Appendix E:
Avalanche Hazard Studies

LARRY HEYWOOD
SKI AND SNOW CONSULTANT
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April 23, 2010

Re: Plum Family Bluffs/Tamarack Street Properties
Avalanche Hazard Assessment and Comments

Dear Mr. Plum:

I have previously reported on your Bluffs Tamarack Street properties in January 2006 and December 2007. Those reports (including all other documents referenced therein) are incorporated as integral parts of this report. You have now requested I analyze your current proposal to develop 6 single family residential dwelling sites (1 off Leverne Street in the Bluffs subdivision and 5 between existing Tamarack Street and the U.S. Forest Service ("USFS") lands) on your 5.6 acres of properties as illustrated in the 2 attached Triad/Holmes Associates maps dated 4/5/2010 titled Proposed 4' Wide Public Pedestrian Access Easement and Upper Building Site 30% Slope Line respectively (the "Triad Maps"). First, your current proposal does not change in any way my assessments or comments in my 2 previous reports.

BUILDING IN THE AVALANCHE RUNOUTS OFF THE TAMARACK STREET EXTENSION

In his 1997 Avalanche Report to the Town of Mammoth Lakes ("ToML"), Art Mears provided a map which identified the Design Magnitude Avalanches (100 year return interval) from the Bluffs area, which are delineated on the Triad Maps. As noted in my January 2006 report, Mears provided a site specific avalanche analysis on your property in November 2003 detailing the Design Magnitude Avalanche requirements for designing (such as avalanche impact loads) and constructing structures within the avalanche runouts.

The 5 residences off the Tamarack Street extension must be designed and constructed to withstand the expected avalanche impact loads as provided by Mears, thereby eliminating most of the avalanche risk to the inhabitants and users of those properties since inhabitants and persons accessing the residences will either be outside of the avalanche area or inside of or below the structure designed to withstand the expected maximum avalanche impact.

The proposed pedestrian access trail along the easterly edge of your properties from the public parking spaces to the USFS lands to the south is mostly outside the avalanche runouts below the Bluffs. Although the proposed trail crosses a section of an avalanche runout, it's much safer from avalanche risk than the current public practice of crossing your property unprotected further to the west.

BUILDING IN THE SNOW DEPOSITION DESIGN ("SDD") ZONE

The 1 residence off Leverne Street in the Bluffs subdivision will be constructed within the ToML's SDD zone. The intent of the SDD zone was to limit development on the Bluffs that might increase snow deposition into the avalanche starting zones to the north and east of the Bluffs that might increase the avalanche risk to other properties below

However, properly placed structures within the SDD zone will in fact decrease both the frequency and size of avalanches which originate from the paths below the Bluffs. This would result from the tendency of wind transported snow to be deposited in the vicinity of and especially downwind of objects. If structures are placed an appropriate distance from starting zones, snow that may have been blown into and deposited in the starting zone will be deposited near the structures. I have worked on a number of residential plans in the Bluffs where the ToML has permitted structures (including the immediately adjacent lot # 55) within the SDD zone based on this premise. Proper orientation and placement of structures in this area is critical so as not to cause greater that natural snow deposition in the starting zones. Generally, the ToML has approved structures which meet the following criteria:

> Structures should be located a minimum of 30 feet to the windward of the point at which the slope steepens to 30 degrees. Structures should be located a minimum of 1.5 times their height above grade to the windward of the point at which the slope steepens to 30 degrees. Should the structures be multilevel, each level should conform to this 1.5 times factor. In some instances, and only after a more rigorous investigation, it may be possible to build closer to the 30 degree point.
>
> Roof, walkways and driveways should be located or positioned such that shedding snow or plowed snow is not directed towards the starting zones.

Based upon the ToML's past approvals, a structure which meets these criteria should be approved.

If you have any questions or need any additional information, please contact me.

Respectfully submitted,

Larry Heywood

Larry Heywood

EIP
ASSOCIATES

March 3, 2006

Craig Olson, Associate Planner
Town of Mammoth Lakes
P.O. Box 1609
Mammoth Lakes, CA 93546

SUBJECT: **Independent Review of Subsequent Avalanche Hazard Analysis Prepared for the Plum Tentative Parcel Map (36-203) in the Town of Mammoth Lakes**

Dear Mr. Olson:

I have reviewed the supplemental information provided in the January 2006 report prepared by Larry Heywood for proposed tentative parcel map (TPM) 36-203. It is my understanding that the applicant has revised their proposal to subdivide the property (current Lot 56) into two separate parcels (Parcel #1 and Parcel #2) in response to previous concerns raised regarding potential avalanche hazard.

I concur with the analysis provided by Mr. Heywood that if the proposed changes to the project are implemented, and the recommended design criteria are followed, most (if not all) of the potential avalanche hazard will be reduced or removed. In particular, the relocation of the existing extension of Tamarack Road will greatly reduce the risk to users of the road, including the staff of the Mammoth Community Water District in accessing their facilities, as well as members of the public who make use of the road to access the adjacent public lands. I hope this provides the information you require to comply with the Town's SDD Ordinances. If not, please feel free to contact me.

Respectfully submitted,

John Moynier
Director of Water Resources
EIP Associates

LARRY HEYWOOD
SKI AND SNOW CONSULTANT
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Email: larryheywood@sbcglobal.net

January 20, 2006

Mr. Terry Plum
P.O. Box 8208
Mammoth Lakes, California 93546

Re. Plum Property
Avalanche Hazard Analysis and Comments

Dear Mr. Plum
At your request I offer the following analysis and comments on your proposal to subdivide and adjust property lines on Lot # 56 in the Bluffs and the adjacent property off of Tamarack Street. You propose to subdivide these properties into three separate parcels. The first parcel will be accessed off of LaVerne Street in the Bluffs subdivision. The second and third parcels will be accessed off an extension of Tamarack Street. Specifically you have asked me to address the following issues and concerns relative to their impact on any potential or perceived avalanche risk.

The feasibility of building a residence on Lot#56 in the Bluffs and within the Town of Mammoth's Snow Deposition Design Zone (SDD), parcel #1

The feasibility of subdividing and building residences on the lower section of #Lot 56 and the property to the north, parcel #2 and #3

To review and evaluate John Moynier's letter dated June 22, 2004 in which he provides a review of your proposal to subdivide Lot#56

Each of these general issues are related and also include a number of details and considerations which I will try to address below. As you are aware the Bluff's area and adjoining properties have been the subject of considerable study and analysis including some of which I conducted. As part of this analysis, for your project, I have reviewed many of these documents. I have also reviewed the following documents which are specific to your proposal and plans. Arthur Mears May 1997 Avalanche Hazard Change Resulting From The Bluffs; Arthur Mears November 4, 2003, Avalanche Mitigation Analysis, Tamarack Road Lots; John Moynier June 22, 2004, Independent Review of Avalanche Studies Prepared for the Plum Tentative Parcel Map; Tentative Parcel Map No. 36-203; A revised access map; no date.

BUILDING IN THE SNOW DEPOSITION DESIGN ZONE (SDD)

Parcel #1 in your proposed subdivision and property line adjustment is located off of Le Verne Street in the Bluff Subdivision. Access will be from the Le Verne Street and will necessitate the construction of the residence within the Town of Mammoth's SDD. The intent of the SDD was to limit development on the Bluffs that might increase snow deposition into the avalanche starting zones to the north and east of the Bluffs. During the development of the Bluffs subdivision there was concern that structures and or activities within the Bluffs would increase the avalanche risk to the properties below.

Although there may be some argument that certain types of activities within the Bluffs could increase avalanche frequency from the avalanche paths to the north and east, such activity will not increase the size of avalanches from these paths. It has been my position that properly placed structures within the SDD will in fact decrease both the frequency and size of avalanches which originate from the paths below the Bluffs. This would result from the tendency of wind transported snow to be deposited in the vicinity of and especially downwind of objects. If structures are placed an appropriate distance from starting zones, snow that may have been blown into and deposited in the starting zone will be deposited near the structures. I have worked on a number of projects in the Bluffs where the town has accepted this premise and allowed construction of structures within the SDD. Proper orientation and placement of structures in this area is critical so as not to cause greater than natural snow deposition in the starting zones. Generally the Town has approved structures which meet the following criteria.

> Structures should be located a minimum of 30ft to the windward of the point at which the slope steepens to 30 degrees.
>
> Structures should be located at a minimum of 1.5 times their height above grade to the windward of the point at which the slope steepens to 30 degrees. Should the structures be multilevel each level should conform to this 1.5 times factor.
>
> Roof, walkways, and driveways should be located or positioned such that shedding snow or plowed snow does not directed be towards the starting zones.

Based upon the Town's past approvals, a structure which meets these criteria should be approved.

BUILDING IN THE AVALANCHE RUNOUTS OFF TAMARACK

Parcels #2 and #3 will be located at the eastern edge of Lot #56 and will be accessed from an extension of Tamarack Street. The Snowcreek golf course is immediately to the east of these parcels. I understand that you recently purchased the Miller property which is to the north and is continuous with lower portion of Lot #56. Previously you had proposed to access these parcels from an extension of Tamarack that would run into the upper portion of the parcels. Recently you have proposed to relocate the extension of Tamarack. With this change, the access to these parcels will be from the lower eastern edge of the parcels.

These parcels are located at the bottom of the avalanche paths which start below the Bluffs. There has been more than one documented avalanche occurrence just to the west and north of these parcels. In his 1997 Avalanche report to the Town, Mears provided a map which identified the Design Magnitude Avalanches (100 year return interval) from the Bluffs area. As identified on that map the eastern third of Parcels #2 and #3 are beyond the runout of avalanches from paths below the Bluffs. I understand that in November 2003 Mears conducted a site specific avalanche analysis for you and your neighbor that included both Parcels #2 and #3. In his analysis he provide detailed information on both the Design Magnitude Avalanches that may reach the property. According to this Mears analysis, Design Magnitude avalanches will terminate approximately 70 feet west of the eastern edge of the Snowcreek Golf Course. This is 70 feet from the eastern edge of Parcels #2 and #3. In his report Mears also provided avalanche impact loads and other information for designing and constructing structures within the runout of the avalanches paths on parcels #2 and #3. I understand you had requested this information.

I understand that your current proposal for this area includes the realignment of Tamarack to the eastern edge of the parcels. Additionally you are proposing to build two residences, one on each parcel, just to the west of the Tamarack extension. These residences will be designed and constructed to withstand the avalanche impact loads that were provided by Mears. Winter access to these residences will be from the east.

