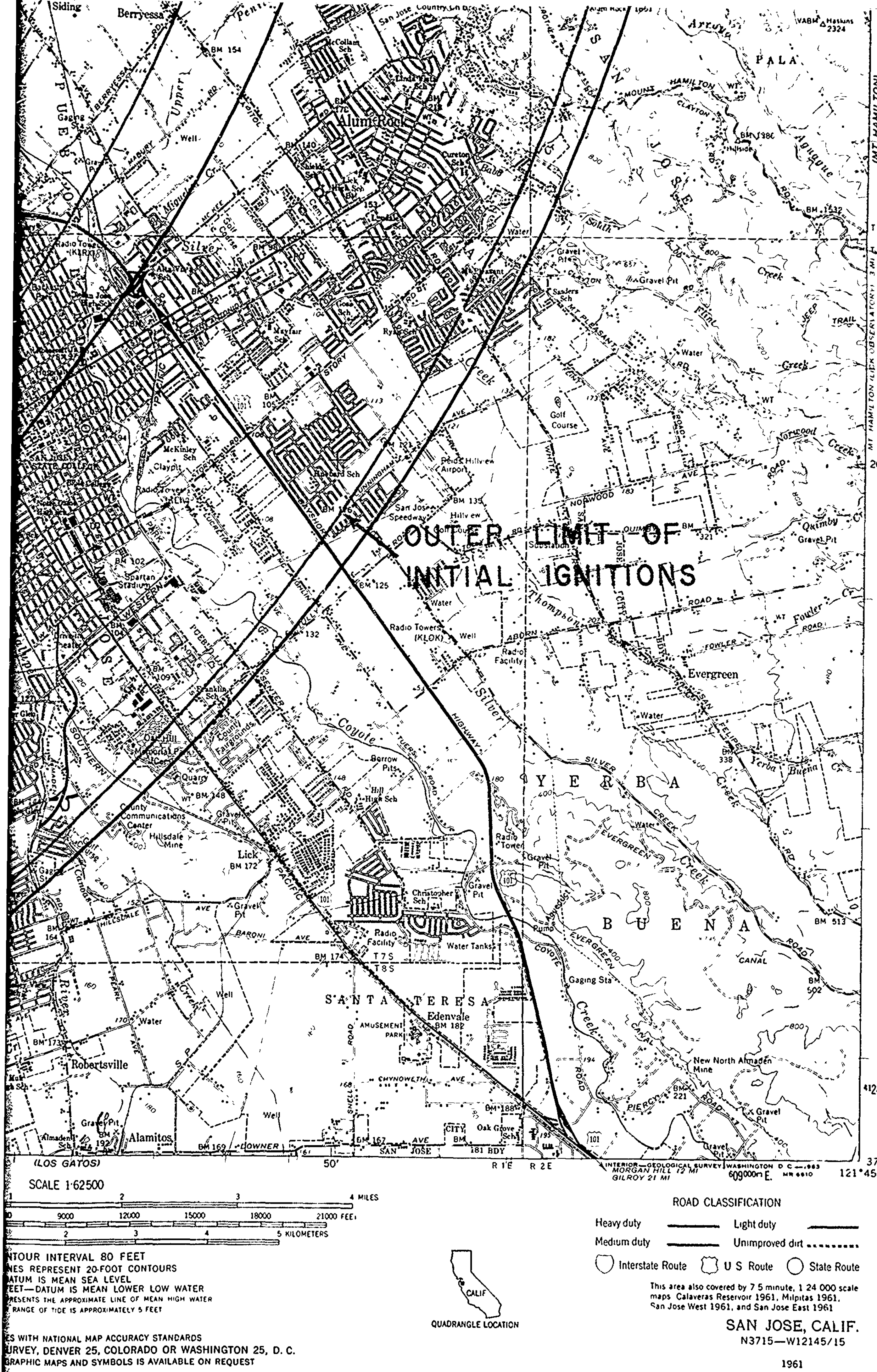


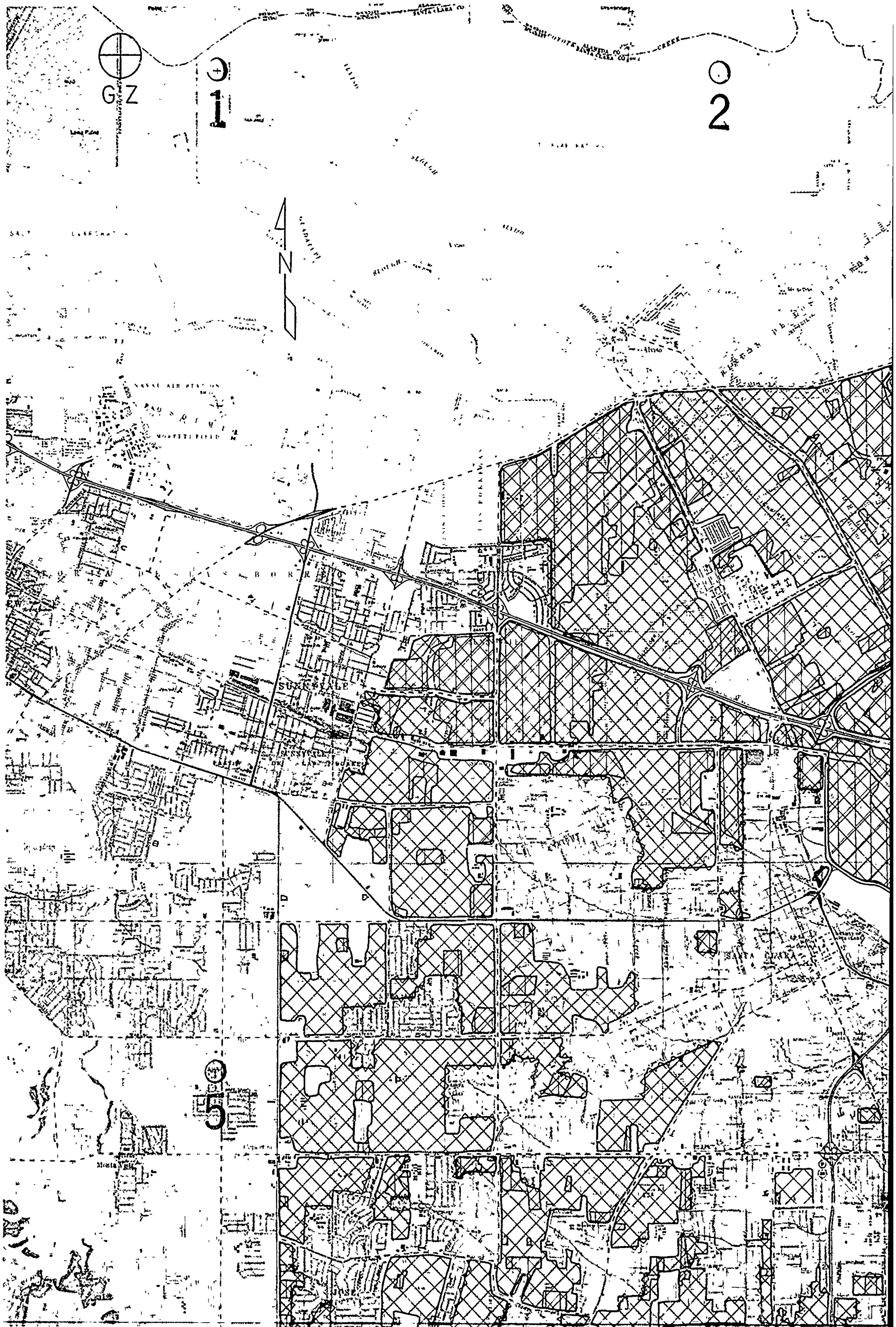
Fig. A-2. Quadrangle sheet with superimposed isobars (black) and isotherms (red) of overpressure and radiant exposure.

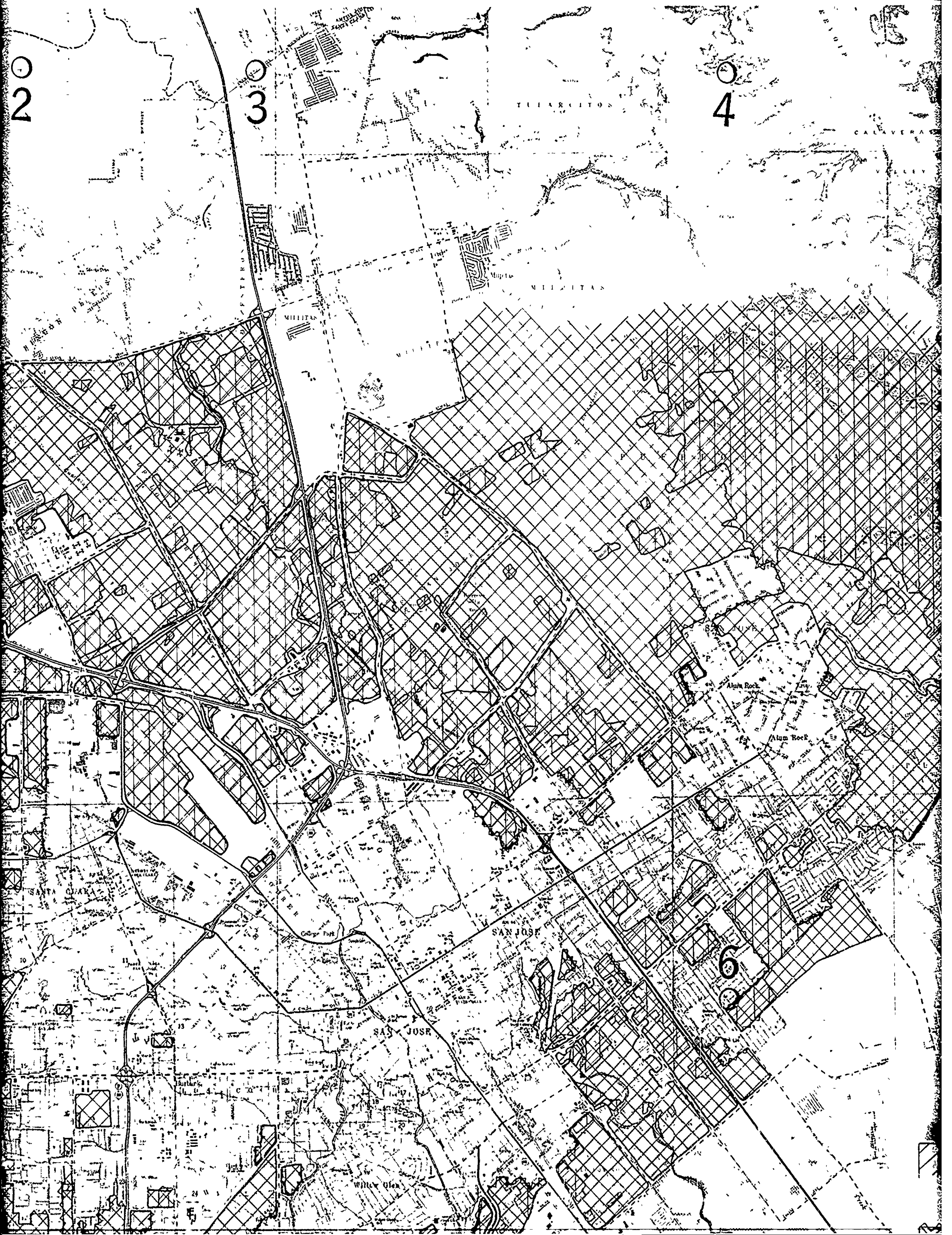
3

The USGS quadrangle sheet (Fig. A-2) has both spherical coordinates (latitude and longitude) and Universal Transverse Mercator coordinates (meters East and North) marked in its margin. Six points on the base maps of Figs. A-3 through A-7 have been identified and their coordinates listed below for both coordinate systems. These points are circles numbered 1 through 4 across the top of the maps, and 5 and 6 on either side of the middle of the maps. Each circle encloses a grid mark on the base map.

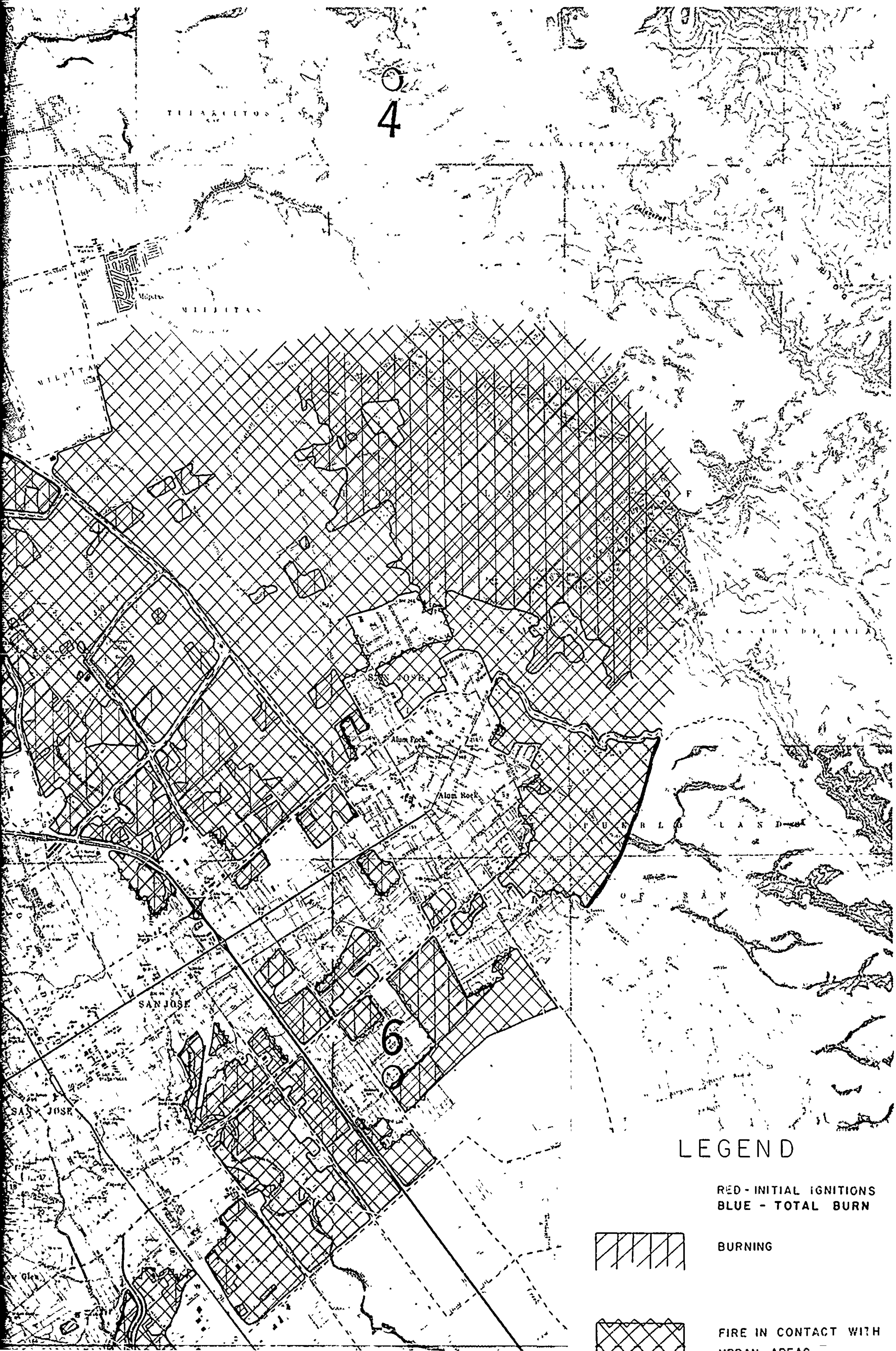
POINT NO.	UTM COORDINATES	SPHERICAL COORDINATES
1	584760 m.E. 4145950 m.N.	122° 2' 30" W. 37° 27' 30" N.
2	592130 m.E. 4146040 m.N.	121° 57' 30" W. 37° 27' 30" N.
3	595820 m.E. 4146080 m.N.	121° 55' W. 37° 27' 30" N.
4	603180 m.E. 4146160 m.N.	121° 50' W. 37° 27' 30" N.
5	584900 m.E. 4132090 m.N.	122° 2' 30" W. 37° 20' N.
6	603360 m.E. 4132300 m.N.	121° 50' W. 37° 20' N.

