AVALANCHE HAZARD CHANGE RESULTING FROM "THE BLUFFS," MAMMOTH LAKES, CALIFORNIA – WITH MITIGATION RECOMMENDATIONS

Prepared For

Mr. Craig Tackabery and

Mr. William Taylor,

Town of Mammoth Lakes

Prepared By

Arthur I. Mears, P.E., Inc.
Gunnison, Colorado
May, 1997

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May 3, 1997

Mr. Craig Tackabery
Town Engineer
P. O. Box 1609
Mammoth Lakes, CA 93546

Dear Mr. Tackabery:

The attached report on avalanche hazard and mitigation at the Bluffs was prepared as outlined in my consulting agreement with the Town of Mammoth Lakes.

Please contact me if you have any questions.

Sincerely,

Arthur I. Mears

Arthur I. Mears, P.E. (CO)
Avalanche-Control Engineer

Encl.

1 REPORT OBJECTIVES AND LIMITATIONS

As discussed in our consulting services agreement with the Town of Mammoth Lakes, this report has the following **objectives**:

1. Delineation of avalanche paths, including mapping of design-magnitude runout distances (Figure 1);
2. Discussion of possible effects of avalanches on existing development;
3. Determination of how development of the Bluffs might affect the avalanche runout distances and potential hazard to adjacent property;
4. Discussion of mitigation techniques that could be used to reduce to an acceptable level the hazard increase resulting from the Bluffs development.

This study has been organized as specified in National Environment Policy Act (NEPA) guidelines for preparing an Environmental Impact Statement (EIS) or Environmental Assessment (EA). We understand that a State of California "Environmental Impact Report." (EIR) follows these guidelines with few exceptions (pers. comm. with Bill Taylor). This study is therefore subdivided into three sections as specified in NEPA: 1) description of the *Affected Environment* (Section 2); 2) *Environmental Consequences* of the proposed Bluffs development (Section 3); and 3) Possible *Mitigation Techniques* that could be used to reduce the environmental consequences to an acceptable level (Section 4).

This study also has the following **limitations** which must be understood by all those relying on the results and recommendations:

1. We relied on plotting of the proposed lot boundaries on a 1" = 200' scale topographic map provided by the Town of Mammoth Lakes; lot boundary stakes (if they exist) could not be identified on the ground because of the snowcover. The conclusions of this study depends, therefore, on the accuracy of the plotting of these lot boundaries.
2. Modifications to the positions of lots could change the results of this study.

This study of avalanche effects and mitigation follows a previous "Draft Environmental Impact Report" (EIR) prepared for the Town of Mammoth Lakes by L. K. Johnson and Associates in 1995. As a result of this previous EIR, the Mammoth Lakes Planning Commission required this analysis of potential avalanche impacts, hazard increase, and mitigation.

Recommended mitigation methods are discussed in detail in Sections 4 and 5 of this report.

2 DESCRIPTION OF THE AFFECTED ENVIRONMENT

2.1 SNOW CLIMATE AND STORMS

The study area is located in a "maritime" climate which is strongly modified by the Sierra Nevada Mountains and the high elevation of the surrounding terrain. Thus winter storms can be of very high and prolonged snowfall and precipitation intensity, but protracted periods of clear, dry weather may also occur between major storms.

The snowpack tends to be of fairly high average density and thus may be quite strong when compared with the snowpack found in the continental climates of the central and southern Rocky Mountains. Although the snowpack may often be classified as "strong," weak layers are known to exist especially in the upper portions of the snowpack where poor bonding between the old and new snow occurs at times. These weak layers can serve as "bed surfaces" where shear strength is low and upon which avalanches can and do release.

The region is well-known for its ability to produce major, prolonged storms. For example, during a major storm at the Mammoth Ski Area during February, 1986 (which was recorded at the 8,900-foot elevation snow study site of Mammoth Ski Area), 140 inches (3.56m) of new snow fell during an 8-day period with 27.4 inches (695mm) of water equivalent. This storm increased the snowpack depth by 111 inches (2.82m). This is the largest prolonged snowstorm to have been documented near any developed area in western North America during the past several decades (Mears, 1996). Large, long-running avalanches occurred at many sites in the eastern Sierra Nevada as a result of this storm. One very large avalanche occurred immediately south of Mammoth Lakes, cut a path through the forest on the north-facing slope 600 to 800 feet wide and deposited debris more than 1,200 feet across a flat meadow at the bottom of the steep slope. One large avalanche occurred early in the storm (February 12, 1986) on the slope directly below the proposed Bluffs development even though this slope supports a forest cover (see Section 2.2).

Even during the major storm discussed in the previous paragraph, not all avalanche paths were active. In fact, the majority of avalanche areas within the eastern Sierra Nevada from Bishop to Lake Tahoe either were not active at all, or released early in the storm (such as the avalanche below "The Bluffs") and did not produce spectacular events. This apparently "sporadic" response of the avalanche paths even to major storms is commonly observed throughout the world. In some paths the snowpack will be stronger and more well bonded than at others and avalanches do not occur. These same avalanche paths may produce exceptional avalanches during subsequent storms when different snowpack, storm, temperature, and wind conditions prevail.

In summary, the Mammoth area, including the terrain at and below the Bluffs, has the propensity for major storms and extensive avalanching given the proper snowpack and storm conditions. The eastern Sierra Nevada is well known among avalanche professionals as an area prone to heavy storms and large avalanches.