Your proposal to realign the road, design and construct the residences to withstand the expected avalanche impact loads, and create the winter access to the east should eliminate most of the avalanche risk to the inhabitants and users of the property. The road relocation will eliminate the avalanche risk for users of the road through most of the property since most of the new alignment is outside of the Design Magnitude Avalanche. Inhabitants and persons accessing the residences will either be outside of the avalanche area or inside of the structures designed to withstand the expected maximum avalanche impact.

RESPONSE TO JOHN MOYNIER REVIEW

In his June 22, 2004 review of your Tentative Parcel Map, Mr. Moynier addressed a number of avalanche occurrence and safety issues related to your property. Specifically he offered details of avalanche events he claims to have observed on your and adjacent properties and a discussion of the safety of recreation and water district employee users of the property.

In his review Mr. Moynier reports observations of avalanche occurrences that reached the MCWD well site and that "traveled through the property onto the flat land of the lower slope below". From this description, it is not clear if these observations conflict with Mr. Mears calculated avalanche runout delineations which is 70 feet west of the Plum Snowcreek Golf Course property line. The MCWD well site is located to the south of your property. Avalanches reaching this site would not necessarily have traveled through your property to reach this site. Mr. Moynier's description of avalanches traveling onto the flat land of the lower slope appears to be in agreement with the Mear's calculated runout zone. The area identified by Mears as 70 feet west of the golf course is on flat land.

There are two factors which suggest the observations of Mr. Moynier should be viewed with some skepticism. I understand, based upon your conversations with MCWD staff and in particularly Mark Busby, Maintenance Superintendent, that MCWD staff has never observed avalanches reaching the well site. Additionally I understand from your conversation with Mr. Busby that MCWD staff has not need to access this well site in the winter. Secondly, it does not appear that Mr. Moynier nor for that matter anyone else ever contested or challenged the Mear's 1997 avalanche map, commissioned by the Town of Mammoth which clearly identifies the well site and the eastern edge of your property outside of the avalanche runout zones.

Mr. Moynier offers considerable personal opinions on the MCWD staff's and general public's exposure to avalanches in accessing the well site and the public lands to the south of your property while crossing your private property. It is important to note that this hazard already exists and that your proposed subdivision will not increase the risk to these current users. The new proposed alignment of Tamarack to the east edge of your property will actually provide a route through your property that is beyond the Design Magnitude Avalanche. This well allow MCWD a safer winter route across your property. As for the public access, this is your private property, if necessary you could prohibit trespass across it. I understand you hope to avoid this option.

I hope this report provides the information you require. If you have any questions or need any additional information, please contact me.

Respectfully submitted

Larry Heywood

ARTHUR I. MEARS, P.E., INC.
Natural Hazards Consultants
555 County Road 16
Gunnison, Colorado 81230
Tel/Fax: 970-641-3236
artmears@rmii.com

November 4, 2003

Mr. Michael J. Miller
Stoney-Miller Consultants
14 Hughes, Suite B-101
Irvine, CA 92618

RE: Avalanche mitigation analysis, Tamarack Road Lots, Mammoth Lakes, CA

Dear Mr. Miller:

At your request, I have completed an avalanche-dynamics and mitigation analysis of your lot and Terry Plum's lot on Tamarack Road in Mammoth Lakes. Details of this analysis are attached. My analysis is based on lot locations shown in the grading plan by Triad/Holmes Assoc., dated "7/24/2003;" substantial changes to this plan may invalidate my results.

I have concluded the following:

a. Avalanches will stop on the road and/or on the access extension assuming the proposed southward extension of Tamarack Road and the additional 20-foot access extension are both completed as shown on the grading plan and that these surfaces will be kept free of snow;
b. Houses located east of the road and access extension will not require additional mitigation, assuming the Tamarack Road and access extension have both been cleared of snow at the time of the avalanche;
c. However, if it cannot be safely assumed that snow clearing has taken place before the avalanche, both houses will require mitigation through structural reinforcement of the uphill-facing (west surfaces), as discussed in "mitigation."

Please contact me if you have any questions.

Sincerely,

Arthur I. Mears, P.E. (CO)
Avalanche-control engineer

1 TERRAIN AND FIELD OBSERVATIONS

The site studied is shown on four photographs (Figures 1 – 4) which provide perspectives from different directions. The largest avalanches begin at elevations of approximately 8,195 – 8,230 feet, approximately 250 – 280 feet above and west of the proposed building locations. The primary avalanche hazard will result from dry slab avalanches which will be formed by snow deposited by strong west to southwest winds. The avalanche starting zones[1] will be located between and below distinct bedrock outcroppings (Figures 1 and 3).

Inspection of terrain configuration on the lower slope (above the proposed Tamarack Road extension) suggest avalanches reached this area in the past, possibly reaching to the building sites. This is further confirmed by a) starting zone slopes in excess of 35° (sufficiently steep for avalanche initiation), b) a history of avalanches in the area and c) avalanche impact damage to trees (Figures 2 and 4). However, field evidence for avalanches on the lower slope could not be found.

2 AVALANCHE DYNAMICS AND RUNOUT

Avalanches with return periods on the order of 100 years[2] (the “design-magnitude” avalanche) have been computed to assess the need and feasibility of mitigation. This “100-year” return period has previously been considered in Mammoth Lakes and is an order of magnitude estimate of the true return period, which may lie between 30 and 300 years, approximately.

Without the proposed Tamarack Road extension in place, design-magnitude avalanches will terminate approximately 70 feet west of the eastern edge of the Snowcreek Golf Course, as determined by analysis. This runout distance, and the associated speeds and impact pressure potentials at a building site have been computed through statistical analysis of a large database of avalanches that occurred in the Eastern Sierra Nevada and application of an avalanche-dynamics model. The procedure applied three steps as follows:

a. The runout distance (or stopping point) was determined by constructing a detailed slope profile, identifying the starting point and 10° point on the profile, and predicting the runout from a regression equation which was derived from historical data on Sierra avalanches.
b. Avalanche speeds along the profile were computed by fitting a 3-component, stochastic, avalanche-dynamics model to the avalanche profile; this model simulated speeds along the profile.

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[1] *Starting zone – Slopes generally in excess of 30° inclination, where avalanches start, accelerate and increase in mass.*
[2] *Return periods up to 300 years for the design-magnitude avalanche are considered in some United States jurisdictions and are commonly considered in Europe and Canada.*

c. Impact-pressure potential, P, was then computed by the relationship $P = \rho V^2$, where ρ is flowing snow density (150 kg/m^3) and V is computed speed.

Some details of the terrain and avalanche-dynamics analyses are summarized graphically in appendices "A" through "H."

3 RESULTS

Because the dry-snow avalanches which occur during the design event achieve speeds of only 17 m/s (38 mph) or less on the steep slopes, even during design conditions, internal friction will be high and avalanches will stop quickly when encountering objects in their paths. The dynamic analysis indicates the Tamarack Road extension and cut-de-sac at the south end will stop the avalanche, *provided this road is plowed clear of snow at the time of the avalanche*. The approximately 20-foot wide access easement to "MCWD and emergency vehicles" shown on the Triad/Holmes map will also stop the avalanche *if it is also plowed clear of snow* when the avalanche occurs. This will therefore provide mitigation for the buildings.

However it is not prudent to assume the road will always be plowed during the extremely heavy and prolonged storms which could be associated with the design event. At these times snow plowing operations within Mammoth Lakes and Mono County will be an on-going process. Strong winds and drifting snow will quickly fill in the previously-plowed roadway. Furthermore, the extension of Tamarack Road is located within an avalanche area consequently working on the road might exposed equipment operators to unnecessarily high risk.

Given the limitations to road plowing discussed above, and considering the reasonable assumption that the road may not be plowed during a major storm, the proposed houses should be reinforced at the uphill-facing walls for avalanche impact loads.

4 MITIGATION – IMPACT LOADS

Figure 5 illustrates schematically the vertical distribution of loads on the uphill faces of the Miller and Plum houses. Impact loads decrease linearly with height from a maximum of 100 lbs/ft^2 at the base of the wall to zero at a height of 12 feet above grade. The final design loads might be somewhat different than those shown, depending on final building position and orientation with respect to avalanche direction. Because impact is proportional to the square of sine of the deflection angle, the impact pressure will decrease quickly with impact angle. For example, if a wall intercepted the avalanche at a 45° angle, the loads would be decreased to 50 lbs/ft^2.

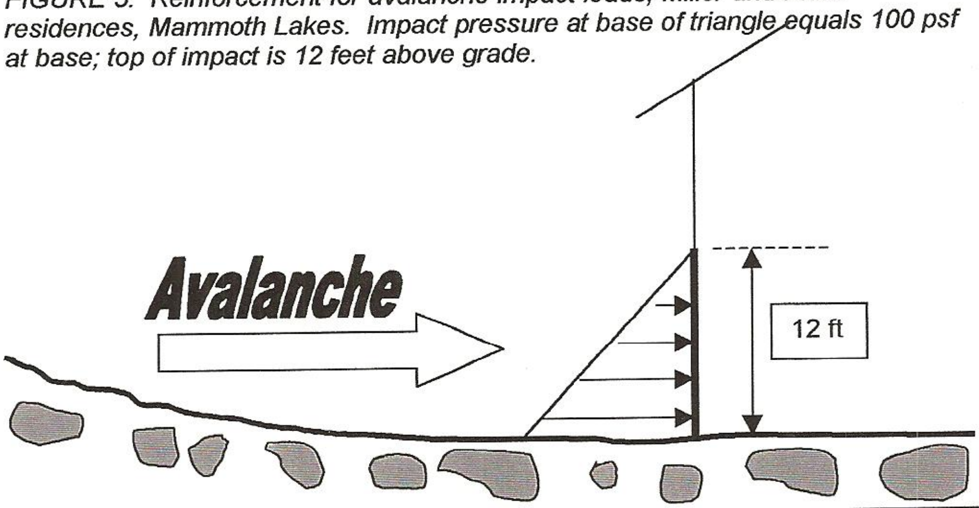
When designing avalanche mitigation into a building, the following additional factors must be considered:

a. Window and doors exposed to the avalanche should also be designed for avalanche impact;
b. Alternate entrances safe from avalanches should be planned;
c. Final loads may require adjustment by an impact factor;
d. Building orientation, shape, or other factors could change the loads;
e. Impact decreases linearly with height.