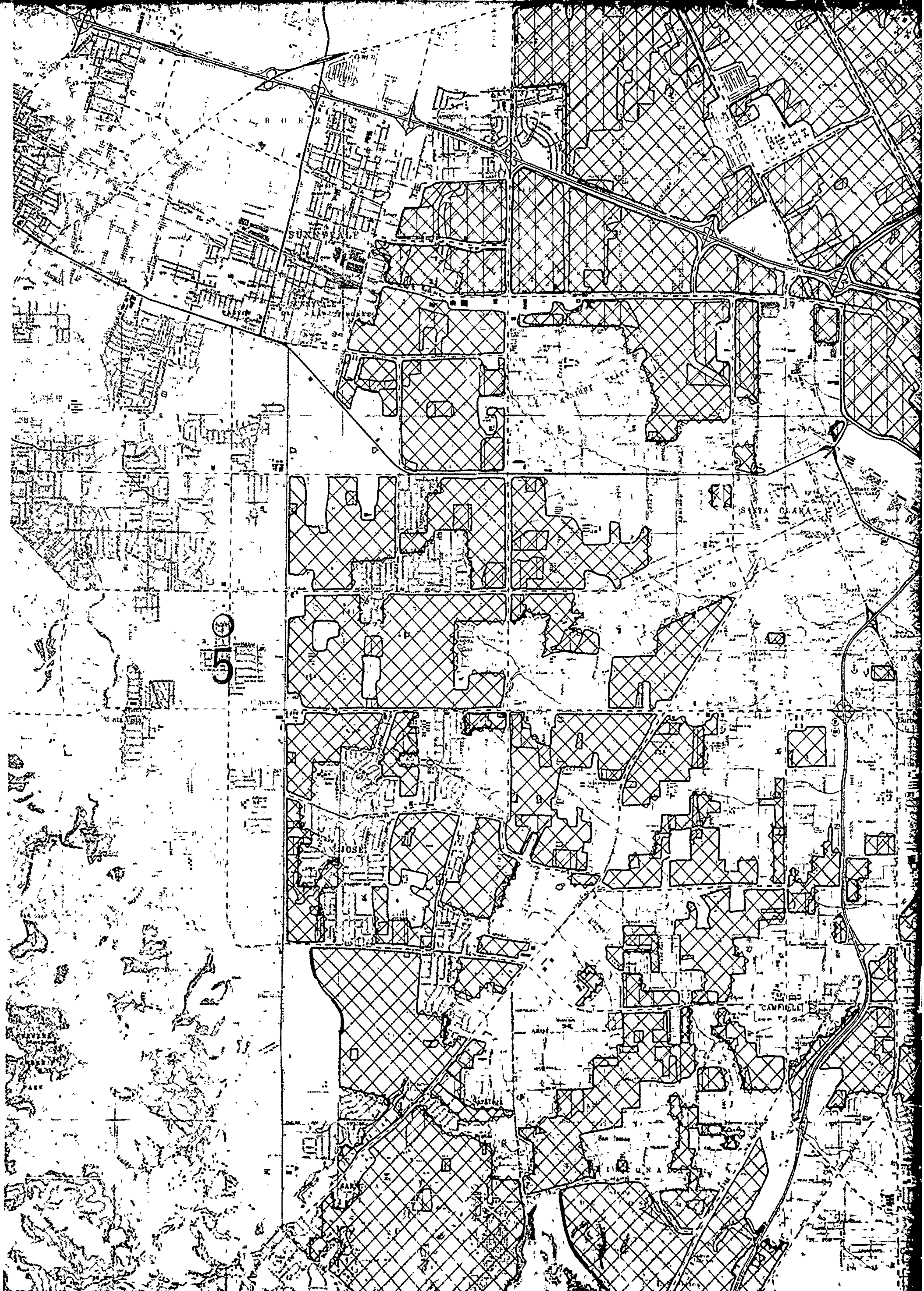
Fig. A-2a. Spherical and Universal Transverse Mercator Coordinates


GZ
1
2
N
NAVAL AIR STATION
SUNNYVALE
SANTA CLARA
5


2
3
4
6
TULARCITOS
MILPITAS
Milpitas
CALAVERAS
VALLEY
Alum Rock
SAN JOSE
SANTA CLARA
College Park
Willow Glen
Burbank

3


4
CALAVERAS
MILPITAS
Alum Rock
Alum Rock
PUEBLO LANDS
OF SAN
SAN JOSE
SAN JOSE
6
LEGEND
RED - INITIAL IGNITIONS
BLUE - TOTAL BURN
BURNING
FIRE IN CONTACT WITH
URBAN AREAS


SUNNYVALE
SANTA CLARA
5
CAMPBELL

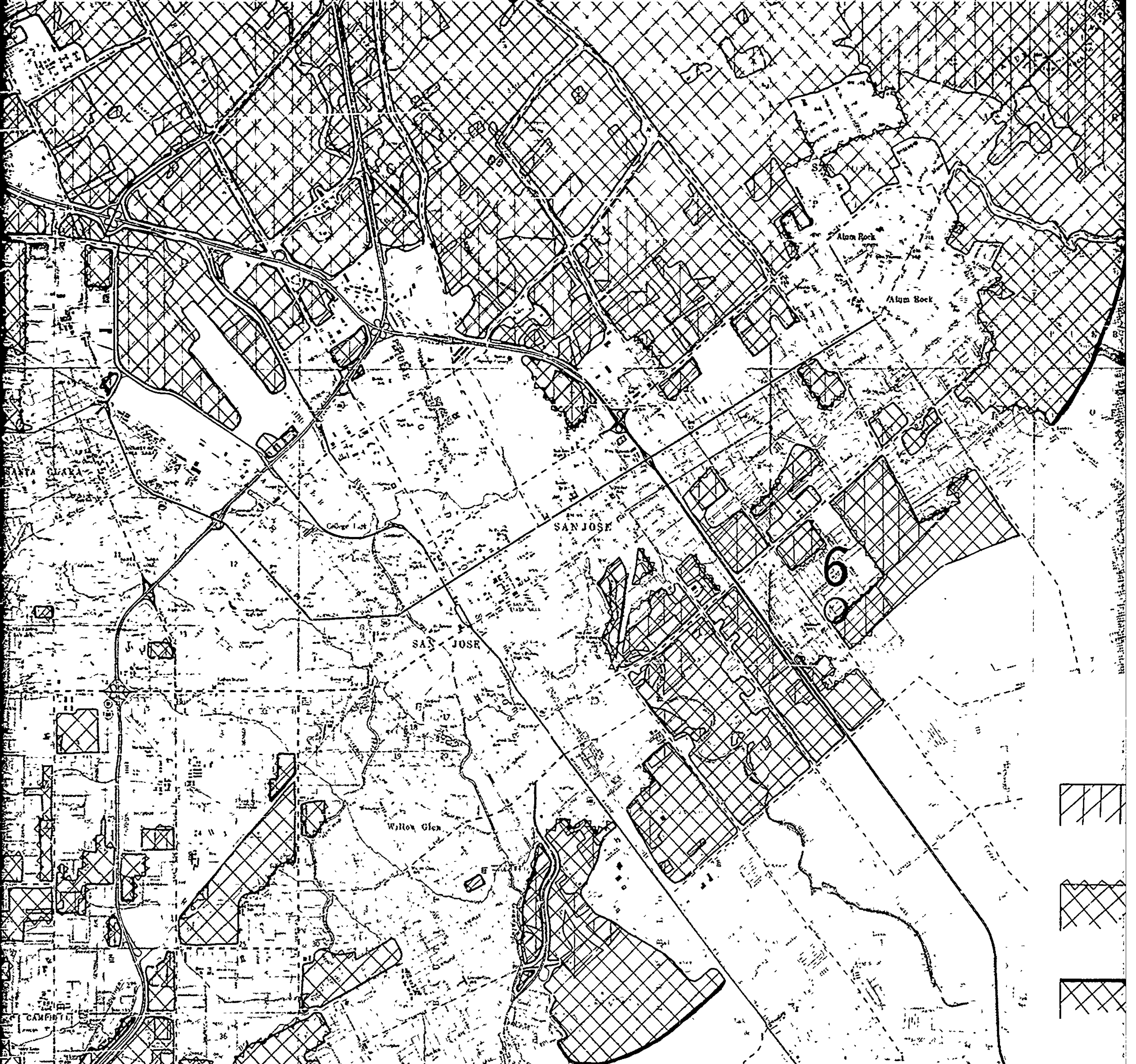


Fig. A-3. Initial Igniti
Vegetated Area:

5

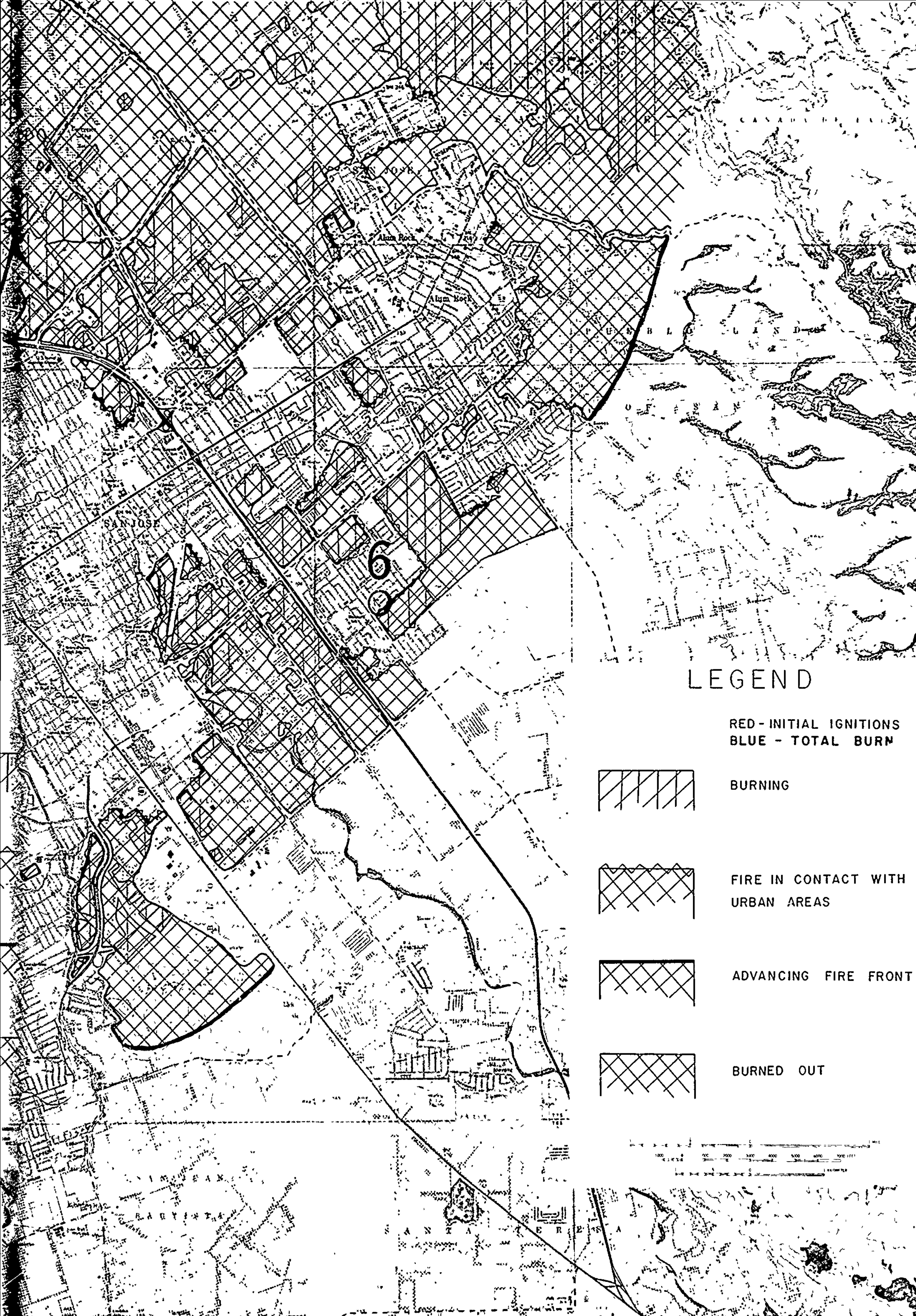
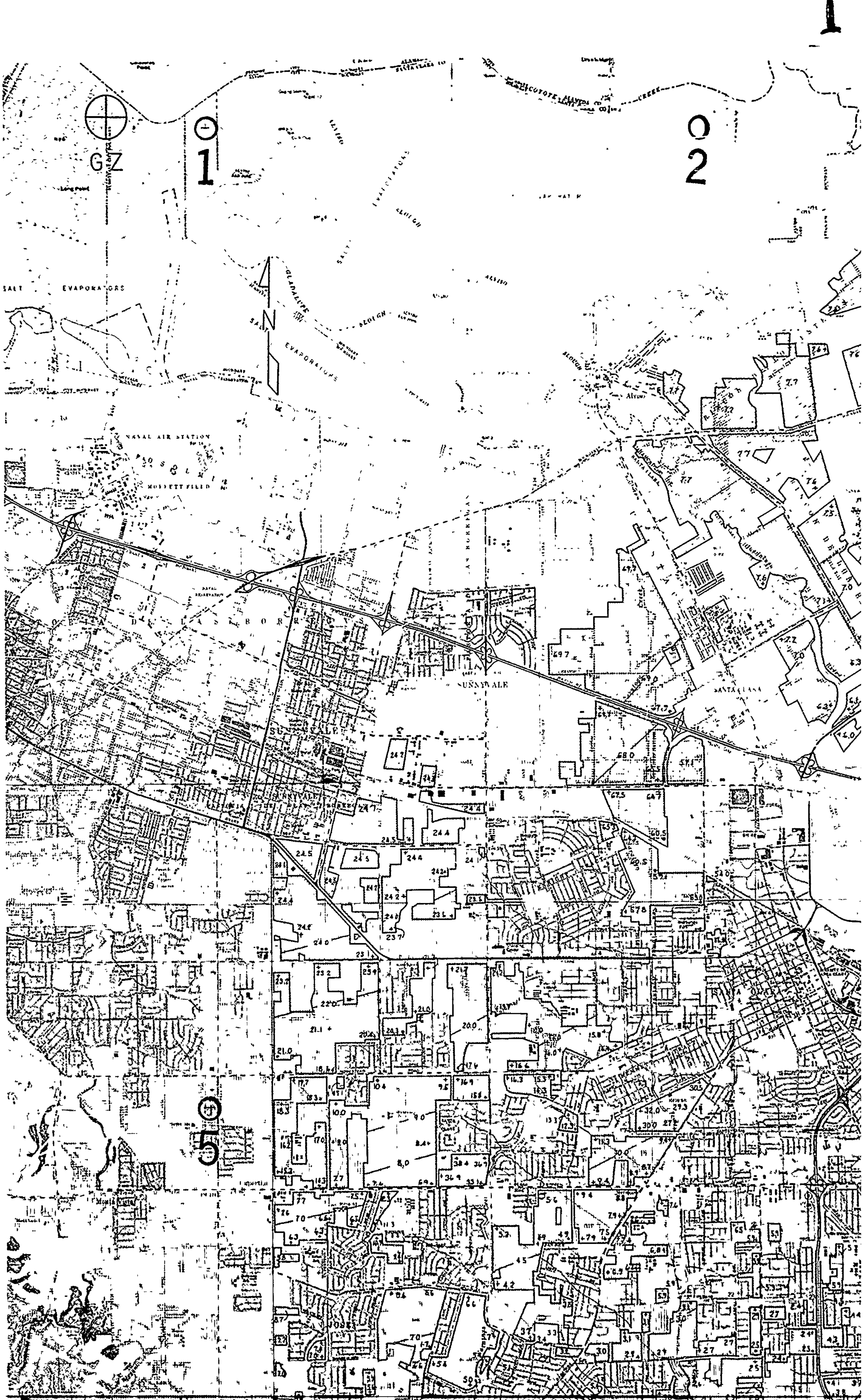
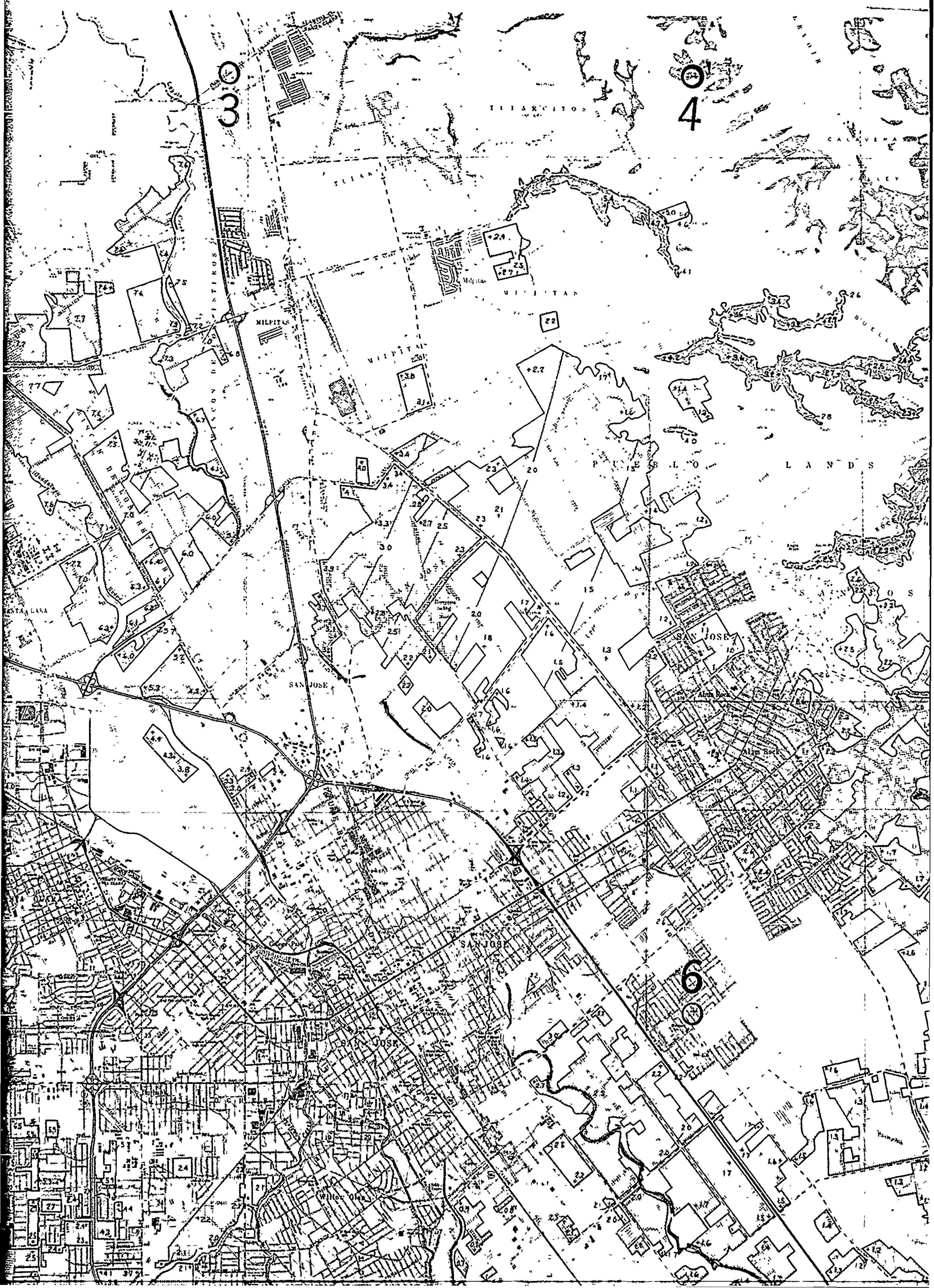