2.2 TERRAIN

As shown on Figure 1, the proposed Bluffs development is located on top of a bench at an elevation of approximately 8,250 - 8,350 feet. Some lots extend downslope to lower elevations. This bench terminates in steep slopes and short cliffs on north through east exposures above Woodmen, Cliff, and Tamarack Drives in Mammoth Lakes. The nearly flat upper surface of the bench (upon which most of the development is planned), currently supports a dispersed Jeffery Pine (*Pinus jefferyi*) forest. Typical "average" distances between the main stems of the larger trees appears to be on the order of 10m (30-35ft) although considerable variation occurs. Some small "park" areas that are nearly devoid of large trees exist. The large average spacing of trees in this forest enables some wind erosion and transport of the snowpack through the forest. Winds blowing from the southwest characterize many major storms in this area. These winds tend to transport and deposit snow over the edge of the bluff onto the steep north through east exposures above the developed area. During the site visit on March 24 - 26, 1997, clear evidence of wind-transported snow was observed near the top of the northeast exposures within and directly below short, steep cliffs.

Even though the steep north through east exposures also support a forest cover, the slopes are sufficiently steep to enable snow avalanche activity at times of either localized or widespread instability. A crown-face fracture approximately 150 feet wide (located at the top of a small slab avalanche) was observed near lot 28 as indicated on Figure 1. Debris from another avalanche was observed below the steep cliffs near lots 16 and 17. These were small avalanches that occurred during an unexceptional snow and storm season. Given the present conditions with no development of The Bluffs, avalanches are able to reach some of the existing buildings near the base of this slope (Figure 1).

2.3 AVALANCHE MAP

The "AVALANCHE MAP" (Figure 1), describes the "affected environment" and indicates the proposed lot boundaries. The stopping positions ("runout distances") determines the extent of avalanche paths. Runout distances of design or design-magnitude avalanches were computed using the procedures summarized below. The design-magnitude avalanche has a size, runout distance and destructive potential that should be considered in land-use planning and engineering of, in this case, residential areas. It has a return period, T, on the order of 100 ($10^{2.0}$) years. The true return period of the design avalanche lies between the limits $10^{1.5} \leq T \leq 10^{2.5}$ years ($\approx 30 \leq T \leq 300$ years).

a. A data base consisting of 72 major avalanches sampled in the eastern Sierra Nevada (from west of Bishop to Lake Tahoe) was used to derive a statistical *regression equation* that predicts avalanche runout distance. All avalanche paths used in this data base consisted of major, or design-magnitude avalanches with 100 year return periods, approximately (Mears, 1988; McClung and Mears, 1991). The regression equation is highly "area specific;" it is derived from avalanche paths sampled in this region and is used to predict avalanche runout distances in this specific area.
b. The regression equation uses the parameters "β" (average slope angle from the 10° point on the avalanche centerline profile to the top of the avalanche path), and " **Xβ**" (horizontal distance from the top to the 10° point) to compute the average slope angle "α" from the top of the path to the end of the runout zone.
c. Given the data base and terrain measurements discussed in "a" and "b," design magnitude avalanche stopping positions were calculated and drawn on Figure 1. This avalanche map represents the "Affected Environment" existing prior to development of the Bluffs.

The computation procedure described above was used to project avalanche runout zones into the developed area below the steep terrain. Because the avalanche paths support a forest, we assume runout distances would be reduced because of the increased frictional forces and uneven snowpack typical of forests. The effect of this increased friction was considered in calculations. Furthermore, even during design avalanche conditions a large single slab avalanche probably would not affect the entire area at one time because the forest cover results in an inhomogeneous snowpack.

As indicated on Figure 1, several houses along Woodmen Street, Cliff Circle, and Tamarack Street would be exposed to design magnitude avalanches. Most of these houses are located near the lower limit of avalanche runout, therefore they would not be exposed to frequent avalanches. It is beyond the scope of this analysis to determine the destructive potential of avalanches at each building site, although preliminary calculations indicate that some of the existing buildings would probably suffer some damage from avalanche impact.

3 ENVIRONMENTAL CONSEQUENCES OF BLUFFS DEVELOPMENT (ENVIRONMENTAL "IMPACTS")

Construction on some of the lots in the Bluffs could increase the avalanche hazard for the following reasons.

3.1 EXPOSURE TO AVALANCHES ON NEW LOTS

Building on lots 22, 23, 24, and 25 (Block 11), lots 29 and 36 (Block 10) and 27, and 28 (not assessed) would expose buildings north of The Bluffs to potential avalanche impact and hazard. These lots lie entirely within the mapped avalanche area, as shown on Figure 1 therefore the potential avalanche hazard on these lots is not avoidable regardless of building location. Portions of lots 54 - 56 , lots 11-19 and lots 38 - 45 also include avalanche terrain within their boundaries, however building on these lots could easily take place outside any avalanche area.

3.2 WIND DRIFT EFFECTS

Building on lots 11 - 19, 38 - 45, and 54 - 56 (20 lots total), could change snow deposition patterns in the avalanche starting zones below the bluff. The exact locations of buildings on these lots have not been specified but construction could influence the snow deposition patterns in this area of strong winds and occasional prolonged, high-intensity storms (Section 2.1). Location of buildings near the top edge of the starting zones would interrupt wind flow, accelerate wind velocity between the buildings and increase snow erosion and transport between the buildings. This would increase the amount of snow deposited locally on the steep starting zones in some locations and could also increase avalanche frequency (not runout distance or destructive potential) in these areas. Increased avalanche frequency would be an adverse impact to property owners located within avalanche runout zones on Woodmen Street, Cliff Circle, and Tamarack Street.