Report prepared by,

Arthur I. Mears, P.E. (CO)
Avalanche-control engineer

FIGURE 5. Reinforcement for avalanche impact loads, Miller and Plum residences, Mammoth Lakes. Impact pressure at base of triangle equals 100 psf at base; top of impact is 12 feet above grade.



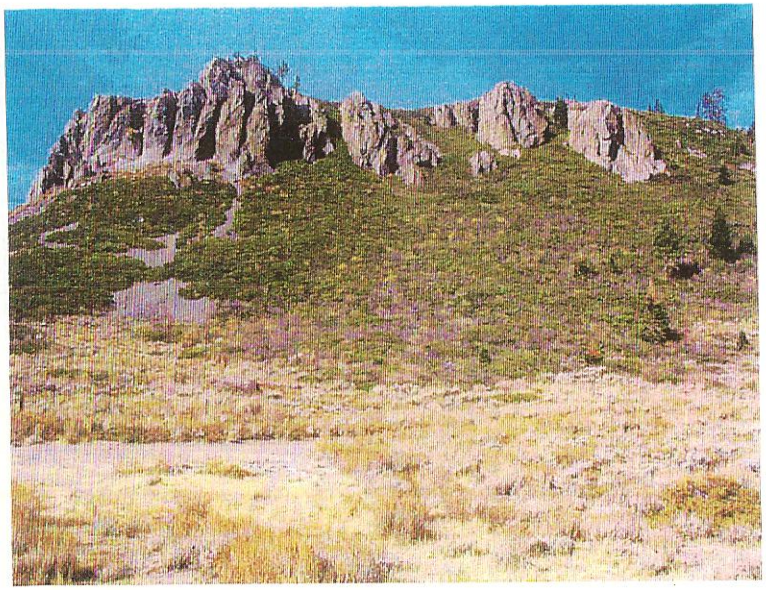


FIGURE 1. Largest avalanches begin between and below rock outcroppings; view is from building sites; view toward west.

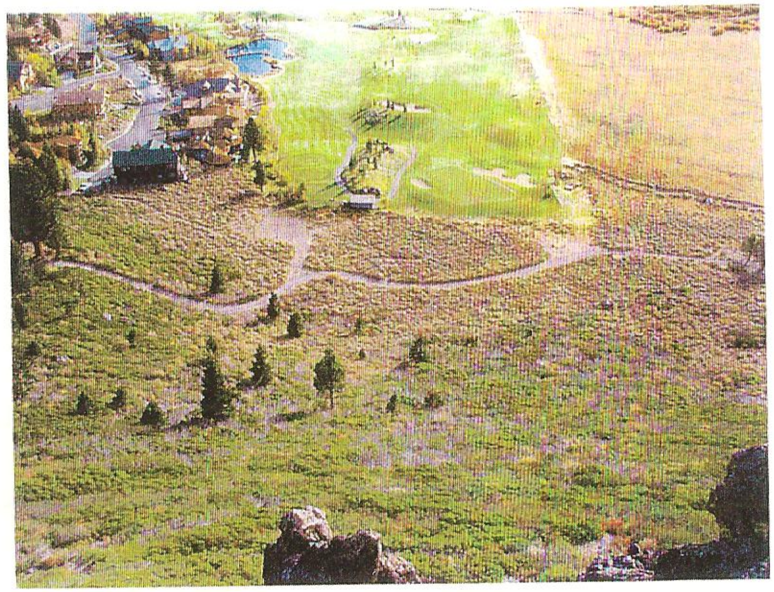


FIGURE 2. View is looking east from starting zones to building sites and golf course.

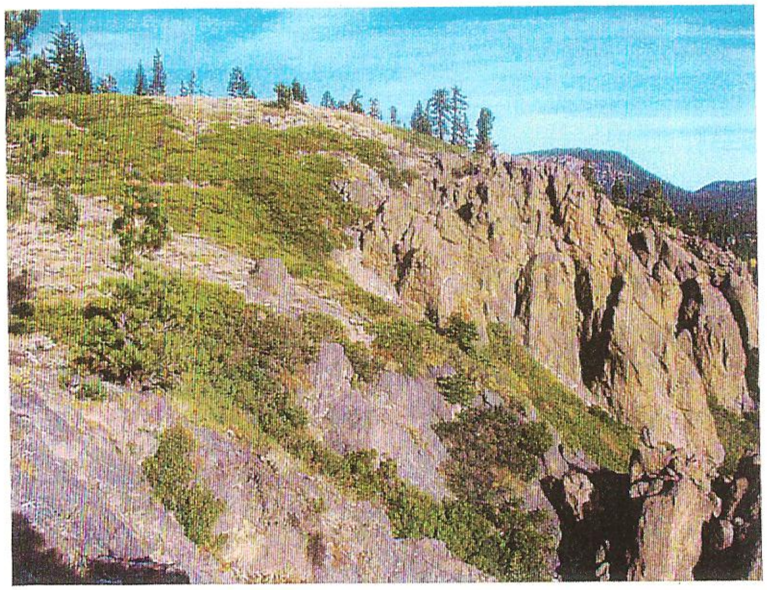


FIGURE 3. Blowing snow is transported from left to right into steep areas between and below rock outcroppings.

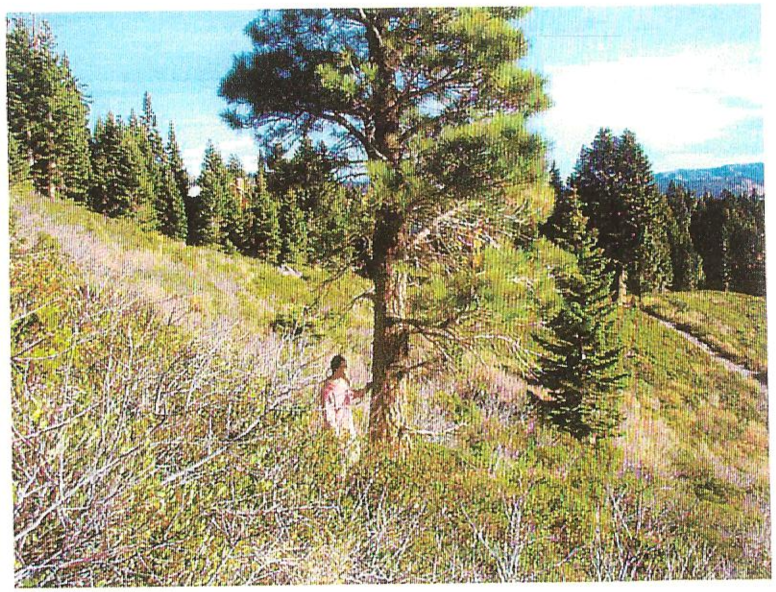
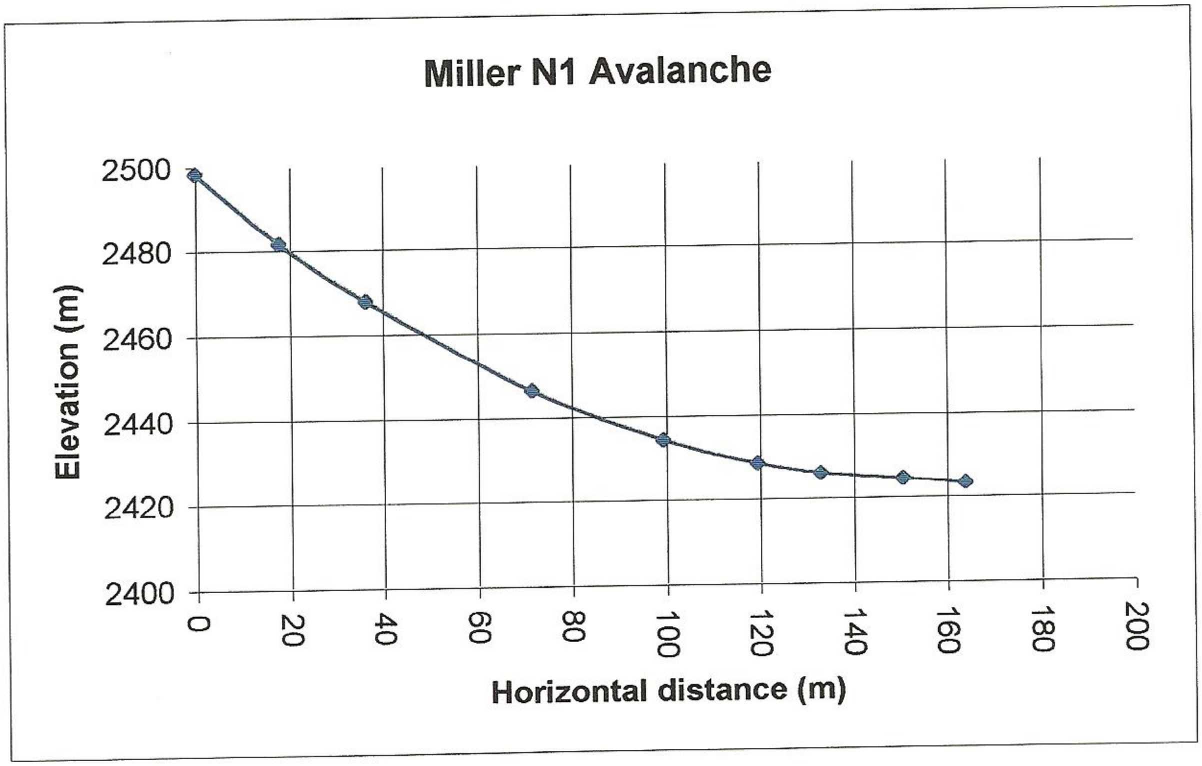


FIGURE 4. Conifer tree on slope a short distance above Tamarack Road extension has broken limbs which suggests avalanche impact