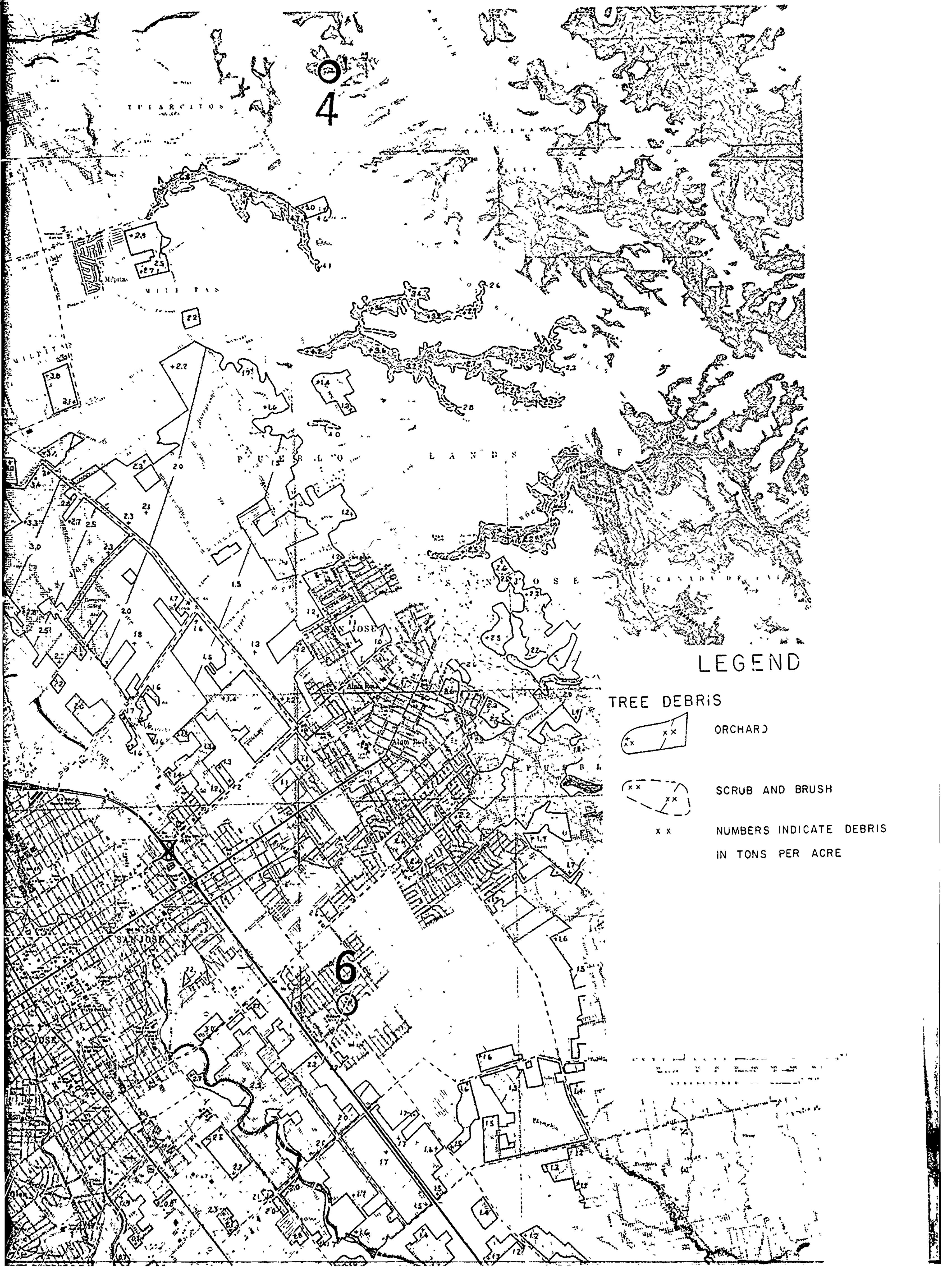
Fig. A-3. Initial Ignitions (Red) and Total Burn (Blue) — Vegetated Areas in and Around San Jose


GZ
1
2
5
SALT EVAPORATORS
NAVAL AIR STATION
MOFFETT FIELD
SUNNYVALE
Alviso
SANTA CLARA

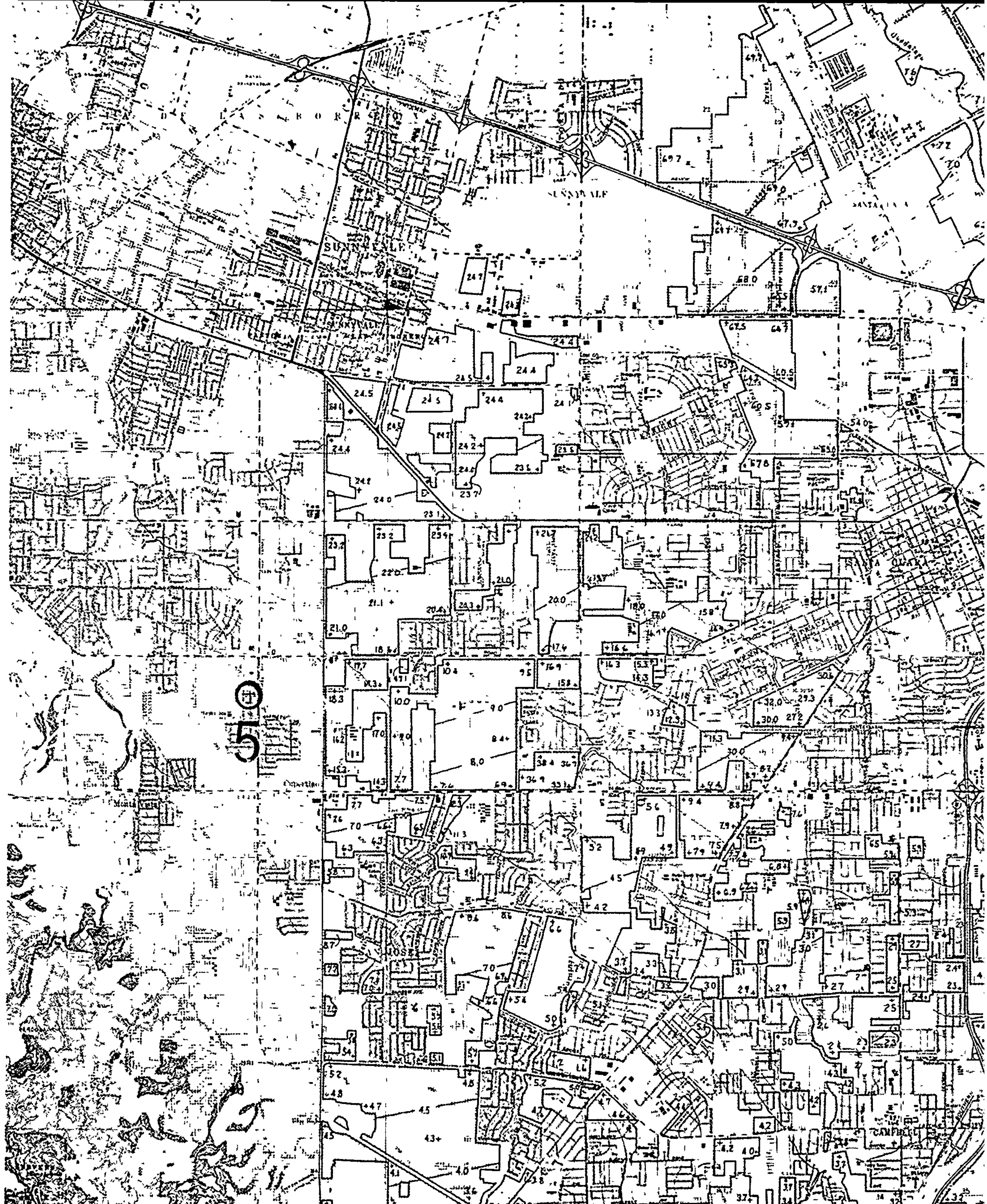
2



3
4
6
TULARCITOS
CALAVERAS
MILPITAS
Milpitas
PUEBLO LANDS
SAN JOSE
Alum Rock
Willow Glen



LEGEND
TREE DEBRIS
ORCHARD
SCRUB AND BRUSH
x x NUMBERS INDICATE DEBRIS IN TONS PER ACRE
PUEBLO LANDS OF SAN JOSE
MILPITAS
TULARCITOS
4
6



4

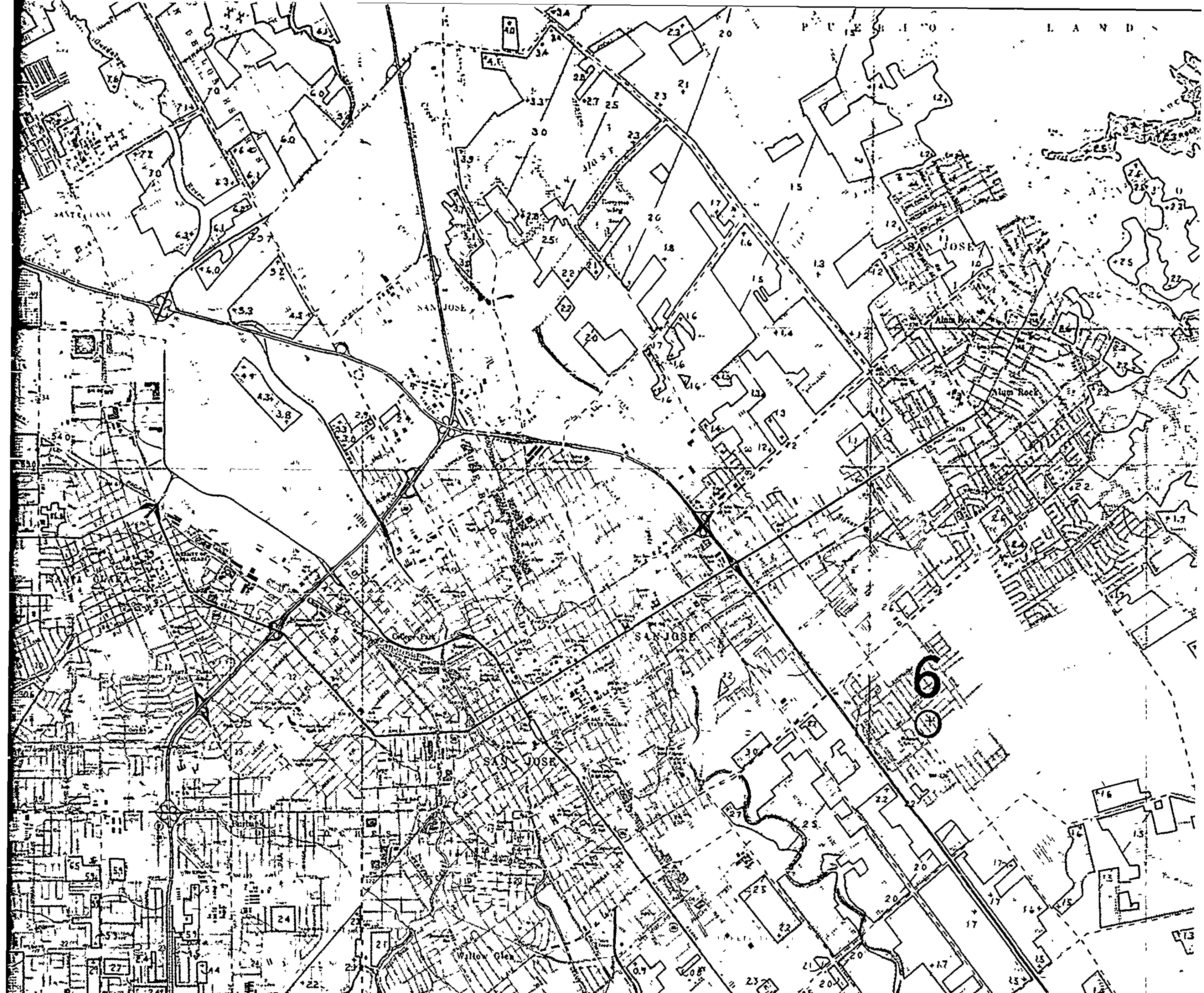
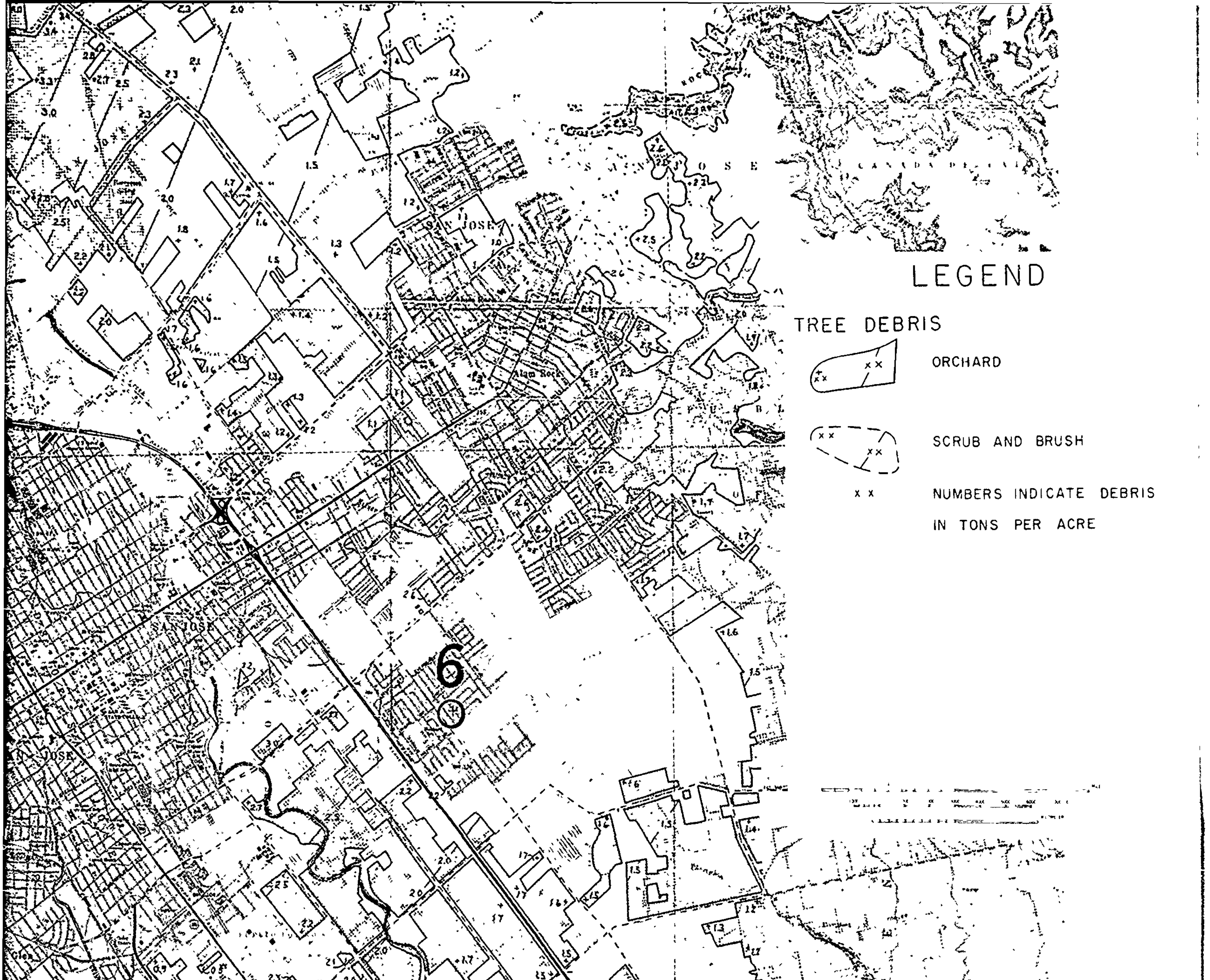
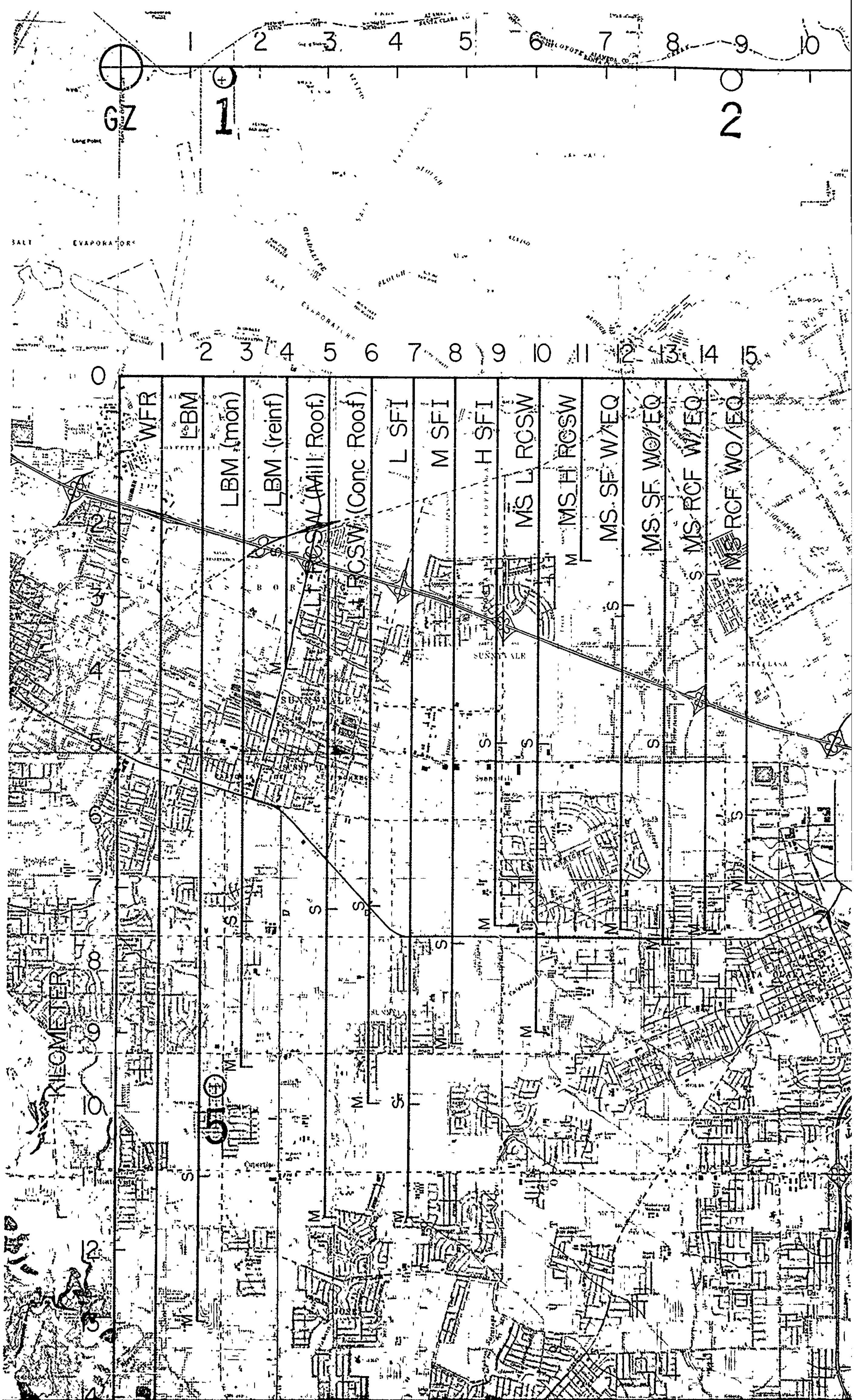