3.3 CUTTING OF TREES

Construction probably would involve removal of trees that currently reduce the amount of wind erosion and transport on the top of the Bluffs. Depending on the amount and location of tree removal, this would result in additional amounts of snow being transported into avalanche starting zones below the bluff. If additional snow is transported into starting zones, this would also increase avalanche frequency and hazard to those living on Woodmen Street, Cliff Circle, and Tamarack Street. Avalanche runout distance, velocity, or destructive effects would not be changed. Tree cutting would increase avalanche hazard on terrain below lots 11 - 19, 38 - 45, and 54 - 56 or on steep upper parts of these lots.

3.4 INTRODUCTION OF ARTIFICIAL AVALANCHE TRIGGERS

Plowing of snow over the edge of the bluff, blowing snow from driveways and decks, or sliding of snow from a roof into the starting zones could inadvertently trigger avalanches. Depending on building locations, this could be a problem on all of the lots listed in Sections 3.1 and 3.2 and would increase avalanche frequency on terrain below the bluff. This introduction of artificial triggers could increase the hazard to people on the lower lots or those using property below The Bluffs. The extent of avalanches shown on Figure 1 would, however, be unchanged; only the frequency would be increased.

4 RECOMMENDED MITIGATION METHODS

Mitigation can be used to reduce each of the environmental impacts discussed in Section 3 of this report. It must be stated at the outset, however, that the recommended mitigation *will not reduce or eliminate the avalanche hazard that currently exists* on Woodmen Street, Cliff Circle, or Tamarack Street. The objective of the mitigation would be to ensure that the avalanche frequency and resulting hazard *is not increased* as a result of the proposed Bluffs project.

Each of the environmental impacts discussed in Sections 3.1 through 3.4 are discussed in numerically corresponding order in this section.

4.1 MITIGATION FOR LOTS 22-25, LOTS 27-28, AND LOTS 29, 36

Lots 27 and 28 are located on terrain that exceeds 30° (approx. 58%) inclination over most of the lot area. Because most of these lots are located in such steep terrain, extensive cuts would be necessary to site buildings on the steep slopes. Such cuts, even if practical from a geotechnical perspective, would increase the avalanche frequency at the building sites. Such increased frequency could not be prevented by anchoring snow to the steep cut slopes above the buildings. Buildings might be reinforced for avalanche loads, however the steep terrain would ensure exposure of persons to small avalanches several times each year.

RECOMMENDED MITIGATION: Non-residential use of the lots.

Lots 22 - 25, block 11, are all located directly in the track and runout zone of avalanches from steep, short north-facing slopes. Frequency of small avalanches on building sites will be too high for residential development.

RECOMMENDED MITIGATION: 1) Non-residential use of these lots (the recommended mitigation); or 2) Location of buildings as far north as possible on the lots *and* reinforcement of buildings for avalanche loads. Design criteria for reinforcement cannot be specified until final building designs are known.

Lots 29 and 36 (Block 10) are located north of a future extension of Woodmen Street. Construction of this street would reduce (but not eliminate) the avalanche hazard on Lots 29 and 36 because the street surface would serve as a catching structure. Rare events would cross the street, impact buildings on these lots, and could catch persons outside of the buildings.

RECOMMENDED MITIGATION: Calculate avalanche design criteria at the buildings (during building design) and reinforce buildings for avalanche forces. The probability that persons would be caught while outside the buildings is sufficiently small to be disregarded in planning and design at these locations.

4.2 MITIGATION FOR LOTS 11 - 19, 38 - 45, AND 54 - 56

RECOMMENDED MITIGATION: Any construction on these lots, including houses, garages, out-buildings, and fences, must be **no less than 150 feet** from the point to the north or east where the slope steepens to 30° (approx. 58%). This distance should be measured at a right angle to the top of the slope. The upper avalanche boundary on Figure 1 is located approximately at the top of the 30° slope, however this point must be determined by field measurements. Figure 2 is a diagrammatic representation of this mitigation concept. As presently platted, it appears as though lots 13 - 18 and possibly 40 - 45 (12 lots) are not sufficiently long to satisfy this recommendation and provide adequate building area for an average single-family house. These lots may need to be eliminated or the subdivision re-platted in this area. Site-specific field measurements are necessary on each of these lots to determine if room exists to satisfy this slope setback recommendation. Additionally, the Town of Mammoth Lakes should grant front yard setback variances from the proposed Pine and Fir Streets to help satisfy this recommendation.

4.3 ADDITIONAL MITIGATION FOR LOTS 11 - 19, 38 - 45, AND 54 - 56 (TREE CUTTING)

RECOMMENDED MITIGATION: Same as mitigation discussed in 4.2. Additionally, cutting of existing trees should not be permitted within the 150 foot setback from the 30° (58%) slope. Planting of new trees within the 150-foot setback area (to achieve a denser forest) cannot be used to shorten the recommended setback distance.

4.4 MITIGATION FOR INTRODUCTION OF ARTIFICIAL TRIGGERS

RECOMMENDED MITIGATION: Conform to the mitigation recommendations 4.1 - 4.3 *and* ensure that no snow is plowed, pushed, or blown into the avalanche starting zone or onto slopes of 30° (58%) or more. This will require that driveways are not located between the houses and the edge of the slope. Fences should not be built within the 150 foot setback area recommended in

Section 4.2 to help satisfy this recommendation. Fences can create snow deposits in their downwind area, which, if they extend onto the steep terrain can increase avalanche frequency and potential hazard to those living below the steep slopes.