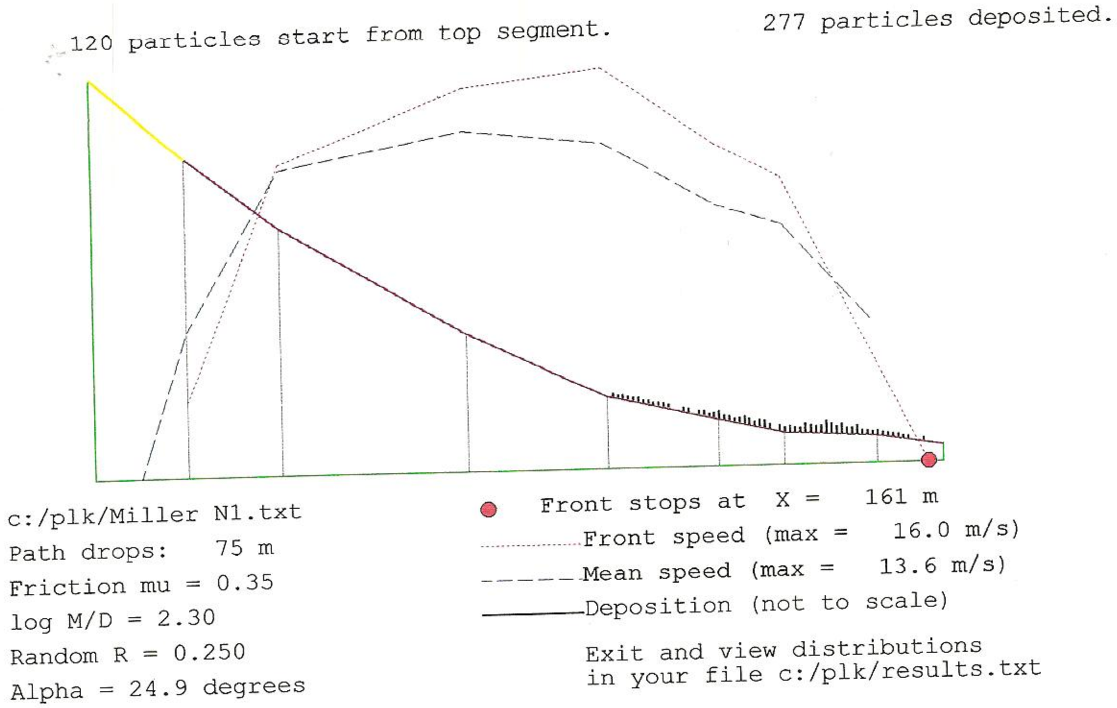
Avalanche Profile and x/y coordinates

Mike Miller N1

Raw Data in feet		**Data in meters**		**Segment Data**			
X-feet	Y-feet	X-meters	Y-meters	L-meters	Ang - Deg	Sum L	Avg Angle
0	8195	0	2498			0	
58	8140	18	2482	24	43.5	24	43.5
119	8095	36	2468	23	36.4	47	40.0
235	8025	72	2447	41	31.1	89	35.9
326	7985	99	2434	30	23.7	119	32.8
392	7966	120	2429	21	16.1	140	30.3
436	7958	133	2426	14	10.3	154	28.5
494	7953	151	2425	18	4.9	171	26.1
538	7949	164	2423	13	5.2	185	24.6



Appendix A. Slope profile used in avalanche dynamics analysis (above Miller, no new road)

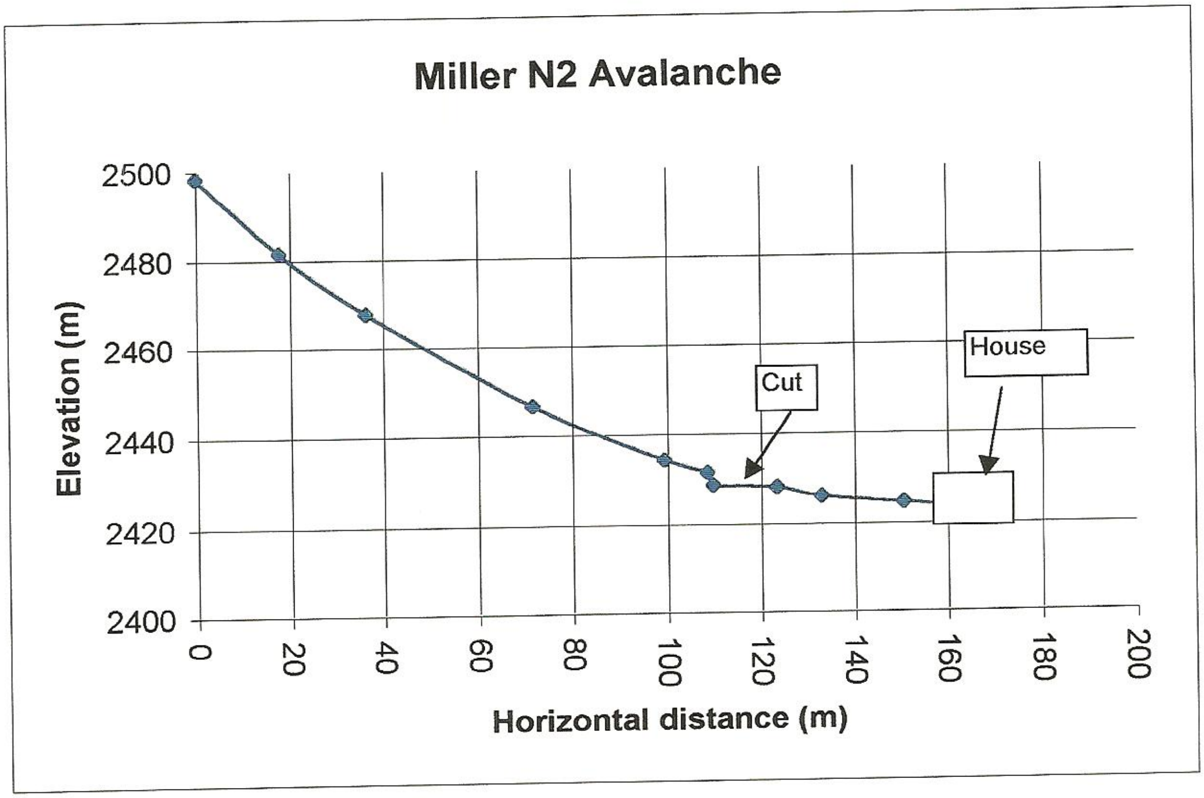


Appendix B. Dynamics graphical output, N1 avalanche.

Avalanche Profile and x/y coordinates

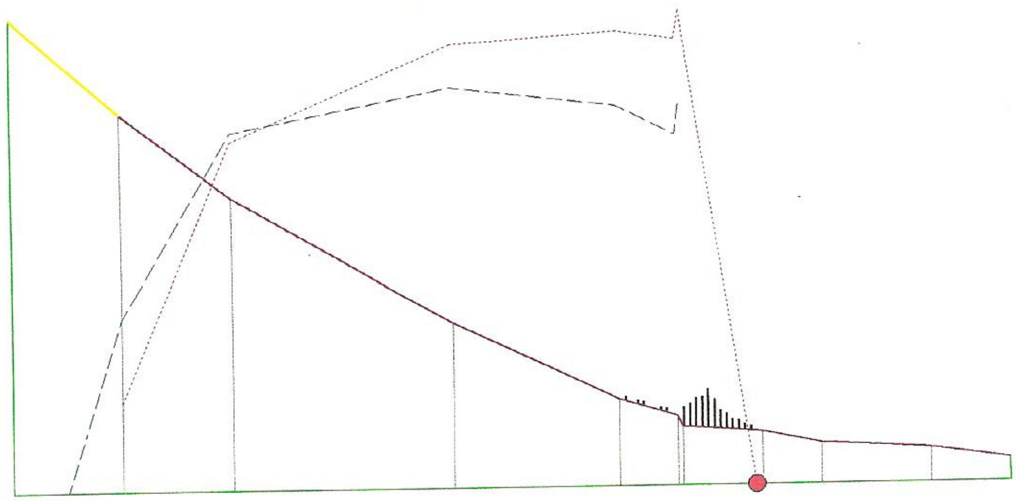
Mike Miller N2

Raw Data in feet		**Data in meters**		**Segment Data**			
X-feet	Y-feet	X-meters	Y-meters	L-meters	Ang - Deg	Sum L	Avg Angle
0	8195	0	2498			0	
58	8140	18	2482	24	43.5	24	43.5
119	8095	36	2468	23	36.4	47	40.0
235	8025	72	2447	41	31.1	89	35.9
326	7985	99	2434	30	23.7	119	32.8
356	7975	109	2431	10	18.4	129	31.7
360	7966	110	2429	3	66.0	132	32.5
405	7964	123	2428	14	2.5	145	29.7
436	7958	133	2426	10	11.0	155	28.5
494	7953	151	2425	18	4.9	173	26.1
538	7949	164	2423	13	5.2	186	24.6



Appendix C. Slope profile used in avalanche-dynamics analysis (above Miller, new road in place)

120 particles start from top segment. 237 particles deposited.



c:/plk/Miller N2.txt

Path drops: 74 m

Friction mu = 0.35

log M/D = 2.30

Random R = 0.250

Alpha = 29.8 degrees

● Front stops at X = 121 m

.... Front speed (max = 16.0 m/s)

_ _ _ _ _ _ Mean speed (max = 13.5 m/s)