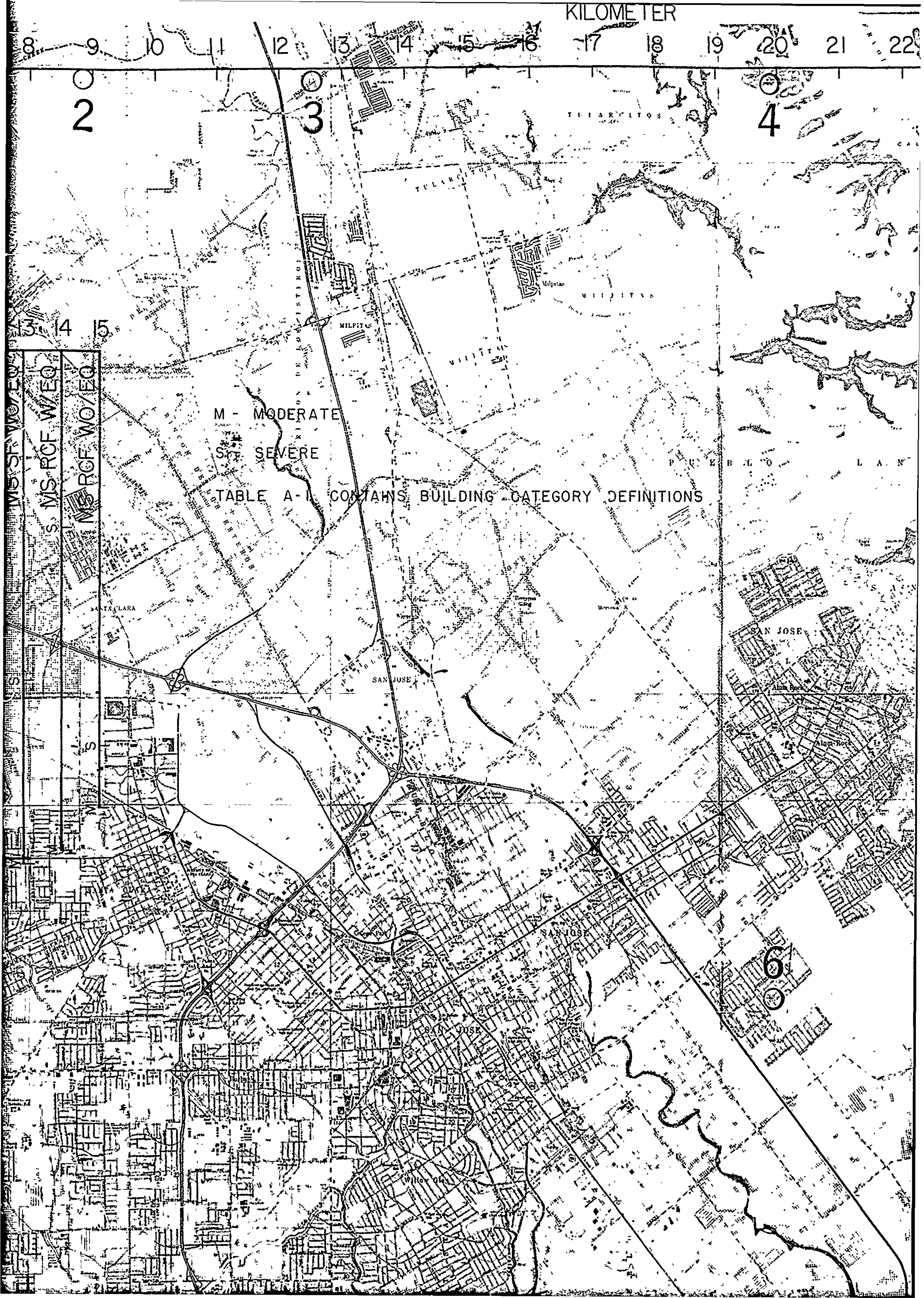
Fig. A-4. 5



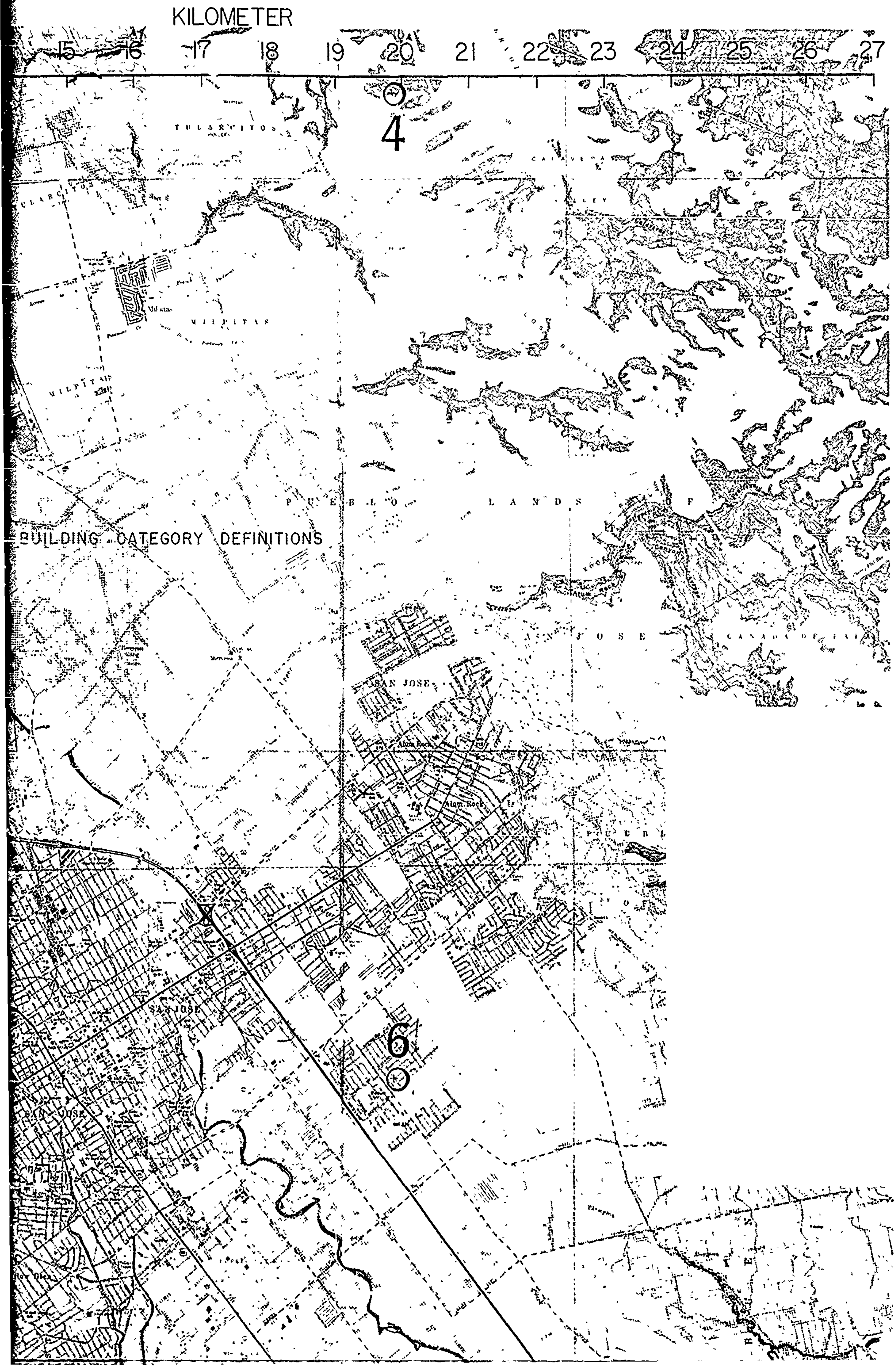
6

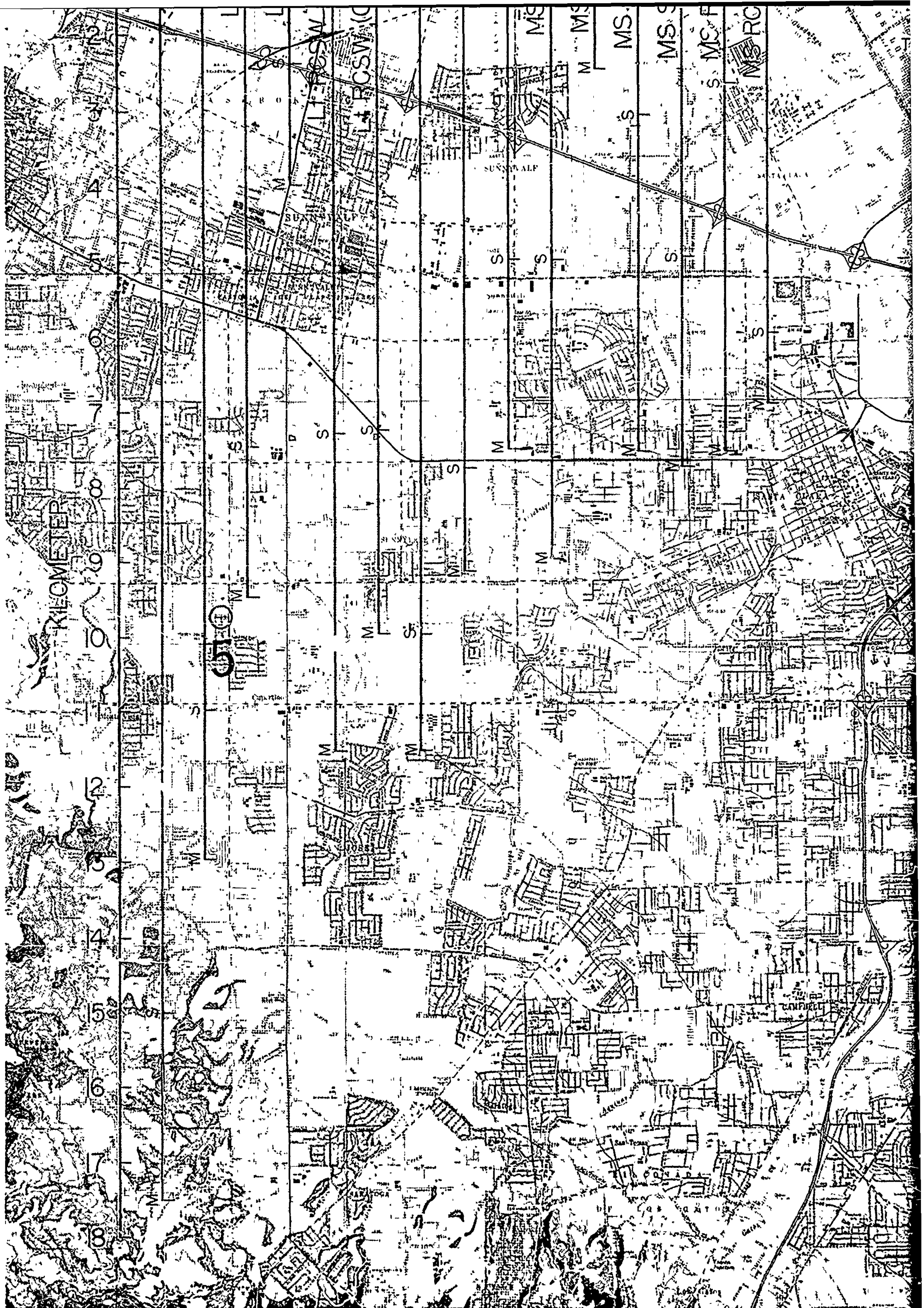
Fig. A-4. Tree Debris in and Around San Jose —
Air Blast and Fire


GZ
1
2
KILOMETER
WFR
LBM
LBM (mon)
LBM (reinf)
L RCSW (Mill Roof)
RCSW (Conc Roof)
L SFI
M SFI
H SFI
MS L RCSW
MS H RCSW
MS SF W/EQ
MS SF WO/EQ
MS RCF W/EQ
MS RCF WO/EQ
SUNNYVALE
SANTA CLARA
5


KILOMETER
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
2
3
4
6
13 14 15
MS SF WO/EQ
S MS RCF W/EQ
MS RCF WO/EQ
M - MODERATE
S - SEVERE
TABLE A-I CONTAINS BUILDING CATEGORY DEFINITIONS
TULARCITOS
MILPITAS
SANTA CLARA
SAN JOSE
Alum Rock

5


KILOMETER
15
16
17
18
19
20
21
22
23
24
25
26
27
4
MILPITAS
PUEBLO LANDS OF
BUILDING CATEGORY DEFINITIONS
SAN JOSE
SAN JOSE
Alum Rock
6