5 ALTERNATE MITIGATION METHODS: CATCHING DAMS, SUPPORTING STRUCTURES, DIRECT PROTECTION

5.1 CATCHING BARRIERS (DAMS)

Catching barriers (or dams) are sometimes built at right angles to avalanche flow and are intended to stop avalanches completely and store avalanche debris behind the structures. They are usually earthen structures derived from material obtained in the area of the dam. Design of catching dams requires knowledge of design avalanche velocity, V, avalanche flow thickness, d, and snow depth on the ground, h. Required height of the dam, H, can then be calculated

$$H = d + h + V^2/2kg, \qquad (1)$$

where k is an empirically-determined constant between 0.5 and 1.5, and g is the gravitational acceleration (9.8m/sec^2 in the m-k-s system). Assuming a snow depth, h of 3m (10ft) when the design avalanche occurs, an avalanche thickness d, of 1.5m (5ft), and a velocity V of ≈10m/sec (≈33ft/sec) based on avalanche-dynamics calculations in this study and many personal observations of small avalanches, the required height of a barrier would be 9.6m (31.5ft) on the *uphill* side (Figure 3). An earthen barrier of this height would be more than 100 feet wide (in the slope direction) and must extend across the entire slope. Such construction would require removal of a wide band of the forest which would in turn help accelerate the avalanche and increase wind-drift effects behind the barriers. The velocity assumed in these calculations (10m/sec) would be variable depending on position. At the eastern end of the study area velocities would be larger (≈15m/sec) and dams would need to be significantly higher. Earthen barriers are not recommended for the reasons discussed.

Structural walls are sometimes used instead of earthen dams. Because they are much narrower, walls require less space than dams, however they must be as high as the earthen barriers discussed above. Structural dams do require reinforcement for avalanche impact pressures that can be estimated by the relationship

$$P = \rho V^2, \qquad (2)$$

where ρ is the avalanche flowing density (assumed to be 150 kg/m^3) and V is the velocity (assumed to be 10-15m/sec). Application of equation (2) indicates a unit pressure of 15-34kPa (314-706lbs/ft^2), values to be used for this feasibility study only, not final design. It would, however, be difficult to stabilize the high walls required (see previous paragraph) against such pressures. Extensive excavation for footings would be required. Because of the above-mentioned design difficulties, structural walls are not a feasible option on these slopes.

5.2 SUPPORTING STRUCTURES

Supporting structures are sometimes built in the steep upper portions of avalanche paths (the "starting zones") to anchor the snow to the ground and prevent avalanches from releasing. Such structures must be designed to resist internal deformation of the snowpack (creep) and slip at the snow/ground interface (glide). Creep and glide pressures are of the same order as the overburden pressure of the snowpack on the ground, which, in this area of heavy snowfall can be more than 300 lbs/ft^2. Supporting structures must also be as deep as the "design" snowpack (a design return period up to 100 years is used). In the wind drift area directly below The Bluffs where avalanches begin, the snow could be more than 6m (20ft) deep, thus lateral forces on the fences would be 6000 pounds per foot of fence length, a value to be used in feasibility analysis only, not final design. Two rows of fences built continuously across the slope would be necessary to prevent avalanches. Construction of such high fences would require removal of large areas of forest in the starting zone which would further destabilize the snowpack during deep, rapid snow accumulations or thaws. Supporting structures are not feasible at this location.

5.3 DIRECT PROTECTION

Buildings have been reinforced for avalanche loads (when avalanches are small and of low energy (like those below The Bluffs) at many locations in western North America and Europe. This is the best form of mitigation that could be used to *protect buildings* at this location. Special design for avalanche forces is best done during the initial design phase of the buildings. During initial design buildings can be oriented, shaped, and located so that avalanche forces are minimized, doors and windows avoided in exposed areas, and foundations specially designed to stabilize the building against large horizontal forces. In some cases special building shapes, such as wedge-shaped prows facing uphill or ramp-roofs are used to provide a streamlined surface that minimizes loads.

Unfortunately re-design or "retrofitting" an existing building is extremely difficult, sometimes impossible. Buildings inadvertently placed in avalanche areas usually do not have the best locations, orientations, or shapes that minimize the avalanche forces. Foundations usually have not been specially designed, and windows and doors are not located in areas away from avalanches. Furthermore, reinforcing buildings does nothing to protect the people who may be outside when the avalanche occurs. For this reason locating any buildings, even those specially designed for avalanche loads, may actually increase the overall hazard if it also increases the development potential in avalanche paths. Building reinforcement should be considered only where the avalanche return period is thought to be long (ideally more than 30 years) and the hazard to persons outside the buildings is statistically insignificant.

One possible mitigation would be to redesign and rebuild all buildings that are exposed to avalanches so that design-magnitude avalanche forces are accommodated. This would require site-specific analysis for each building, since the resulting pressures result not only from the avalanche energy but also from the size, shape and orientation of each building. Although special building design will only protect persons who happen to be inside when the avalanche occurs, the aforementioned problem of people being exposed outside would not be increased if areas are already developed.