________ Deposition (not to scale)

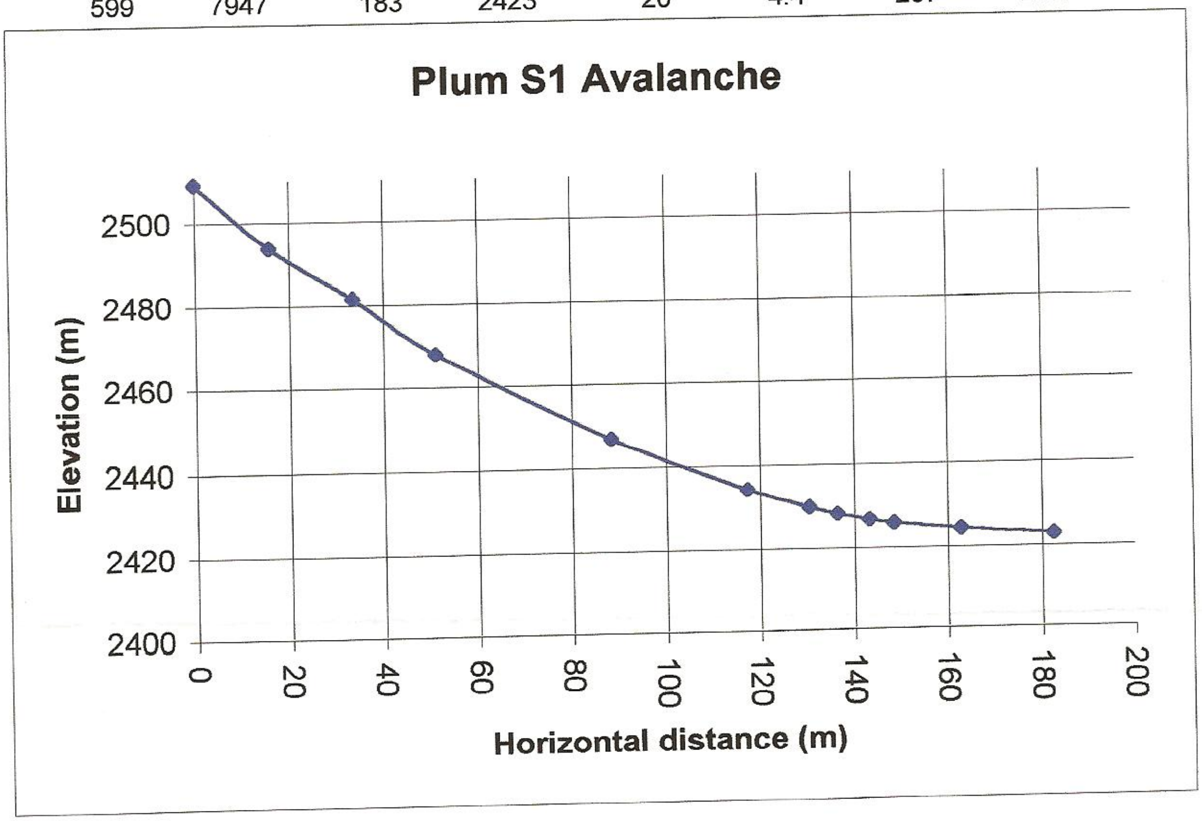
Exit and view distributions
in your file c:/plk/results.txt

Appendix D. Dynamics graphical output, N2 avalanche.

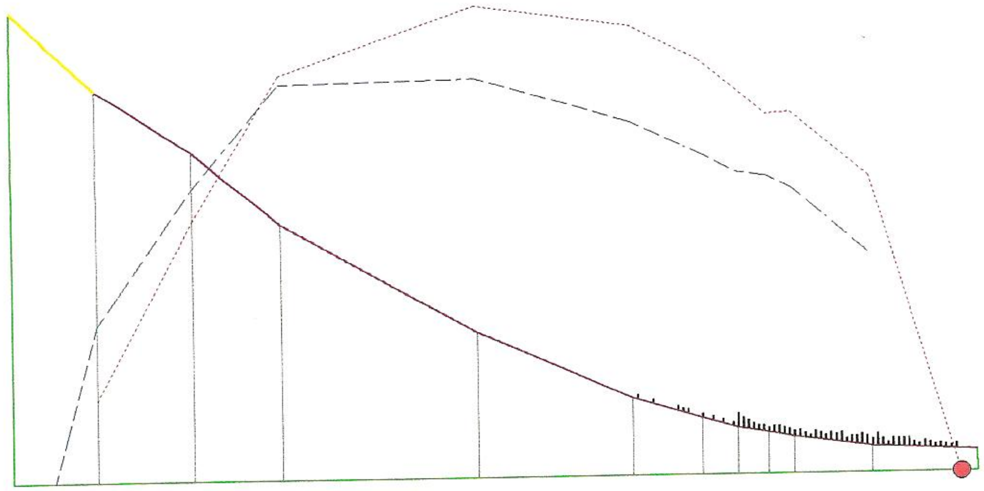
Avalanche Profile and x/y coordinates

Terry Plum S1

Raw Data in feet		Data in meters		Segment Data			
X-feet	Y-feet	X-meters	Y-meters	L-meters	Ang - Deg	Sum L	Avg Angle
0	8230	0	2509			0	
52	8180	16	2494	22	43.9	22	43.9
110	8140	34	2482	21	34.6	43	39.3
168	8095	51	2468	22	37.8	66	38.8
290	8026	88	2447	43	29.5	109	35.1
385	7985	117	2434	32	23.3	140	32.5
428	7970	130	2430	14	19.2	154	31.3
448	7965	137	2428	6	14.0	160	30.6
470	7960	143	2427	7	12.8	167	29.9
487	7957	148	2426	5	10.0	172	29.3
534	7952	163	2424	14	6.1	187	27.5
599	7947	183	2423	20	4.4	207	25.3



109 particles start from top segment. 291 particles deposited.



c:/plk/Miller S1.txt

Path drops: 86 m

Friction mu = 0.35

log M/D = 2.30

Random R = 0.250

Alpha = 25.5 degrees

Front stops at X = 180 m

Front speed (max = 17.0 m/s)

Mean speed (max = 14.4 m/s)

Deposition (not to scale)

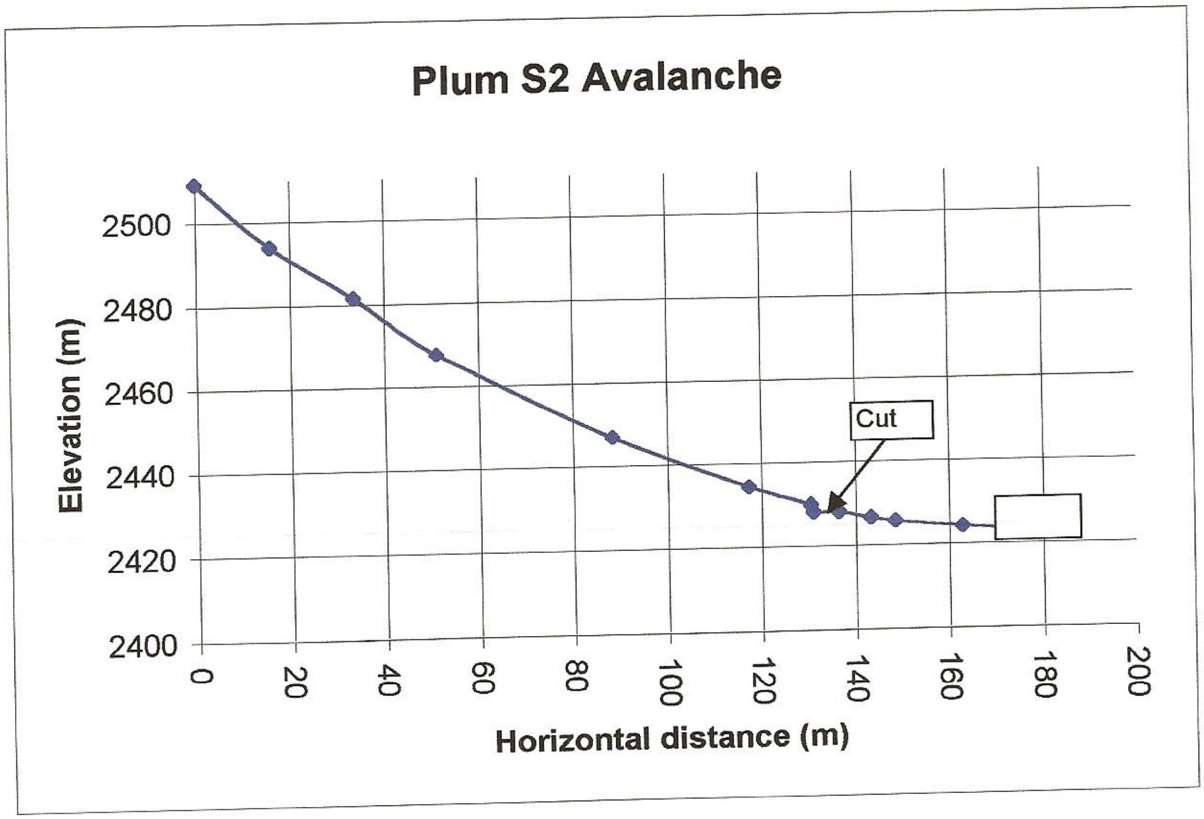
Exit and view distributions
in your file c:/plk/results.txt

Appendix F. Dynamics graphical output S1 avalanche.

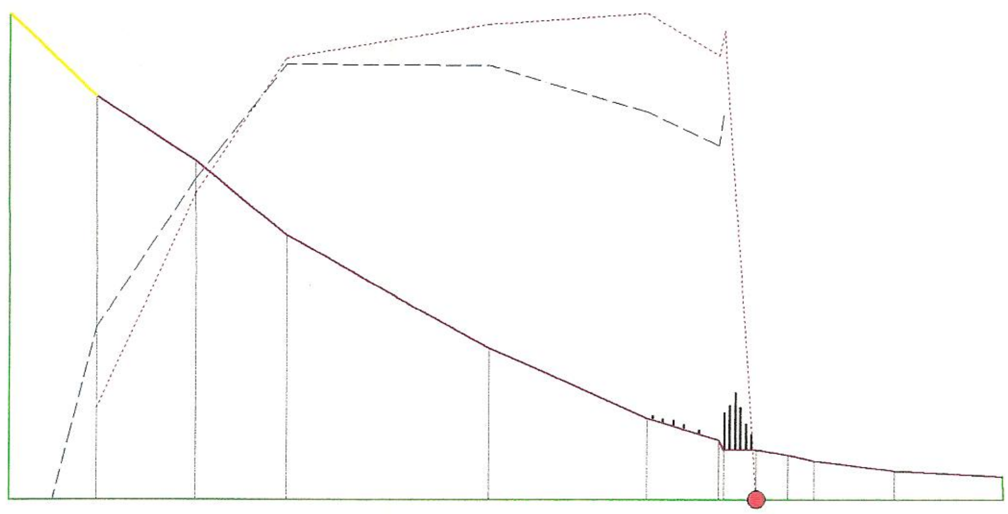
Avalanche Profile and x/y coordinates

Terry Plum S2

Raw Data in feet		Data in meters		Segment Data			
X-feet	Y-feet	X-meters	Y-meters	L-meters	Ang - Deg	Sum L	Avg Angle
0	8230	0	2509			0	
52	8180	16	2494	22	43.9	22	43.9
110	8140	34	2482	21	34.6	43	39.3
168	8095	51	2468	22	37.8	66	38.8
290	8026	88	2447	43	29.5	109	35.1
385	7985	117	2434	32	23.3	140	32.5
428	7970	130	2430	14	19.2	154	31.3
430	7965	131	2428	2	68.2	156	31.6
448	7965	137	2428	5	0.0	161	30.6
470	7960	143	2427	7	12.8	168	29.9
487	7957	148	2426	5	10.0	173	29.3
534	7952	163	2424	14	6.1	188	27.5
599	7947	183	2423	20	4.4	208	25.3



109 particles start from top segment. 247 particles deposited.



c:/plk/Miller S2.txt

Path drops: 86 m

Friction mu = 0.35

log M/D = 2.30

Random R = 0.250

Alpha = 30.5 degrees

Front stops at X = 138 m

Front speed (max = 16.0 m/s)

Mean speed (max = 14.3 m/s)

Deposition (not to scale)

Exit and view distributions
in your file c:/plk/results.txt

Appendix H. Dynamics graphical output S2 avalanche.