KILOMETER
2
3
4
5
6
7
8
9
10
12
13
14
15
16
17
18
CSW
MS
SUNNYVALE
SARATOGA

4

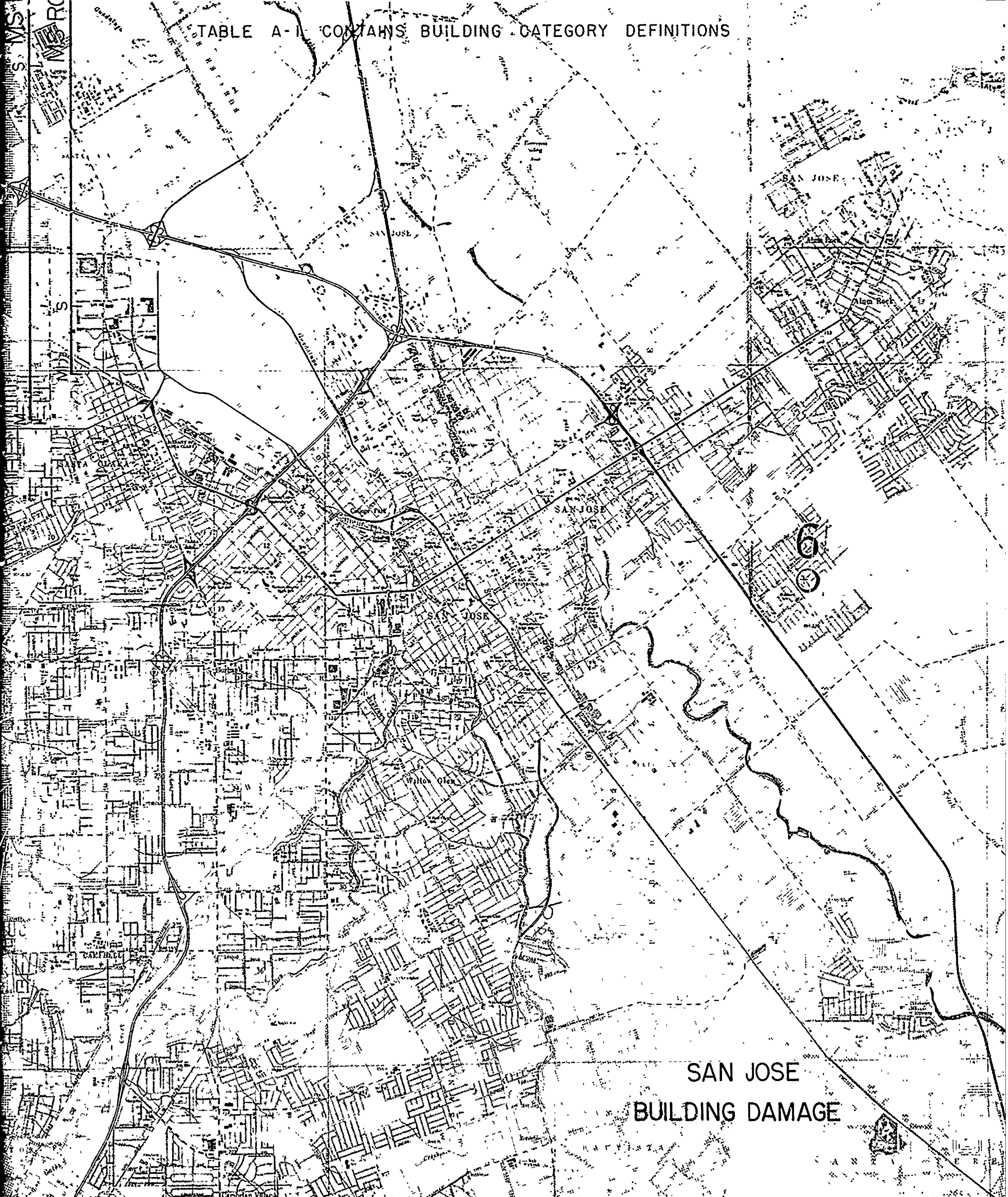


Fig. A-5. Building 5

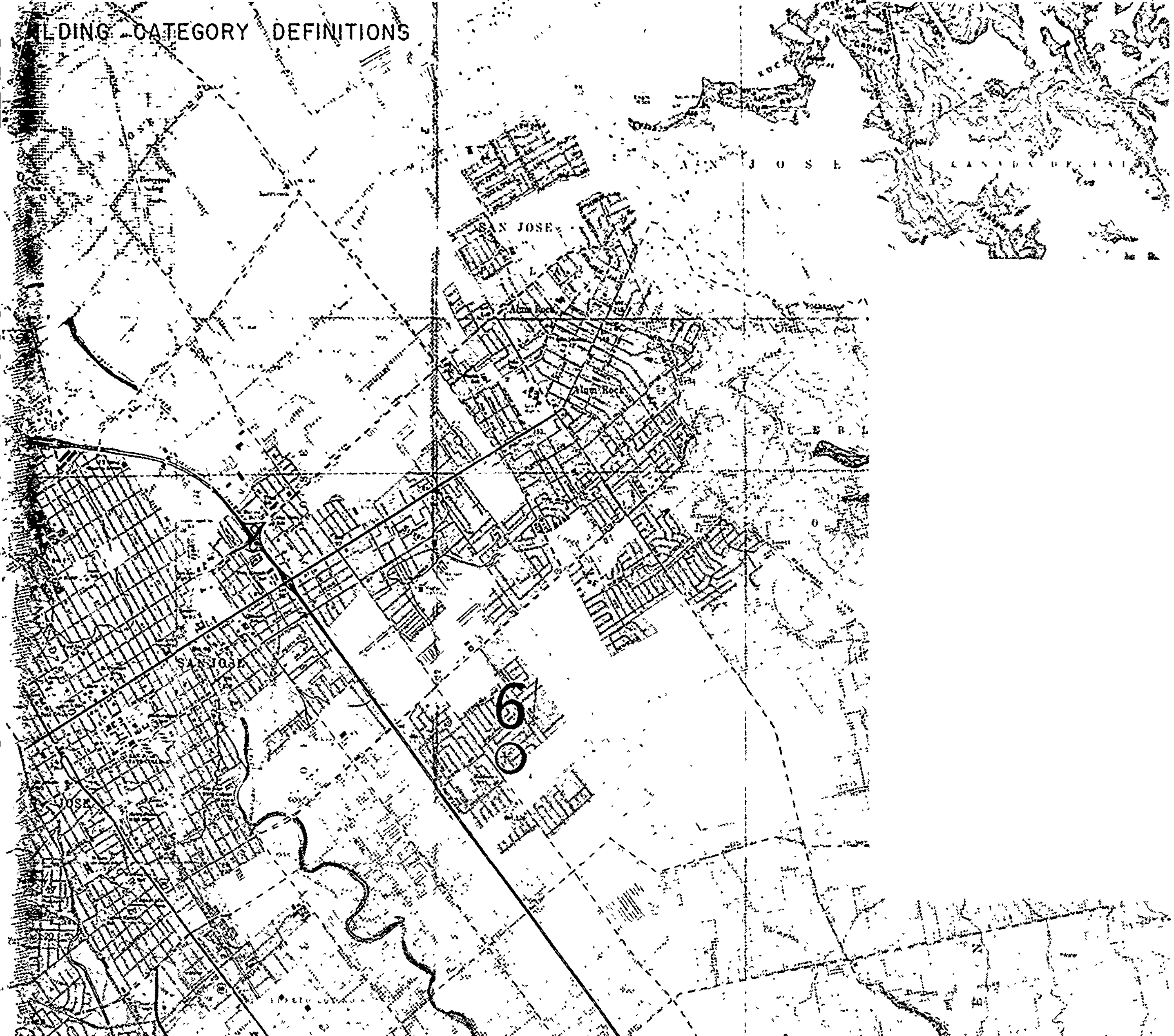
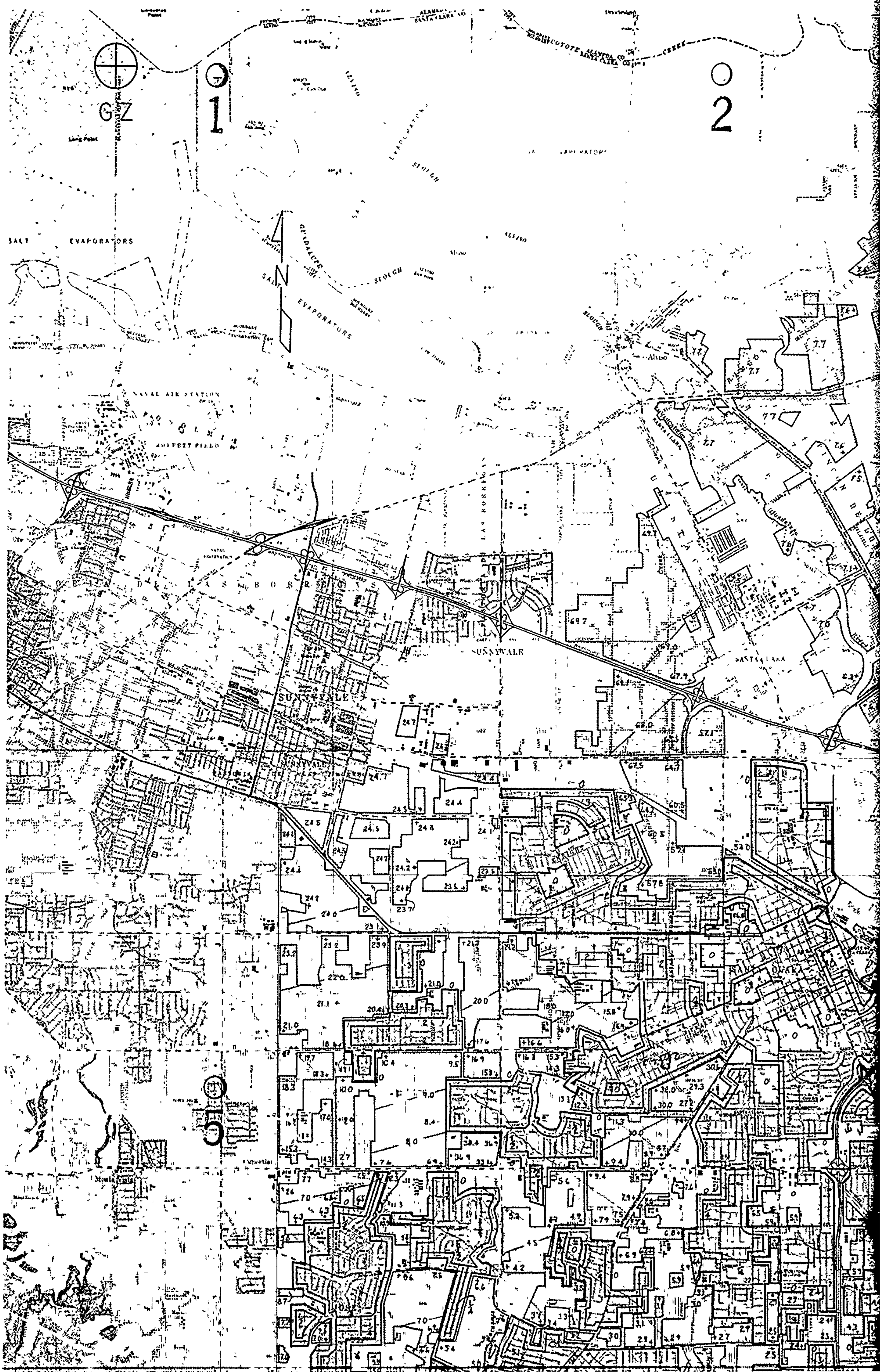
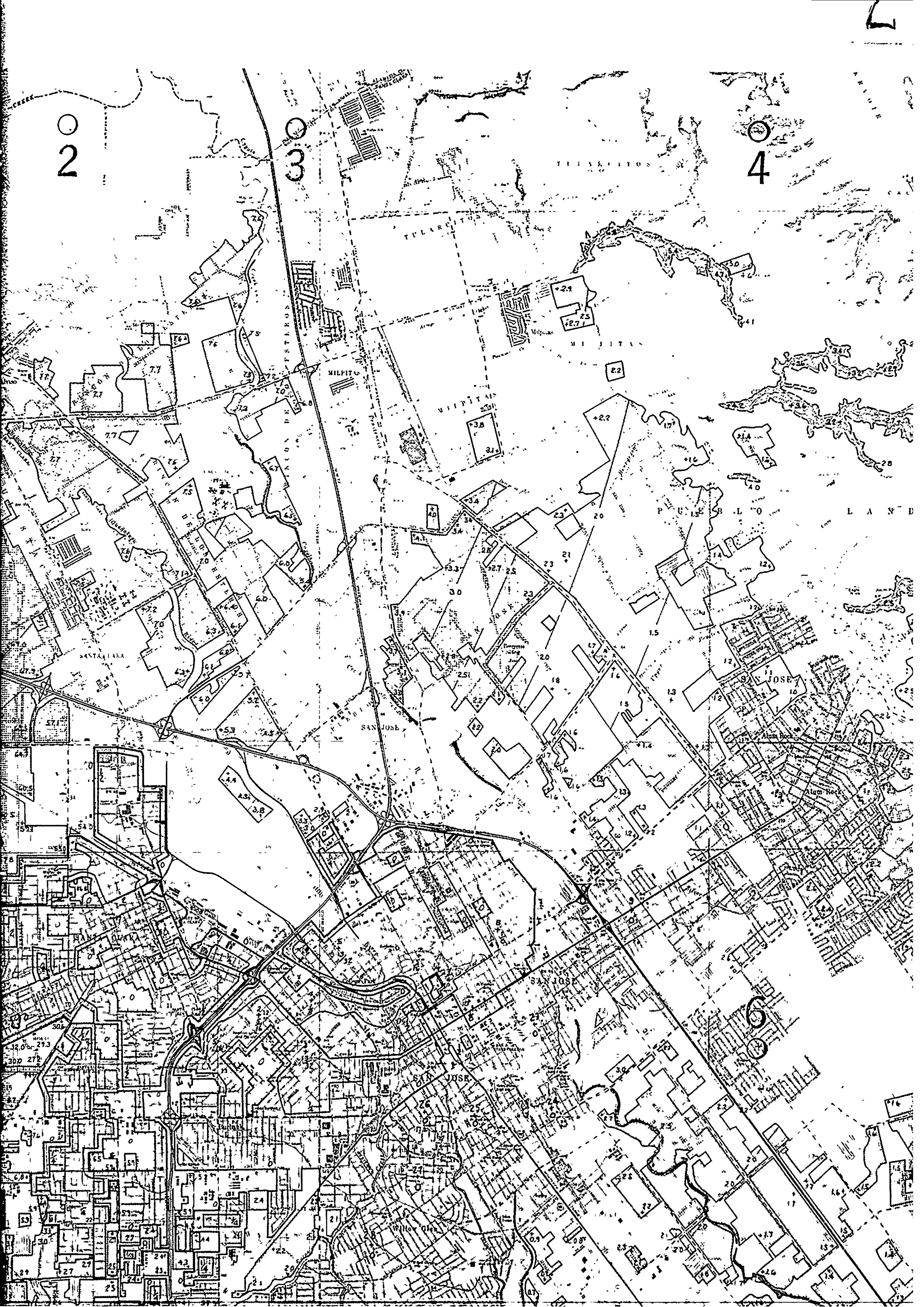


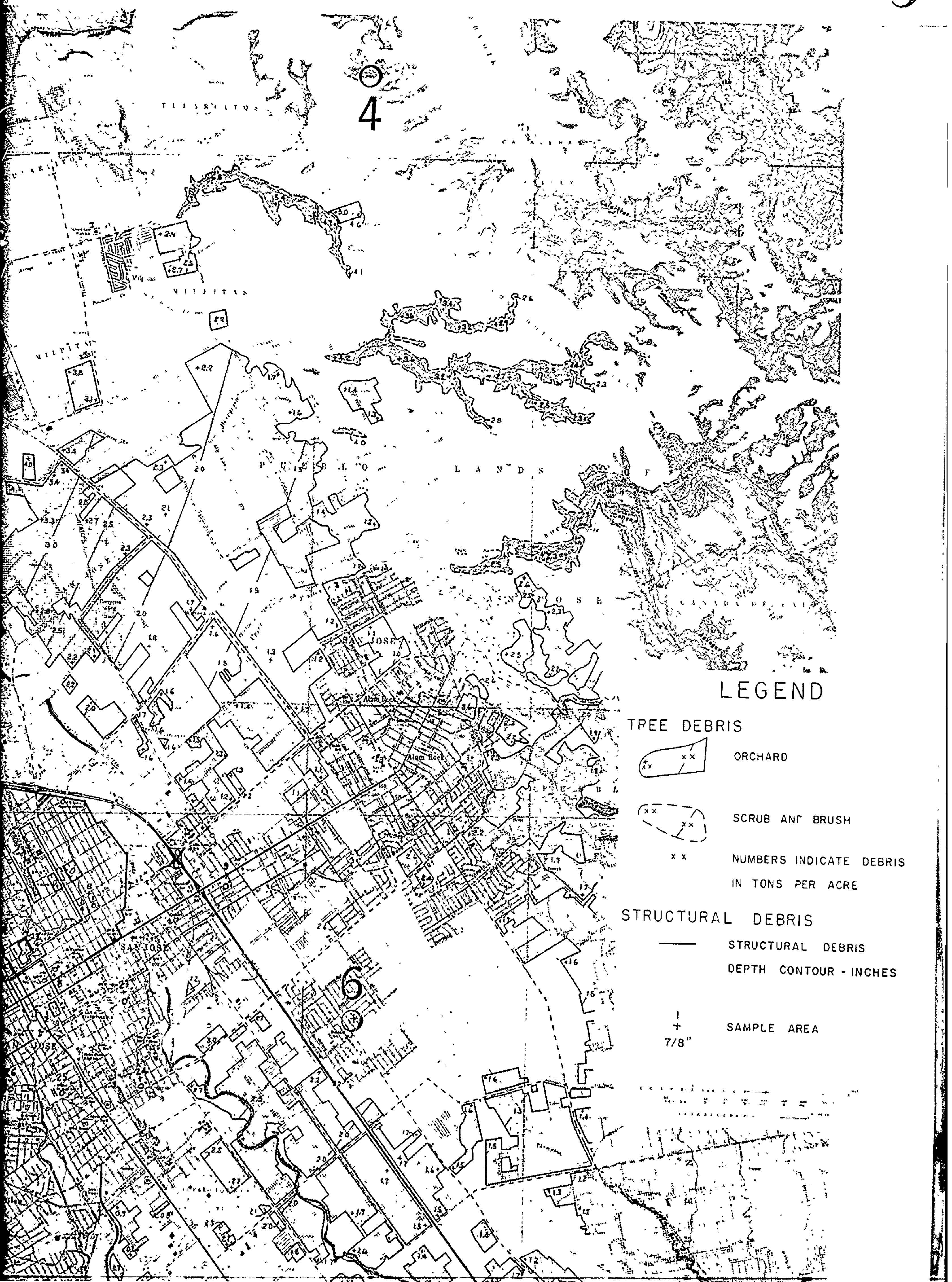
Fig. A-5. Building Damage Radii, San Jose — Air Blast Only

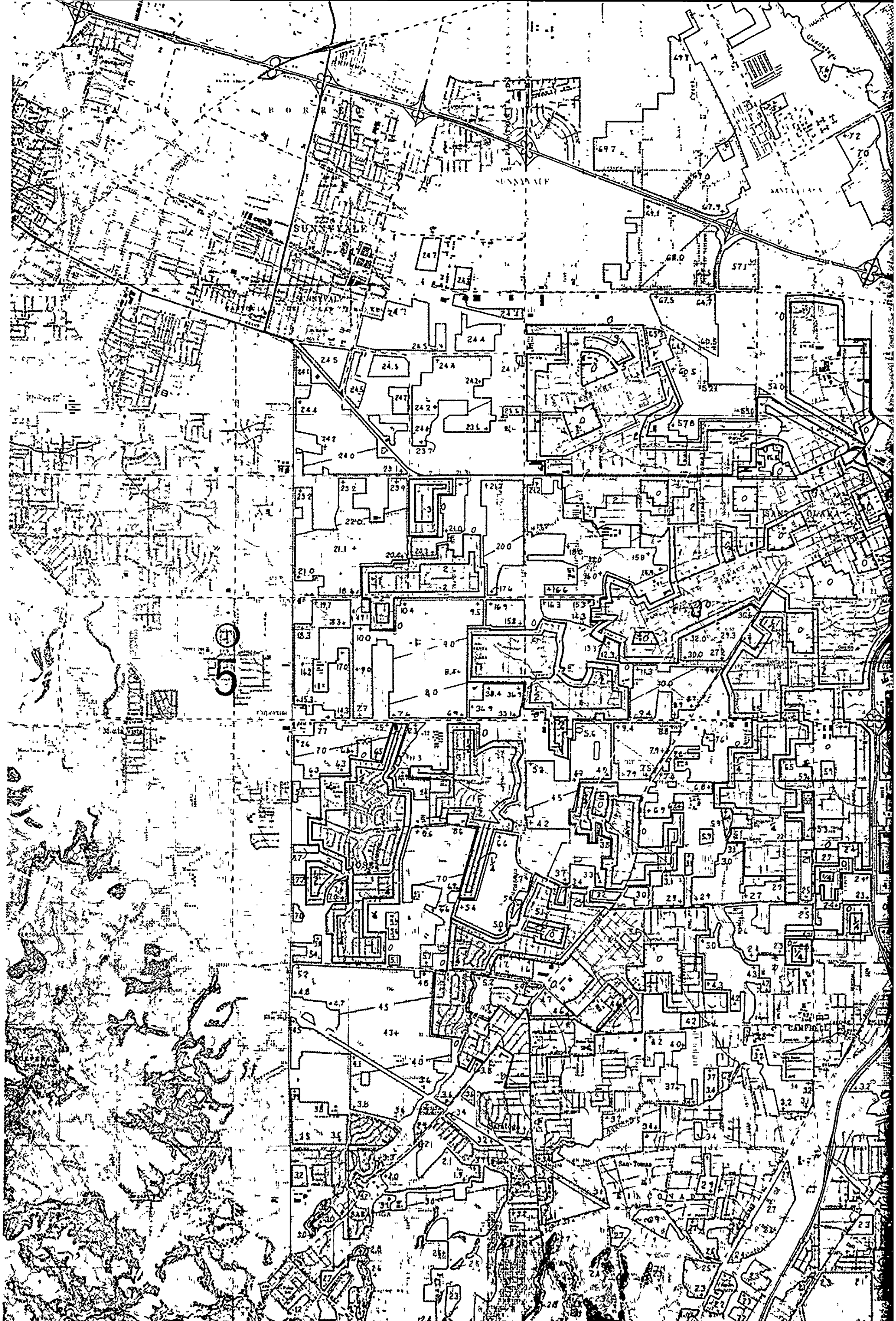
6


GZ
1
2
5
N
SALT EVAPORATORS
EVAPORATORS
SLOUGH
NAVAL AIR STATION
MOFFETT FIELD
SUNNYVALE
SANTA CLARA
Alviso



2
3
4
6
MILPITAS
SAN JOSE
SANTA CLARA
PUEBLO LANDS
TULARCITOS
Alum Rock
Willow Glen