6 REFERENCES

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Report prepared by,

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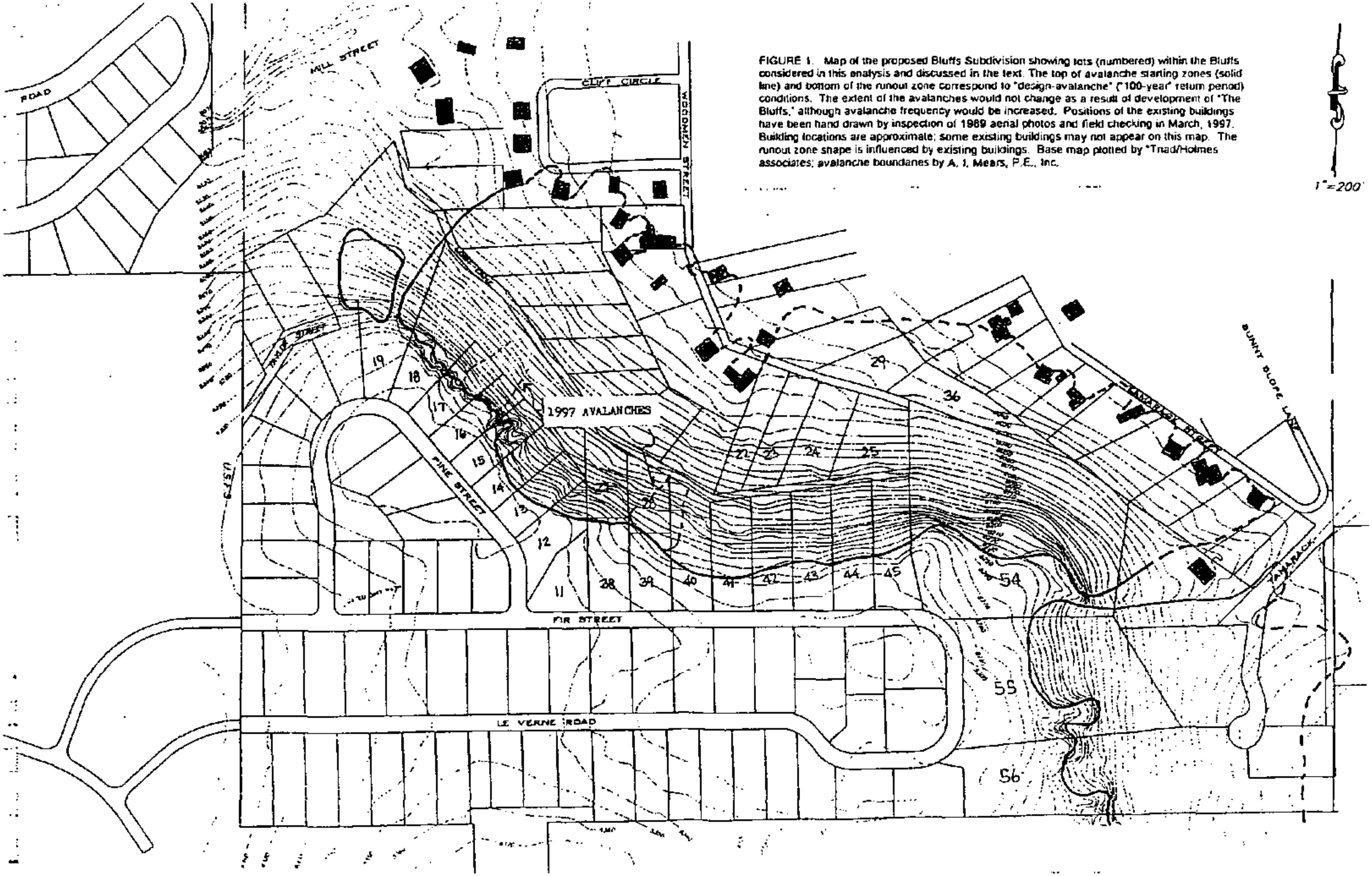


FIGURE 1. Map of the proposed Bluffs Subdivision showing lots (numbered) within the Bluffs considered in this analysis and discussed in the text. The top of avalanche starting zones (solid line) and bottom of the runout zone correspond to "design-avalanche" ("100-year" return period) conditions. The extent of the avalanches would not change as a result of development of "The Bluffs," although avalanche frequency would be increased. Positions of the existing buildings have been hand drawn by inspection of 1989 aerial photos and field checking in March, 1997. Building locations are approximate; some existing buildings may not appear on this map. The runout zone shape is influenced by existing buildings. Base map plotted by "Triad/Holmes associates; avalanche boundaries by A. I. Mears, P.E., Inc.