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,

Arthur I. Mears

Arthur I. Mears, P.E. (CO)
Avalanche-control engineer

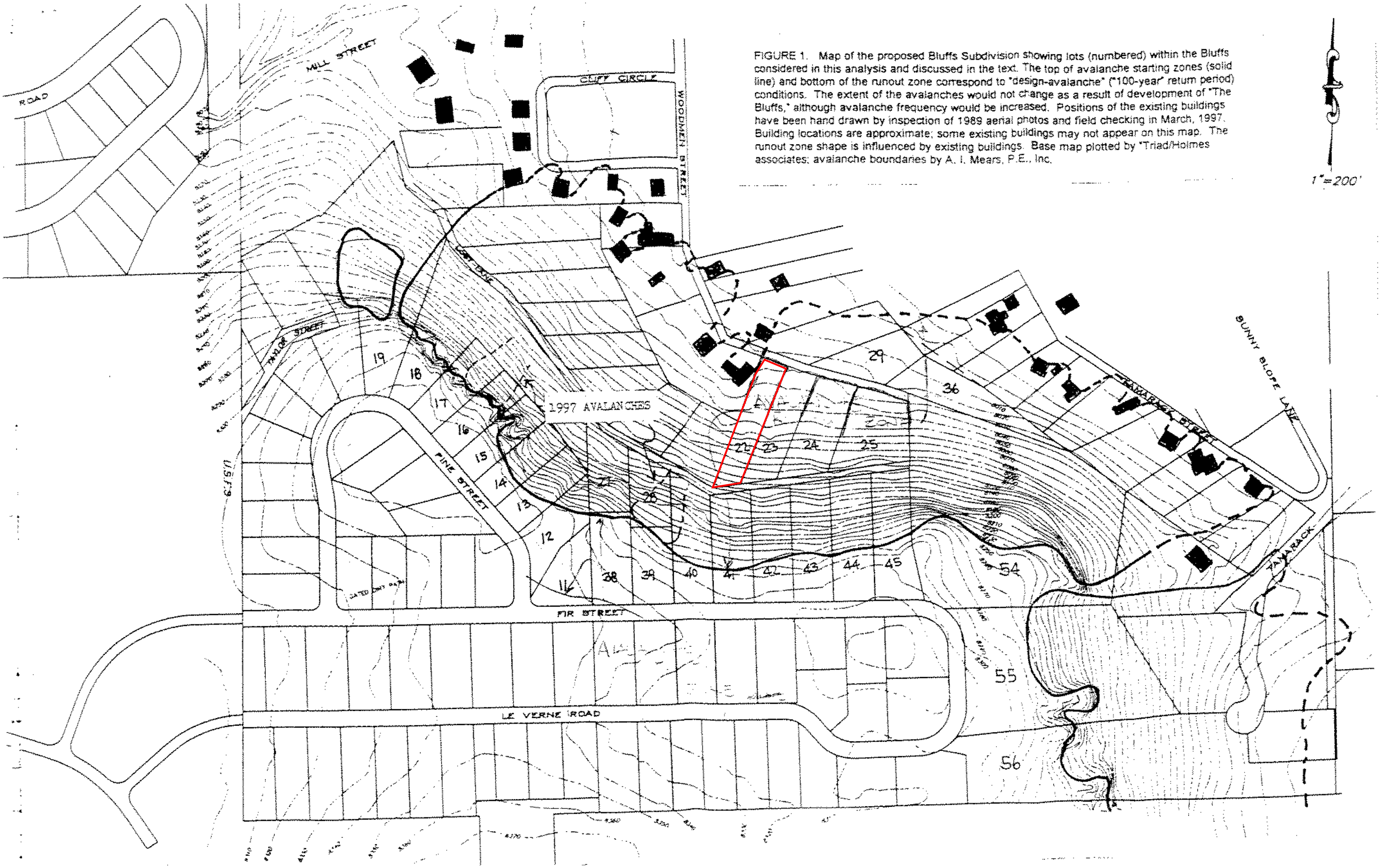

FIGURE 1. Map of the proposed Bluffs Subdivision showing lots (numbered) within the Bluffs considered in this analysis and discussed in the text. The top of avalanche starting zones (solid line) and bottom of the runout zone correspond to "design-avalanche" ("100-year" return period) conditions. The 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.

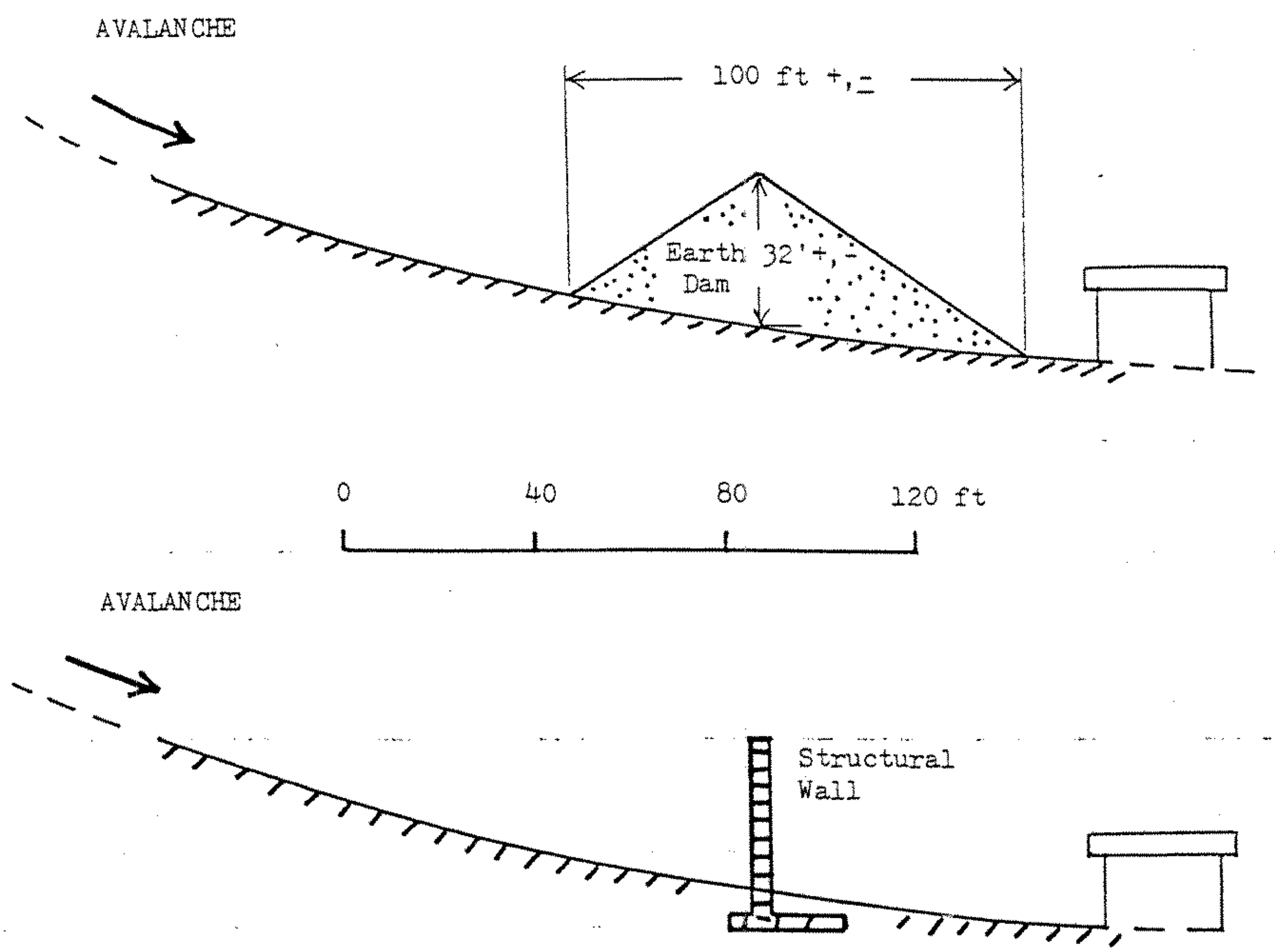

FIGURE 3. Conceptual cross sections of a dam (earthen and structural) that could be used to stop avalanches and store debris above Woodmen and Tamarack Streets, Mammoth Lakes. The critical dimension in dam design is the height above the ground surface on the *uphill side of the barrier*. A large structure 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.