4
MILPITAS
PUEBLO LANDS OF
SAN JOSE
6
LEGEND
TREE DEBRIS
ORCHARD
SCRUB AND BRUSH
NUMBERS INDICATE DEBRIS IN TONS PER ACRE
STRUCTURAL DEBRIS
STRUCTURAL DEBRIS DEPTH CONTOUR - INCHES
SAMPLE AREA
7/8"



4

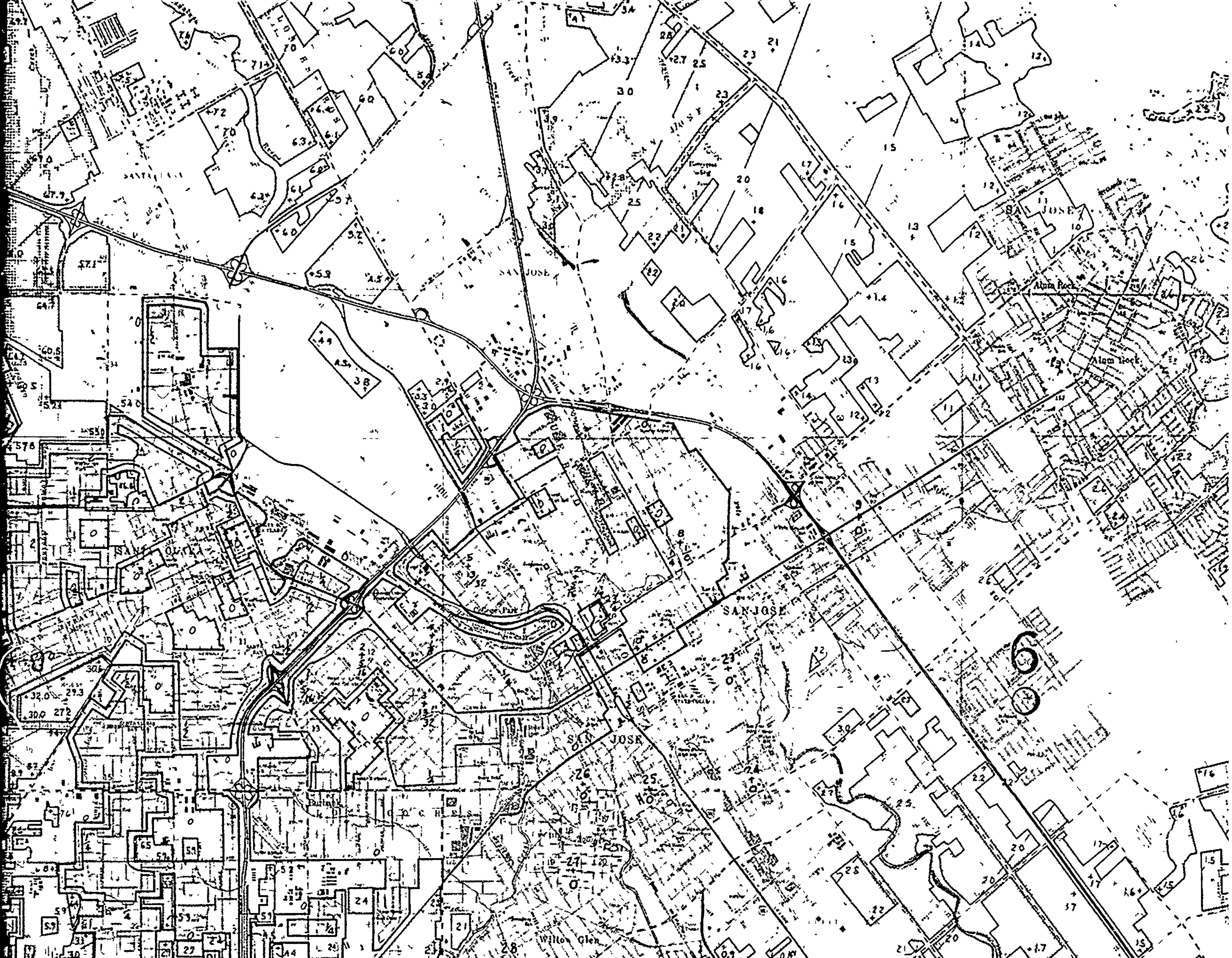


Fig. A-6. Combined Tree
Air Blast Onl

5

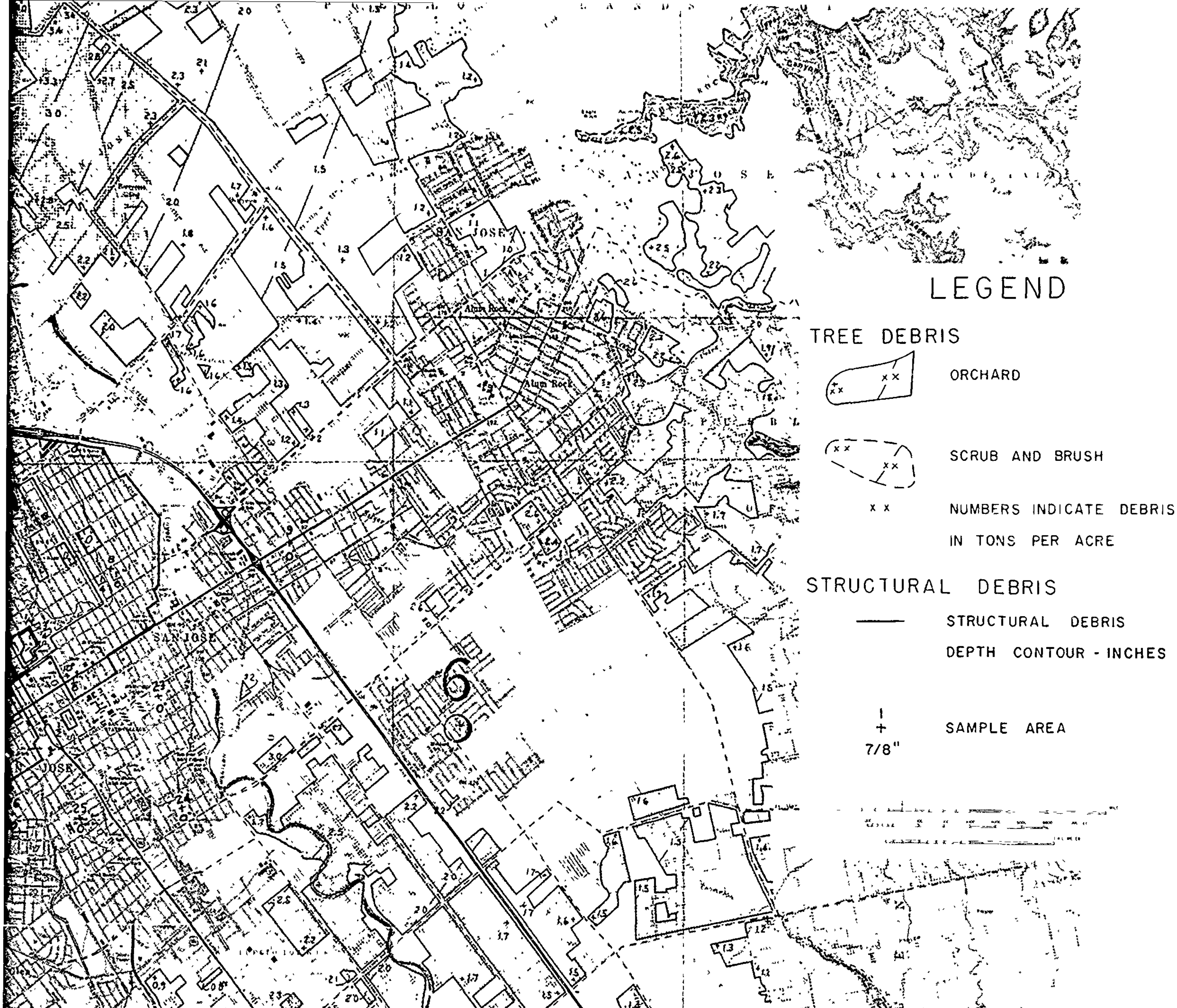
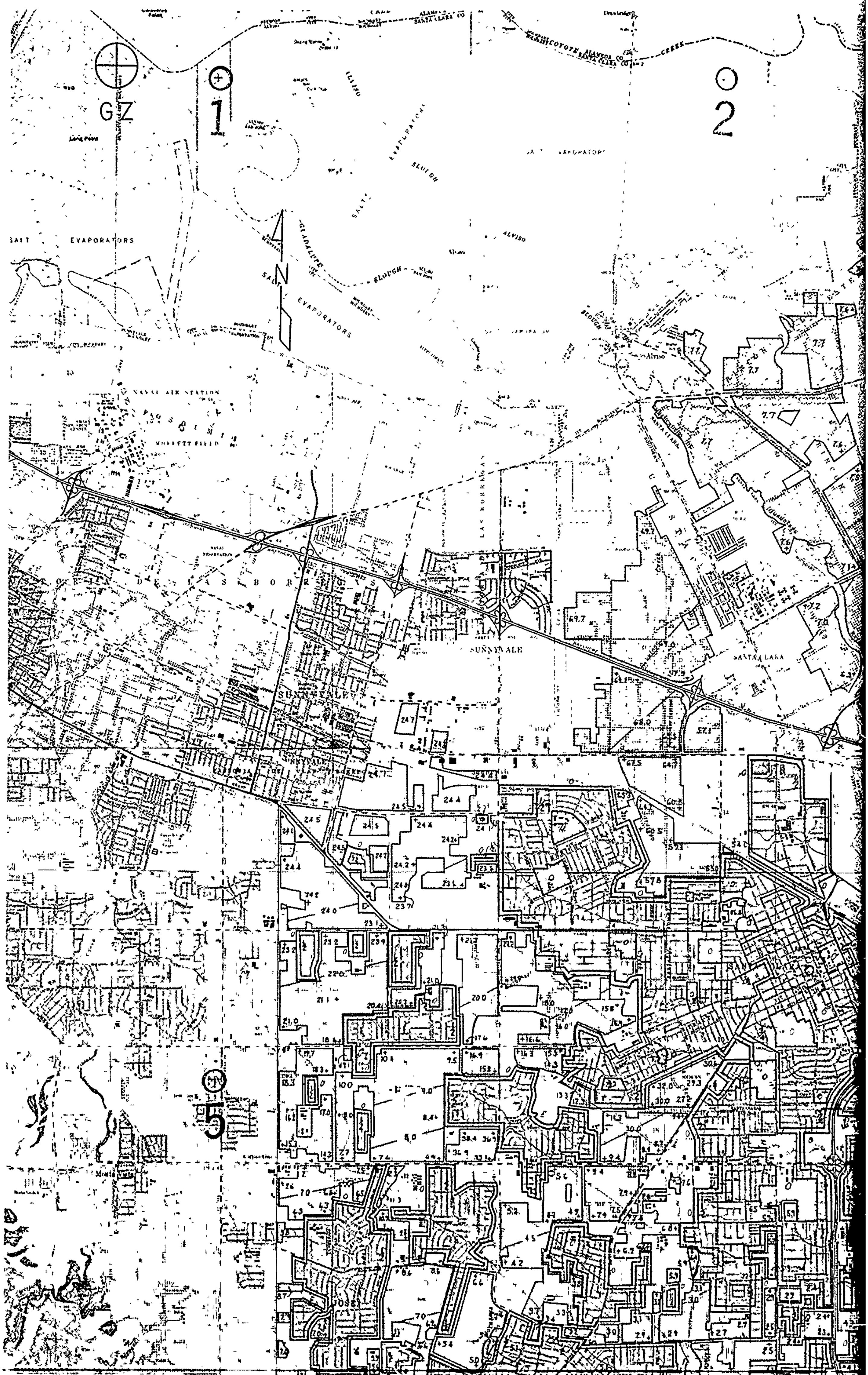
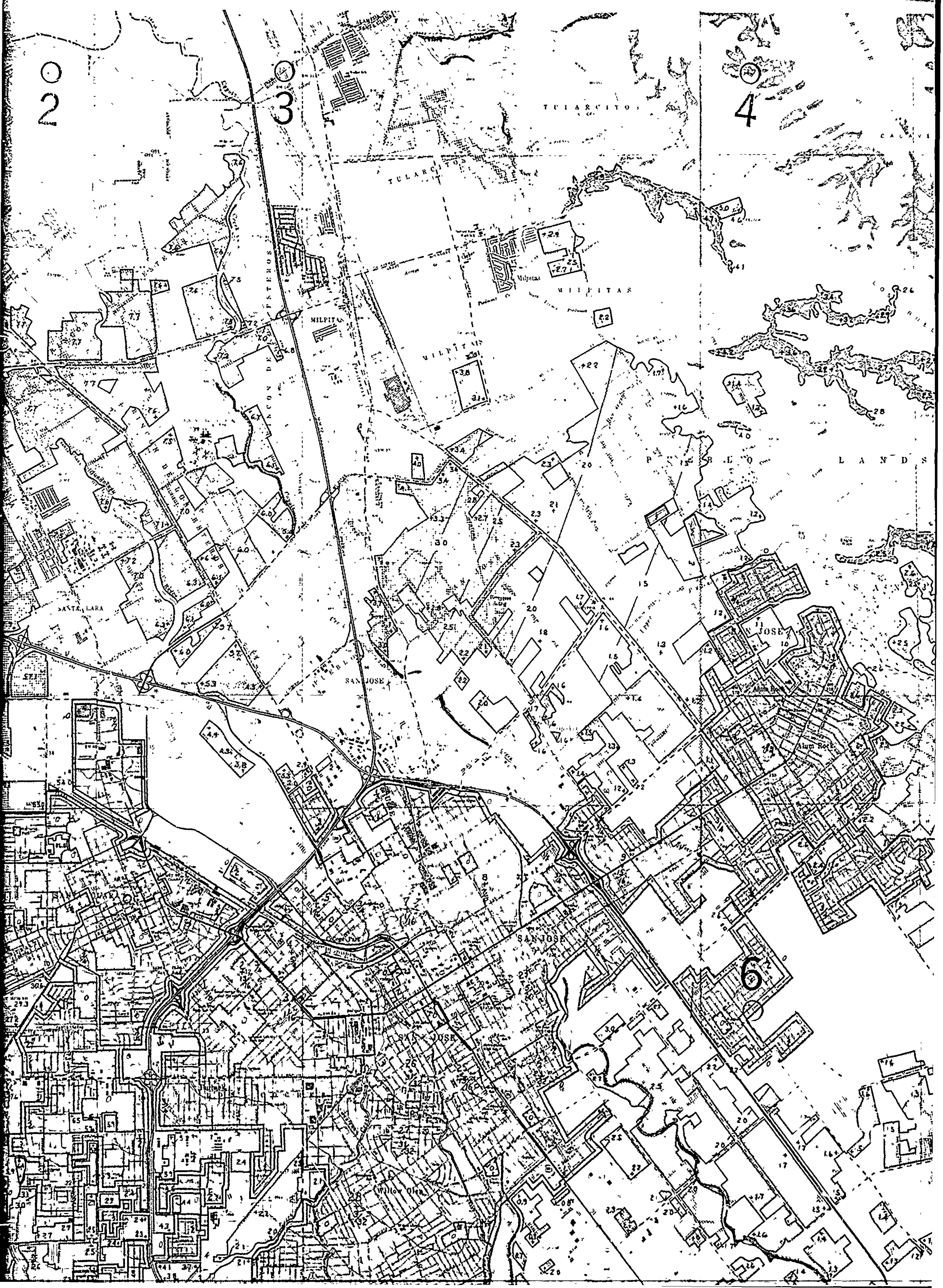


Fig. A-6. Combined Tree Debris and Structural Debris in San Jose — Air Blast Only