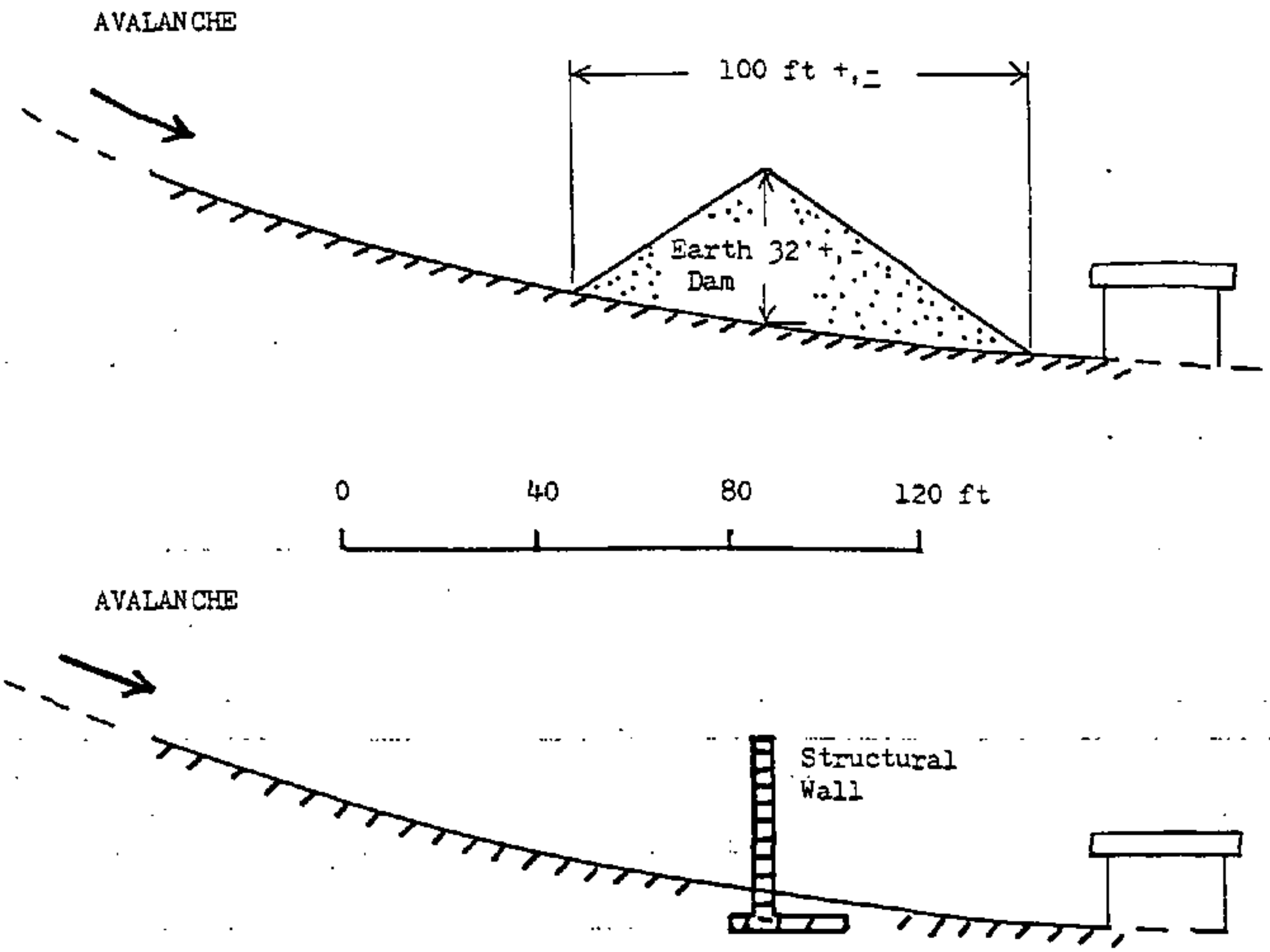


FIGURE 3. Conceptual cross sections of a dam (earthen and structural) that could be used to stop avalanches and store debris above Woodmen and Tamarack Streets, Mammoth Lakes. The critical dimension in dam design is the height above the ground surface on the *uphill side of the barrier*. A large structure is required because the deep, strong snowpack typical in this area may support avalanches and thus must be added to the design height. Such a large structure may not be practical for reasons discussed in the text of this report. Actual dam heights would vary with position along the slope. At some locations even larger structures would be required.

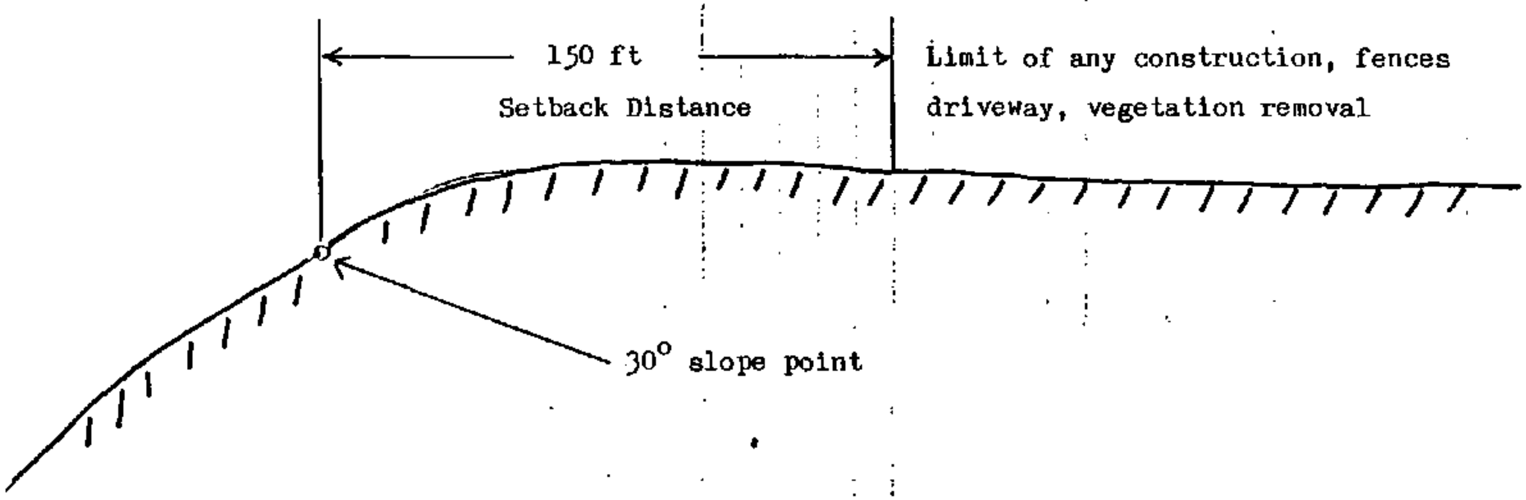
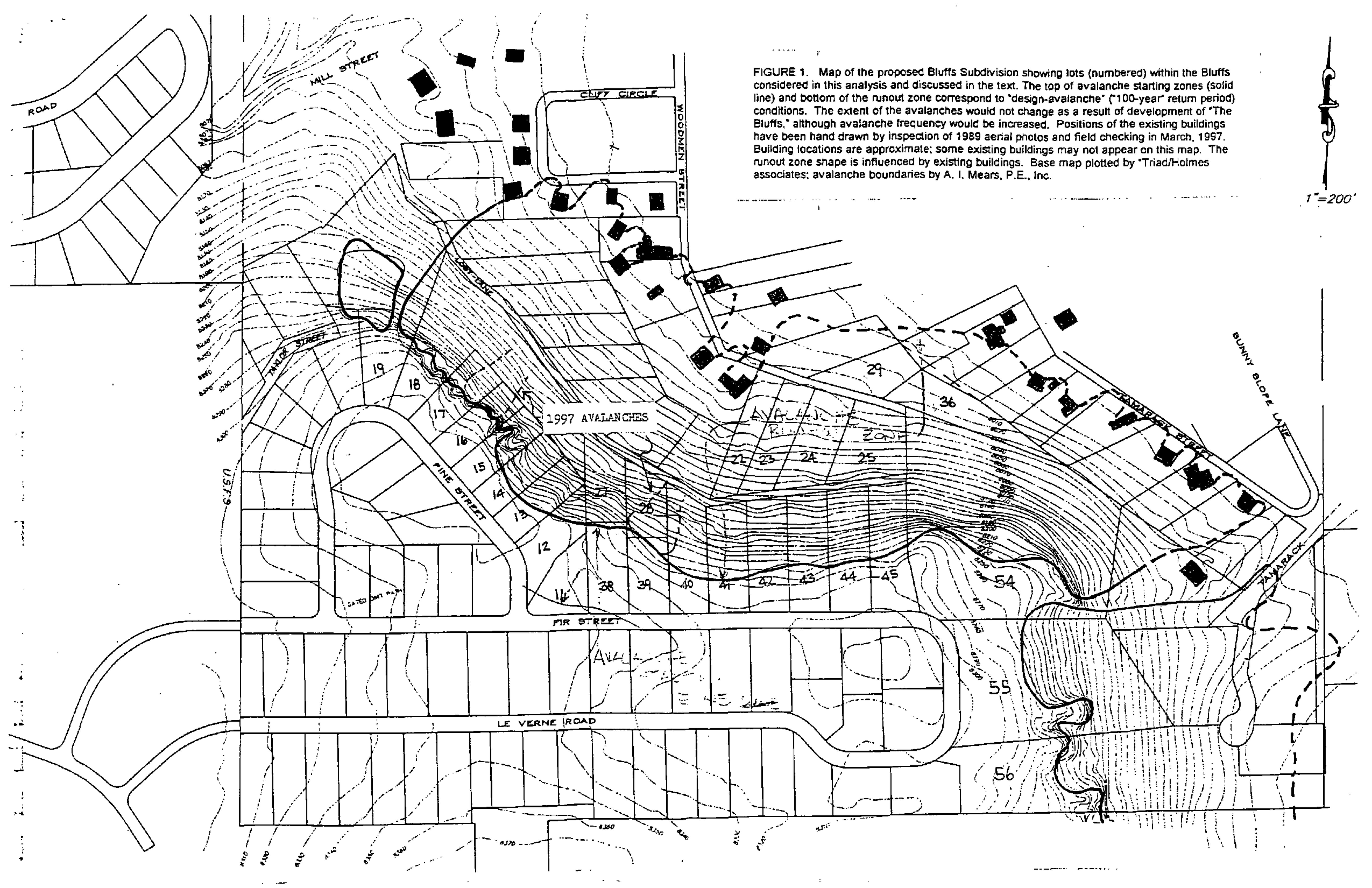