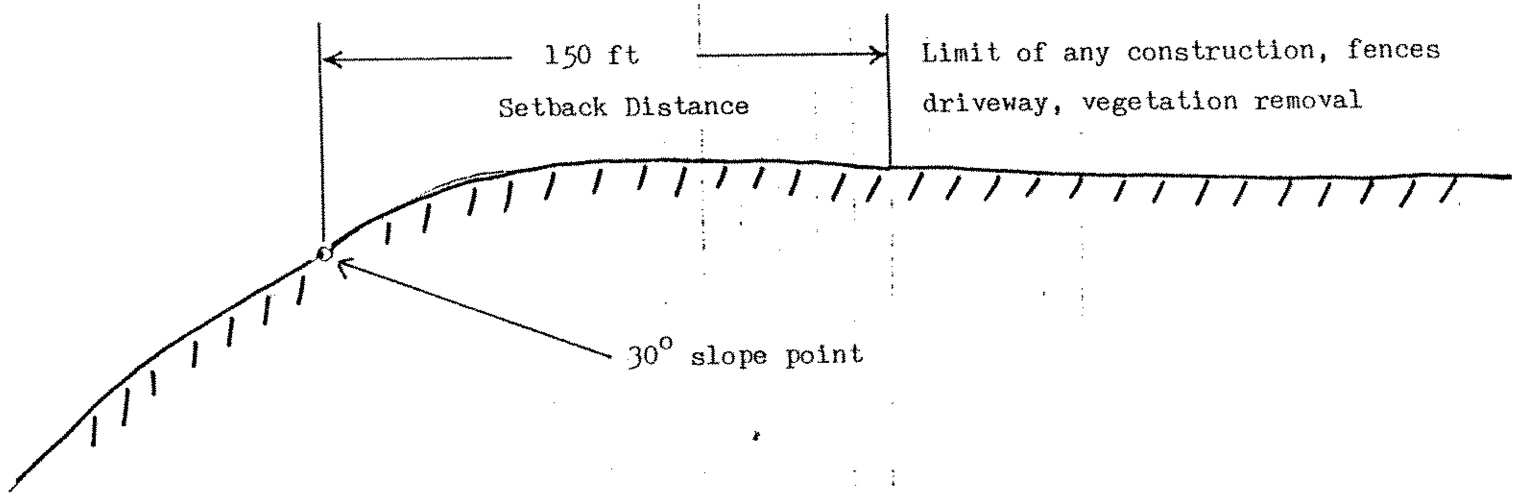

FIGURE 2. Mitigation concept to be used on lots 11 - 19, 38 - 45, and 54 - 56. As discussed in the text, insufficient space may exist on some of the lots for this concept to be executed. Field measurements are necessary to determine the precise location of the 30° point on each lot which would determine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

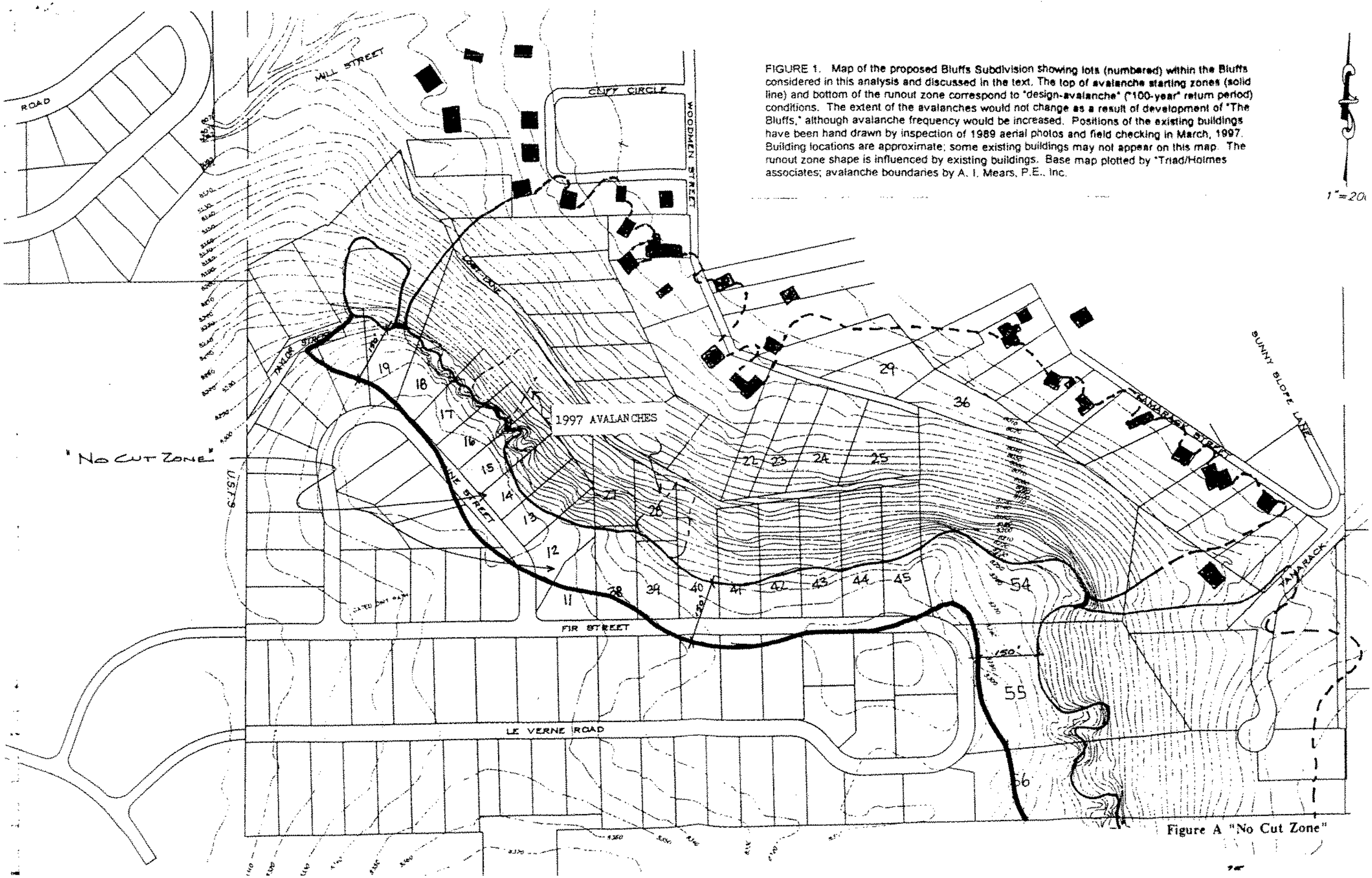

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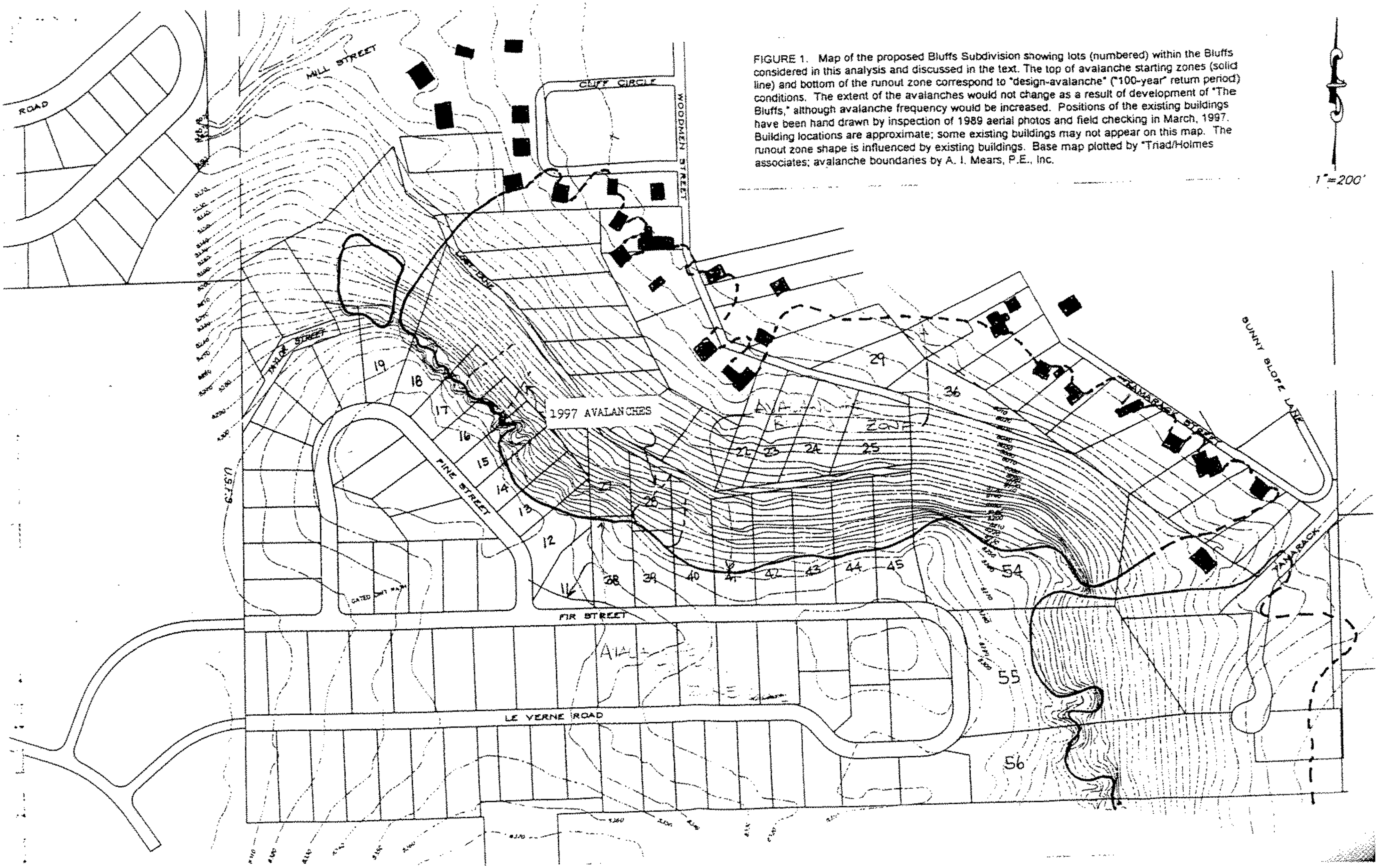
Figure A "No Cut Zone"