6

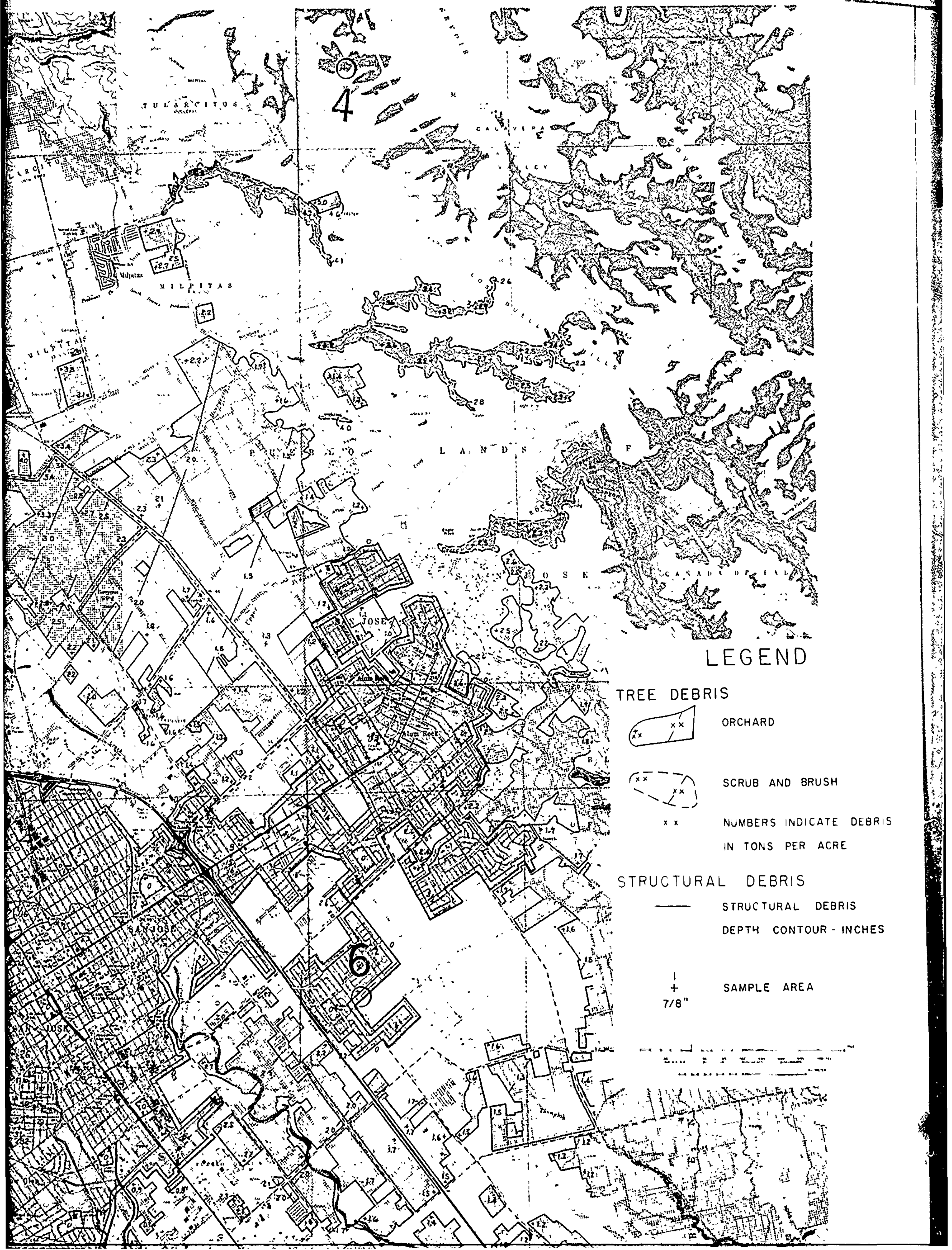


GZ
1
2
5
N
SALT EVAPORATORS
SALT EVAPORATORS
SALT EVAPORATORS
ALVISO SLOUGH
GUADALUPE SLOUGH
COYOTE CREEK
ALAMEDA CO
SANTA CLARA CO
Long Point
ALVISO
Alviso
NAVAL AIR STATION
MOFFETT FIELD
SUNNYVALE
SUNNYVALE
SANTA CLARA
LAS BORREGAS



2
3
4
6
TULARCITOS
MILPITAS
SAN JOSE

5



TULARCITOS
MILPITAS
PUEBLO LANDS OF SAN JOSE
CALAVERA VALLEY
SAN JOSE
Alum Rock
CANADA DE PALA
4
6
LEGEND
TREE DEBRIS
ORCHARD
SCRUB AND BRUSH
NUMBERS INDICATE DEBRIS IN TONS PER ACRE
STRUCTURAL DEBRIS
STRUCTURAL DEBRIS DEPTH CONTOUR - INCHES
SAMPLE AREA
7/8"

4

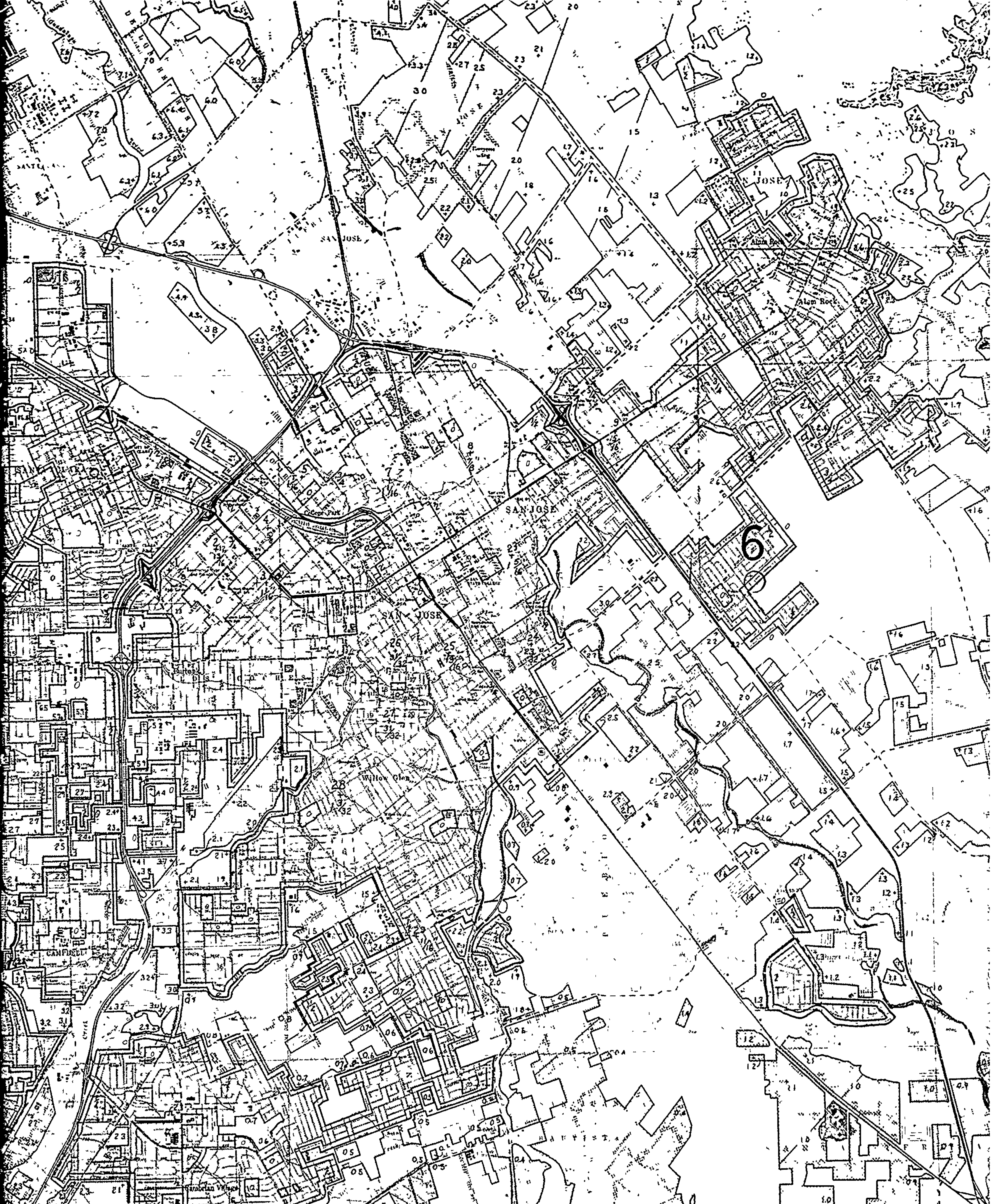


Fig. A-7. Combined Tree Debris Air Blast and Fire

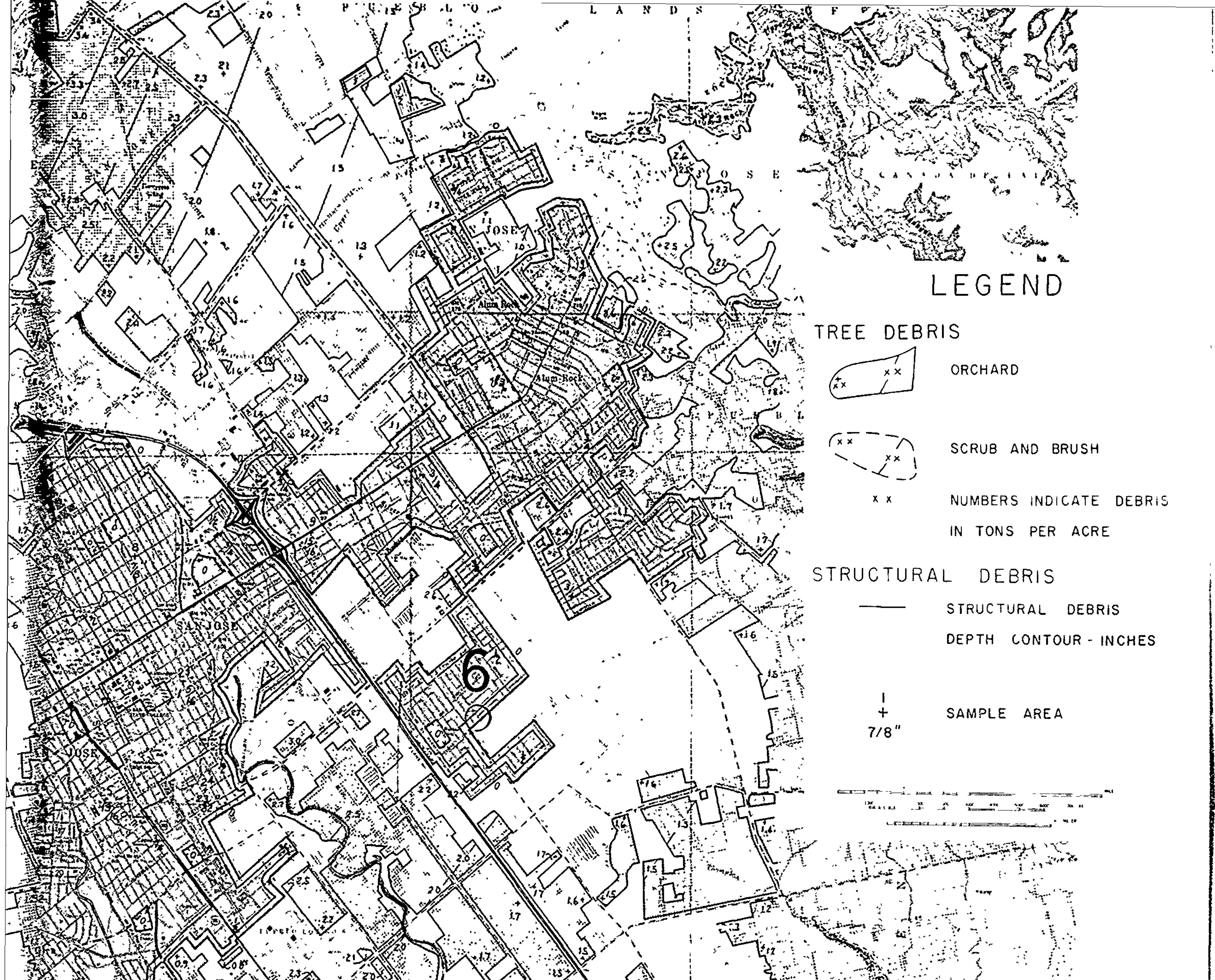


Fig. A-7. Combined Tree Debris and Structural Debris in San Jose — Air Blast and Fire

6

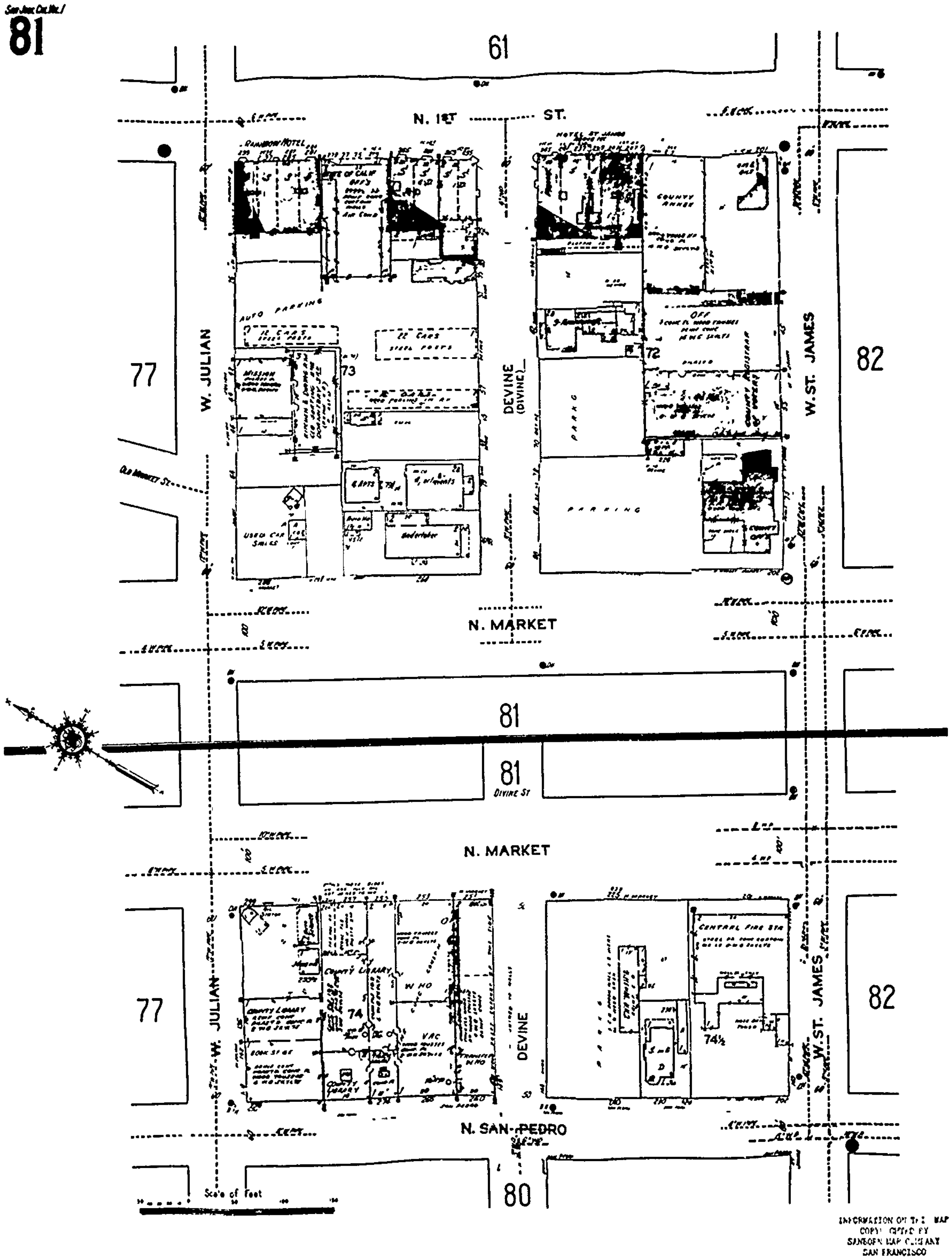


Fig. A-8. Sample Sanborn Map

SAN JOSE

Sanborn Map Sheet No 81, Volume I

ID Cross Street North Market & Devine 7.2 PSI

Address	Use	Type	Stories	Height Ft	Plan Area Sq. Ft	Without Fire	With Fire	Without Fire	With Fire	Area
298 N. San Pedro	7	7c	1	18	8000	(0.037)(18)(8000)(0.02) = 110	(0.037)(18)(8000)(0.28) = 1490	(0.75)(8000)(0.02) = 120	(0.027)(8000) = 220	
284-274 N San Pedro	1	7b	1	18	8500	Insufficient overpressure to	cause significant debris			(270)(310) =
266 N San Pedro	12a	7c	1	20	11,400	(0.037)(20)(11400)(0.02) = 170	(0.037)(20)(11400)(0.28) = 2360	(6)(11400)(0.02) = 1370	(0.03)(11400) = 340	83,700 sq ft
260 N San Pedro	12a	7c	2	20	7600	(0.037)(20)(7600)(0.02) = 110	(0.037)(20)(7600)(0.28) = 1570	(6)(7600)(2)(0.02) = 1820	(0.03)(11400)(2) = 680	
						390	5420	3310	1240	
230 N. San Pedro	1	1b	1	16	1800	(0.7)(1800)(0.04) = 50	(0.7)(1800)(0.42) = 530	(0.625)(1800)(0.04) 40	(0.02)(1800) = 40	
201 N Market	Fire Sta.	5a	2	28	8080	Insufficient overpressure				
225 N Market	3a	3	1	13	1800	Insufficient overpressure	(0.12)(13)(1800)(0.75) = 2110		(0.3)(1800) = 540	
						50	2640	40	580	(220)(270) = 59,400 sq ft
255-257 N Market	7	7b	2	18	5350	Insufficient overpressure				
291 N Market	3b	3	1	15	1100	Insufficient overpressure	(0.12)(15)(1100)(0.8) = 1580		(0.2)(1100) = 220	
258 N. Market	6	1b	2	24	2630	(0.7)(2630)(0.04) = 70	(1.7)(2630)(0.42) = 1880	(0.625)(2630)(2)(0.04) = 130	(0.013)(2630)(2) = 70	
75 W St. James	9	5a	2	28	4900	Insufficient overpressure				
55 W St James	12a	7c	1	16	5850	(0.037)(16)(5850)(0.02) = 70	(0.037)(16)(5850)(0.28) = 970	(6)(5850)(0.02) = 700	(0.03)(5850) = 170	
45 W. St James	9	7c	1	16	6750	(0.037)(16)(6750)(0.02) = 80	(0.037)(16)(6750)(0.28) = 1120	(12)(6750)(0.02) = 160	(0.1)(6750) = 680	
201 N. 1st	3b	2a	1	15	900	(0.02)(900)(0.15) = 10	(0.02)(900)(1.0) = 20	(0.55)(900)(0.15) = 70	(0.2)(900) = 180	
215 N. 1st	9	7c	1	16	8450	(0.037)(16)(8450)(0.02) = 100	(0.037)(16)(8450)(0.28) = 1400	(1.2)(8450)(0.02) = 200	(0.1)(8450) = 850	
227-245 N 1st	6	3	3	46	8800	Insufficient overpressure	(0.12)(46)(8800)(0.6) = 29100		(0.018)(8800)(3) = 340	
42 Devine	1	1b	2	22	2600	(1.7)(2600)(0.04) = 180	(1.7)(2600)(0.28) = 1240	(0.625)(2600)(2)(0.04) = 130	(0.02)(2600)(2) = 100	
79 Devine	1	1b	2	22	2700	(1.7)(2700)(0.04) = 180	(1.7)(2700)(0.28) = 1280	(0.625)(2700)(2)(0.04) = 140	(0.02)(2700)(2) = 110	(490)(610) =
79½ Devine	1	1b	2	22	900	(1.7)(500)(0.04) = 60	(1.7)(900)(0.28) = 430	(0.625)(900)(2)(0.04) = 50	(0.02)(900)(2) = 40	298,900 sq ft
35 Devine	1	1b	2	30	1400	(1.7)(1400)(0.04) = 100	(1.7)(1400)(0.28) = 670	(0.625)(1400)(2)(0.04) = 70	(0.02)(1400)(2) = 60	
259-255 N. 1st	13a	3	2	32	3200	Insufficient overpressure	(0.12)(32)(3200)(0.7) = 8600		(0.1)(3200)(2) = 640	
265-261 N. 1st	13a	3	2	32	3500	Insufficient overpressure	(0.12)(32)(3500)(0.7) = 9400		(0.1)(3500)(2) = 700	
279-273 N 1st	9	5a	2	28	7700	Insufficient overpressure				
299-281 N 1st	6	3	3	44	6300	Insufficient overpressure	(0.12)(44)(6300)(0.65) = 21620		(0.013)(6300)(3) = 240	
44-42 W Julian - Front	2	7c	1	18	3600	(0.037)(18)(3600)(0.02) = 50	(0.037)(18)(3600)(0.28) = 670	(0.25)(36[illegible])(0.02) = 20	(0.007)(3600) = 20	
- Rear	1	3	3	28	4200	Insufficient overpressure	(0.12)(28)(4200)(0.7) = 9880		(0.02)(4200)(3) = 250	
						900	89860	1670	4670	