FIGURE 2. Mitigation concept to be used on lots 11 - 19, 38 - 45, and 54 - 56. As discussed in the text, insufficient space may exist on some of the lots for this concept to be executed. Field measurements are necessary to determine the precise location of the 30° point on each lot which would determine the 150 foot setback distance.



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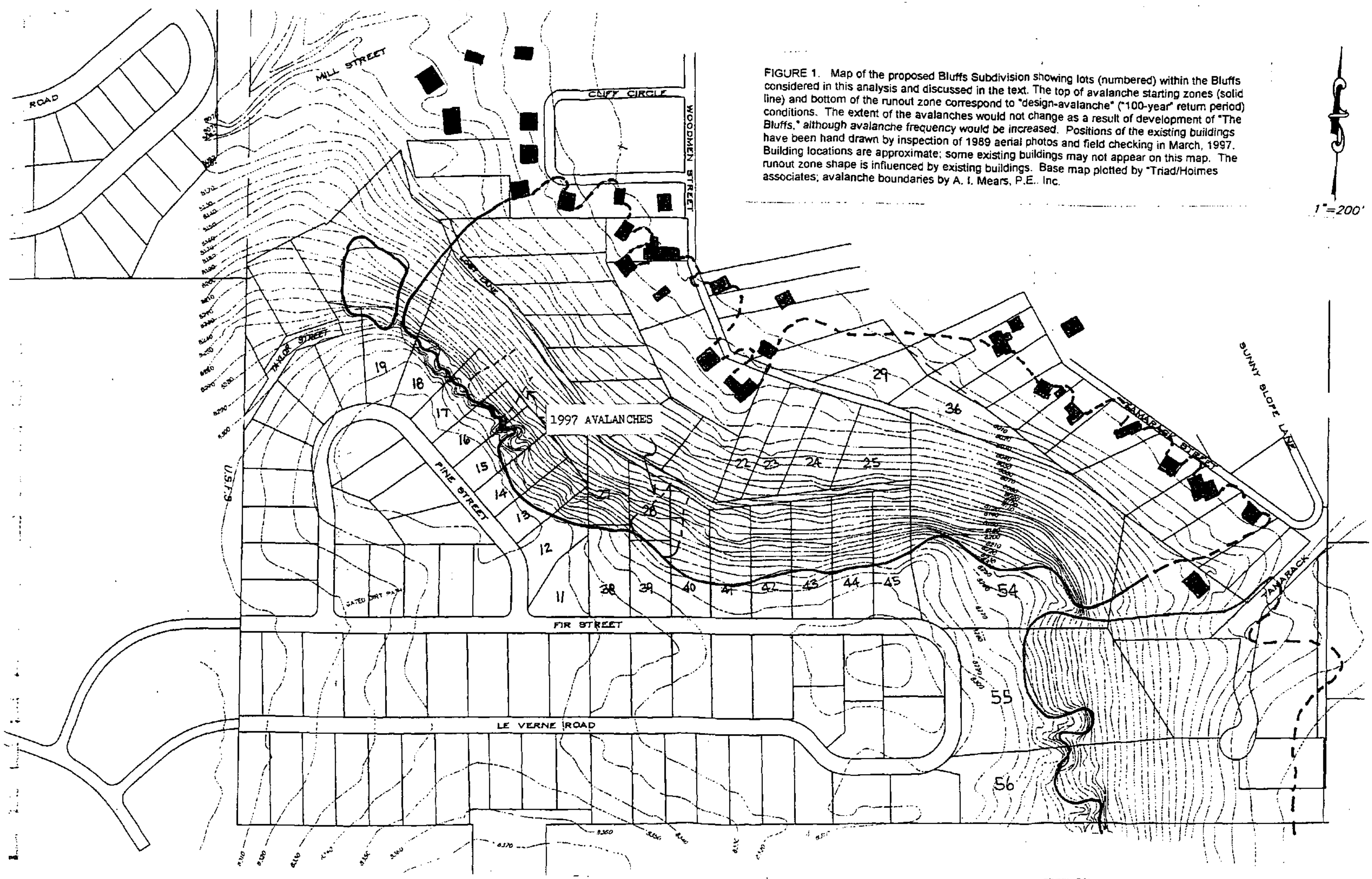

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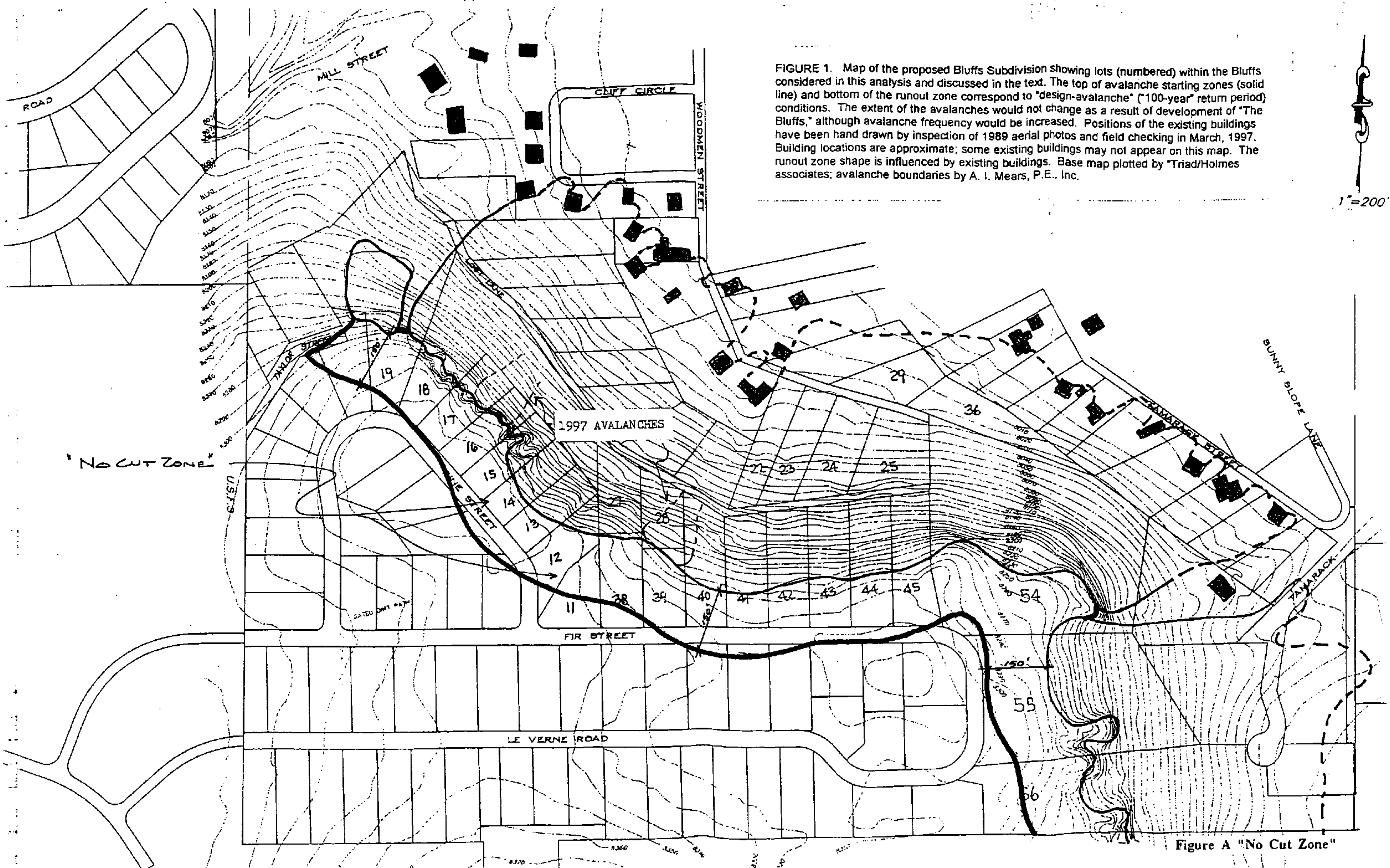

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Figure A "No Cut Zone"