Fig. A-9. Sample Data Sheet

Table A-1

DAMAGE DESCRIPTIONS

Structure No.	Description of Structure	Description of Damage: Severe	Moderate	Light
1	Wood frame residential	Frame shattered and distorted so that for the most part collapsed.	Wall framing cracked, roof badly damaged (many rafters failed, some sections collapsed), interior partitions distorted and partially removed. Wood floors distorted, general cracking and some breakage of joists.	Windows out, doors destroyed or off, interior partitions cracked
2	Wall-bearing building, brick apartment house type; up to 3 stories.	Many bearing walls collapse, resulting in collapse of most of structure.	Exterior walls badly cracked, interior partitions cracked, distorted and partially removed.	Windows out, doors destroyed or off, interior partitions cracked
3	Wall-bearing masonry building, monumental type; up to 4 stories.	Many bearing walls collapse resulting in collapse of structure supported by these walls; some bearing walls may be shielded enough by intervening walls so that part of the structure may receive only moderate damage.	Exterior walls facing blast badly cracked, interior partitions cracked and distorted and partially removed. Toward far end of building damage may be reduced.	Windows out, doors destroyed or off, interior partitions cracked.
4	Reinforced masonry building with concrete or reinforced masonry spandrels.	Walls shattered, severe wall and floor distortion, incipient collapse.	Exterior walls badly cracked, interior partitions cracked, distorted and partially removed. Structural elements (floors, roof, framing, etc.) distorted, extensive cracking and spalling of masonry.	Windows out, doors destroyed or off, interior partitions cracked.
5	Light reinforced concrete shear wall building, single story, with mill type roof.	Severe distortion of walls and roof frame. Incipient collapse.	Some distortion of walls and roof frames, interior panels removed.	Windows out and doors destroyed or off, light roof sheathing removed, interior partitions cracked.
6	Light reinforced concrete shear wall building with light concrete roof.	Severe distortion of walls and roof beams, incipient collapse.	Some distortion of walls, roof slabs partially punched out.	Windows out and doors destroyed or off, interior partitions cracked.
7	Light steel frame industrial building, single story, with up to 5-ton crane capacity. Lightweight, low-strength sheathing.	Severe distortion or collapse of frame.	Some distortion of frame, girts and purlins. Cranes (if any) not operable until repairs made.	Windows out, doors destroyed or off, light sheathing removed.
8	Medium steel frame industrial building, single story, with 25–30-ton crane capacity. Lightweight, low-strength sheathing.	Severe distortion or collapse of frame.	Some distortion of frame, girts and purlins, cranes not operable until repairs made.	Windows out, doors destroyed or off, light sheathing removed.
9	Heavy steel frame industrial building, single story, with 60–100-ton crane capacity. Lightweight, low strength sheathing	Severe distortion or collapse of frame.	Some distortion of frame, girts and purlins, cranes not operable until repairs made.	Windows out, doors destroyed or off, light sheathing removed.
10	Multistory light reinforced concrete shear wall building.	Walls shattered, severe floor and wall diaphram distortion, incipient collapse.	Exterior walls breached or on the point of being so, interior partitions badly distorted or destroyed. Structure permanently racked, extensive spalling of concrete.	Windows out, doors destroyed or removed, interior partitions cracked.
11	Multistory heavy reinforced concrete shear wall building.	Walls shattered, severe floor and diaphram distortion, incipient collapse.	Walls breached or on the point of being so, structure permanently racked. Extensive spalling of concrete. Interior partitions badly distorted or destroyed.	Windows out, doors destroyed or removed, interior partitions cracked.
12	Multistory steel frame office type building, 3–10 stories (earthquake-resistant construction), low strength panels.	Severe frame distortion, incipient collapse.	Some frame distortion, panels and partitions removed.	Windows out, doors destroyed or removed, light siding removed, interior partitions cracked.
13	Multistory steel frame office type building, 3–10 stories (non-earthquake-resistant construction), low strength panels.	Severe frame distortion, incipient collapse.	Some frame distortion, panels and partitions removed.	Windows out, doors destroyed or removed, light siding removed, interior partitions cracked.
14	Multistory reinforced concrete frame office type building, 3–10 stories (earthquake-resistant construction), low-strength panels.	Severe frame distortion, incipient collapse.	Some frame distortion, panels and partitions removed. Some floor and roof damage. General spalling of concrete at beam-column connections.	Windows out, doors destroyed or removed, light siding removed, interior partitions cracked.
15	Multistory reinforced concrete frame office type building, 3–10 stories (non-earthquake-resistant construction), lightweight, low-strength panels.	Severe frame distortion, incipient collapse.	Some frame distortion, panels and partitions removed. Some floor and roof damage. General spalling of concrete at beam-column connections.	Windows out, doors destroyed or removed, light siding removed, interior partitions cracked.

Table A-2

DEBRIS DESCRIPTIONS

I. Commercial – With Fire

	Typical Composition	
	Building Contents	Structural Debris
A. Light	Counter-top furnishings Desk-top furnishings	Glass Doors Suspended ceilings Roofing materials Roof ventilators Corrugated asbestos and iron siding Plaster Suspended lighting fixtures Signs attached to structure
B. Medium	Office furniture Office machines Vending machines	Light partitions Light metal curtain walls Lighting fixtures Light roof decks on metal trusses
C. Heavy	Full filing cabinets Safes	Roof decks Floor decks Steel and reinforced concrete framing members Plumbing fixtures Mechanical equipment

Table A-2, Cont.

I. Commercial — Without Fire

	Typical Composition	
	Building Contents	Structural Debris
A. Light	Desk-top furnishings Counter-top furnishings Magazines Hanging clothing Books	Glass Doors Suspended ceilings Roofing materials Roof ventilators Heating ductwork Signs attached to structure Corrugated asbestos and iron siding Plaster Suspended lighting fixtures
B. Medium	Office furniture Office machines Display cases Vending machines	Light wood sheathing Light partitions Light metal curtain walls Lighting fixtures Light roof decks on metal trusses
C. Heavy	Full filing cabinets Safes	Light roof decks Light floor decks Heavy partitions Wood studs, joists, and rafters Plumbing fixtures Mechanical equipment

Table A-2, Cont.

II. Industrial — With Fire

	Typical Composition: Building Contents	Typical Composition: Structural Debris
A. Light	Trash cans Light warehoused materials	Glass Metal doors Roofing materials Roof ventilators Suspended heaters Suspended lighting fixtures Corrugated asbestos and iron siding Signs attached to structure
B. Medium	Light industrial machinery Hand tools Vending machines Medium warehoused material	Light partitions Light metal curtain walls Lighting fixtures Light roof decks on metal trusses
C. Heavy	Heavy industrial machinery Industrial trucks Heavy warehoused material	Overhead cranes Light roof decks Light floor decks Mechanical equipment

Table A-2, Cont.

II. Industrial — Without Fire

	Typical Composition	
	Building Contents	Structural Debris
A. Light	Rags Papers Trash cans Light warehoused material	Glass Doors Roofing materials Roof ventilators Suspended heaters Suspended lighting fixtures Corrugated asbestos and iron siding
B. Medium	Light industrial machinery Hand tools Vending machines Medium warehoused material	Light wood sheathing Light partitions Light metal curtain walls Lighting fixtures Light roof decks on metal trusses
C. Heavy	Heavy industrial machinery Industrial trucks Heavy warehoused material	Overhead cranes Light roof decks Light floor decks Wood studs, joists, and rafters Plumbing fixtures Mechanical equipment

Table A-2, Cont.

III. Residential — With Fire

	Typical Composition: Building Contents	Typical Composition: Structural Debris
A. Light	Small appliances	Glass Roofing materials Roof ventilators
B. Medium	Light furniture	No change from light category
C. Heavy	Heavy furniture Major appliances Automobiles (in garage)	Furnaces Water heaters Plumbing fixtures

Table A-2, Cont.

III. Residential — Without Fire

	Typical Composition: Building Contents	Typical Composition: Structural Debris
A. Light	Lamp shades Drapes Linens Magazines Dishes Small appliances Books	Glass Doors Roofing materials Roof ventilators
B. Medium	Light furniture	Light wood sheathing
C. Heavy	Heavy furniture Major appliances Automobiles (in garage)	Wood studs, joists, and rafters Furnaces Water heaters Plumbing fixtures

Table A-3

DEBRIS IDENTIFICATION

Sample Area No.*	Sanborn Map No.	Boundary Streets	Over-Pressure (PSI)	Zone	Structural Type	Occupancy % of Area	Debris Characteristics: Blast Alone On-Site	Blast Alone Off-Site	Blast and Fire On-Site	Blast and Fire Off-Site	Remarks
1	199E	State Highway 17 Emory Park Garden	2.5	Residential	1	Residential - 100%	B	A	B	A	Even distribution of offsite debris. Moderage damage to residences.
2	122	McKendrie Naglee The Alameda Park	2.5	Residential - Strip Commerical	1 2 4	Residential - 95% Commercial - 5%	III B I B	III A I A	III B I B	III A I A	
3	144	Fremont Shasta The Alameda Middle-of- Block	2.5	Residential - Strip Commercial	1 10 12	Residential - 90% Commercial - 10%	III B I B	III A I A	III B I B	III A I A	
4	136	Emory W. Taylor Stockton Elm	2.3	Residential Industrial Commercial	1 4 5	Residential - 85% Industrial - 10% Commercial - 5%	III B II B I B	III A II A I A	III B II B I B	III A II A I A	
5	125	Guadalupe Creek Coleman Seymour University	2.4	Residential Industrial	1 4 7	Residential - 95% Industrial - 5%	III B II B	III A II A	III B II B	III A II A	
6	134	W. Julian W. St. John No. Mont- gomery Stockton	2.2	Industrial	4 5 7	Industrial - 100%	B	A	B	A	Large open areas between buildings would cause uneven distribution.
7	58	Jackson E. Empire N. 4th N. 1st	2.3	Residential Commercial	1	Residential - 80% Commercial - 20%	III B I B	III A I A	III B I B	III A I A	
8	8	E. Empire E. Julian N. 21st N. 13th	2.0	Residential	1	Residential - 100%	A	A	A	A	
9	3	E. Santa Clara San Antonio S. King S. 31st	1.8	Residential - Strip Commercial	1 6	Residential - 90% Commercial - 10%	III A I A	III A I A	III A I A	III A I A	
10	49	E. Santa Clara E. St. John N. 7th N. 4th	2.1	Residential Commercial	1 2 10	Residential - 65% Commercial - 35%	III B I B	III A I A	III B I B	III A I A	10-story Medical-Dental Building will contribute a lot of ejected contents.
11	60	200' No. of R. R. E. Julian N. 4th N. 1st	2.2	Residential Industrial	1 4 7	Residential - 60% Industrial - 40%	III B II B	III A II A	III B II B	III A II A	
12	61	E. Julian E. St. James N. 4th N. 1st	2.2	Residential Commercial	1 2 6 10	Residential - 60% Commercial - 40%	III B I B	III A I A	III B I B	III A I A	2 blocks residential. 1 block commercial.

* See Fig. 30

Table A-3, Cont.

Sample Area No.*	Sanborn Map No.	Boundary Streets	Over-Pressure (PSI)	Zone	Structural Type	Occupancy % of Area	Debris Characteristics: Blast Alone: On-Site	Debris Characteristics: Blast Alone: Off-Site	Debris Characteristics: Blast and Fire: On-Site	Debris Characteristics: Blast and Fire: Off-Site	Remarks
13	64	E. Santa Clara E. San Fernando S. 3rd S. 1st	2.1	Commercial	2 10	Commercial - 100%	B	A	B	A	
14	65	E. San Fernando E. San Antonio S. 4th S. 1st	2.1	Commercial	2 10 12	Commercial - 100%	B	A	B	A	Mostly 2-story stores.
15	66	E. San Antonio E. San Carlos S. 4th S. 1st	2.0	Residential Commercial	1 2 5 6	Residential - 35% Commercial - 65%	III A II A	III A II A	III A II A	III A II A	3 blocks; 2 commercial and 1 residential
16	77	R.R. Tracks W. Julian N. 1st N. San Pedro	2.2	Commercial Industrial	2 5 6	Commercial - 35% Industrial - 65%	I B II B	I A II A	I B II B	I A II A	
17	81	W. Julian W. St. James S. 4th S. 1st	2.2	Commercial	2 10 12	Commercial - 100%	B	A	B	A	Downtown San Jose
18	82	W. St. James W. St. John N. 1st N. San Pedro	2.2	Commercial	11	Commercial - 100%	B	A	B	A	Very heavy construction
19	83	W. St. John W. Santa Clara N. 1st N. San Pedro	2.1	Commercial	2 10	Commercial - 100%	B	A	B	A	Center of downtown area.
20	84	W. Santa Clara W. San Fernando S. 1st S. San Pedro	2.1	Commercial	2 10 13	Commercial - 100%	B	A	B	A	
21	89	W. San Fernando Park S. 1st S. Almaden	2.1	Commercial	2 3 10 12	Commercial - 100%	B	A	B	A	
22	90	Park W. San Carlos S. 1st Almaden	2.0	Commercial	2 5 10	Commercial - 100%	A	A	A	A	
23	29	E. San Carlos Middle-of-Block S. 13th S. 10th	1.8	Residential	1	Residential - 100%	A	A	A	A	
24	98	E. Humboldt Martha S. 10th S. 5th	1.8	Residential Commercial Industrial	1 5 7	Residential - 80% Commercial - 10% Industrial - 10%	III A I A II A	III A I A II A	III A I A II A	III A I A II A	

* See Fig. 30

Table A-3, Cont.

Sample Area No.*	Sanborn Map No.	Boundary Streets	Over-Pressure (PSI)	Zone	Structural Type	Occupancy % of Area	Debris Characteristics: Blast Alone On-Site	Debris Characteristics: Blast Alone Off-Site	Debris Characteristics: Blast and Fire On-Site	Debris Characteristics: Blast and Fire Off-Site	Remarks
25	162	Grant W. Virginia Almaden Palm	1.7	Residential	1	Residential - 100%	A	A	A	A	Woodrow Wilson Jr. High School. Heavy reinforced concrete shear wall. Light debris.
26	167	Auzerais W. William Delmas Josefa	1.9	Residential	1	Residential - 100%	A	A	A	A	Uneven distribution
27	189	Hull Brooks Middle-of-Block Bird	1.9	Residential	1	Residential - 100%	A	A	A	A	Spread in uneven piles. Shallow depths.
28	205	Willow Glen Minnesota Lincoln Cherry	1.7	Residential - Strip Commercial	1 4 6	Residential - 90% Commercial - 10 %	III A I A	III A I A	III A I A	III A I A	
29	239	Clark Curtner Newport Cottle	1.5	Residential	1	Residential - 100%	A	A	A	A	

* See Fig. 30

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13. ABSTRACT

This report is divided into two parts. Part I reports on research work directed toward improvement of the model to predict debris from buildings subjected to the blast and fire effects of nuclear weapons. Part II reports on application of the model in support of the Office of Civil Defense Five-City Study.

The research was primarily concerned with the development of multi-yield (other than 20 kt and 20 Mt) building debris charts, and improvement of debris distribution procedures. During work on the multi-yield debris charts, significant inconsistencies in present building damage functions for many building types were discovered. These inconsistencies could not be resolved within the scope of the present study, and therefore charts were prepared only for those building types whose damage functions displayed little or no irregularities. While the charts were in preparation, it was ascertained that overturning can be a significant mode of building damage, especially for tall buildings acted upon by blast from large-yield weapons.

Because of lack of quantitative information on building breakup and subsequent debris transport, only a qualitative discussion of debris distribution is included.

The Five-City Study work was primarily concerned with predictions of target damage for the city of San Jose resulting from the Five-City Study attack on that city.

Predictions were made of initial ignitions and fire spread in wildland fuels, and of debris resulting from the destruction of trees and buildings by the coupled effects of air blast and fire, and detailed descriptions of building damage were provided. These predictions are on file in the Five-City Study Data Bank and are presented for reader convenience in scaled-down and abbreviated form.

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