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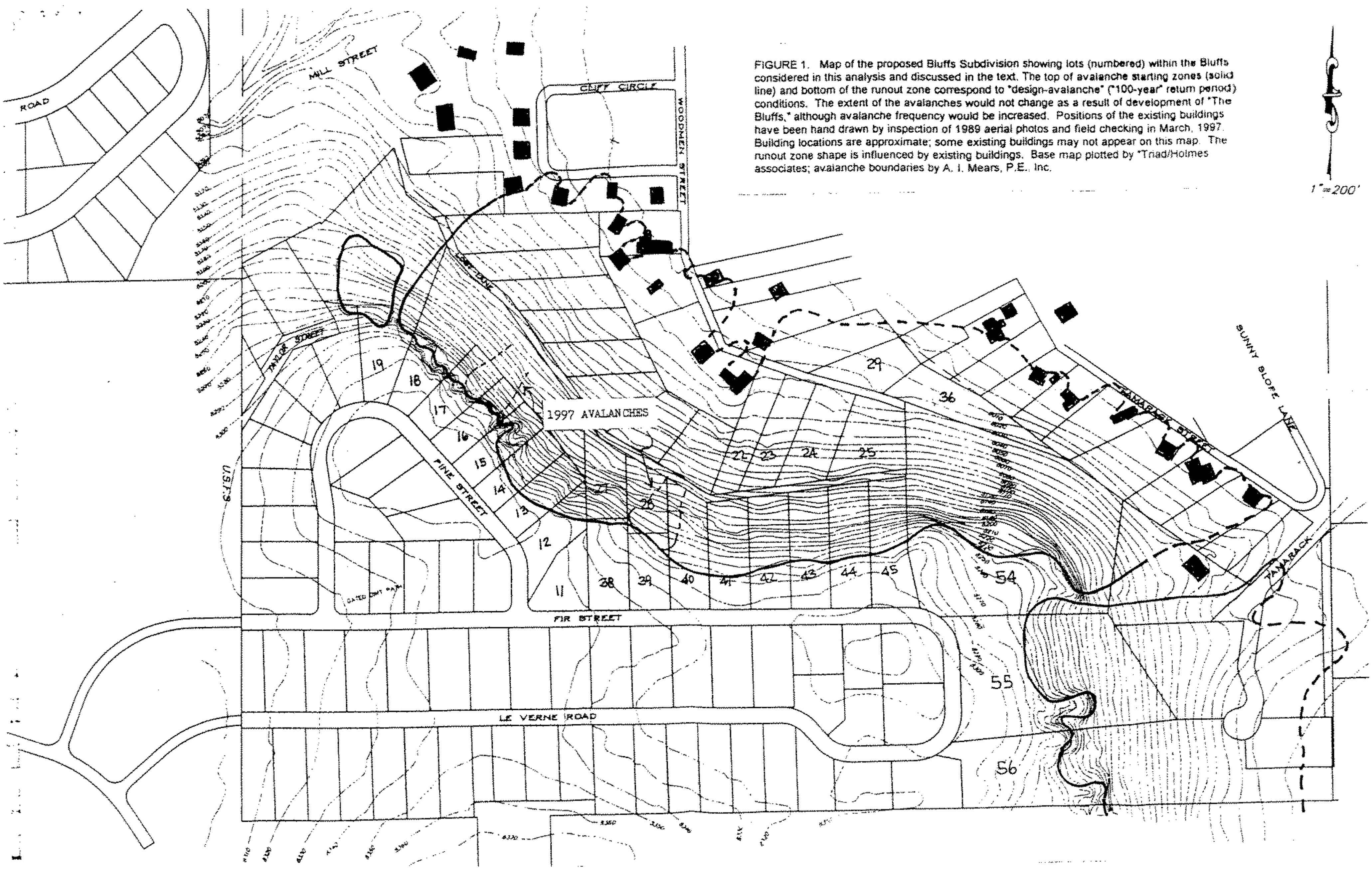

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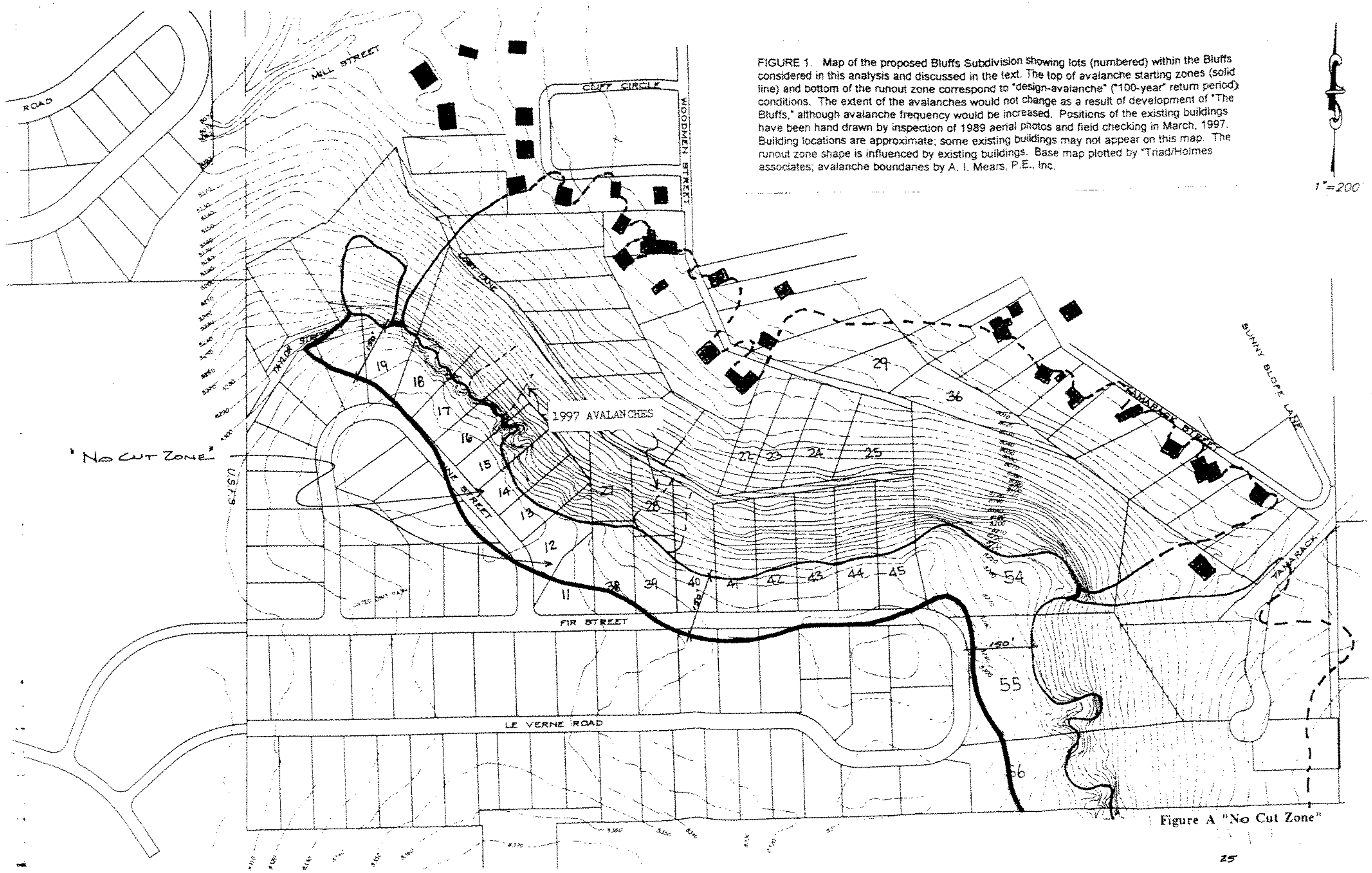

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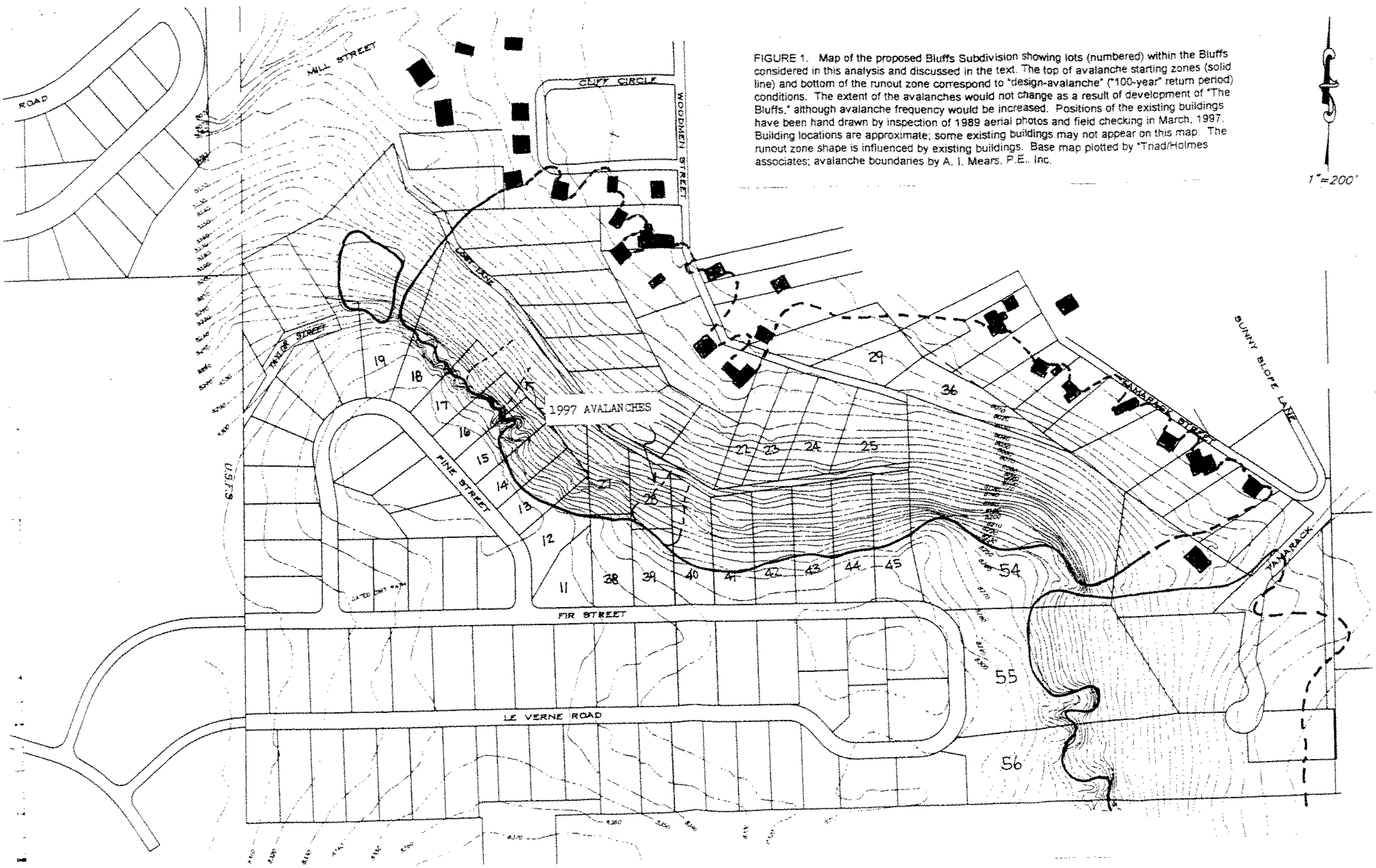
Figure A "No Cut Zone"



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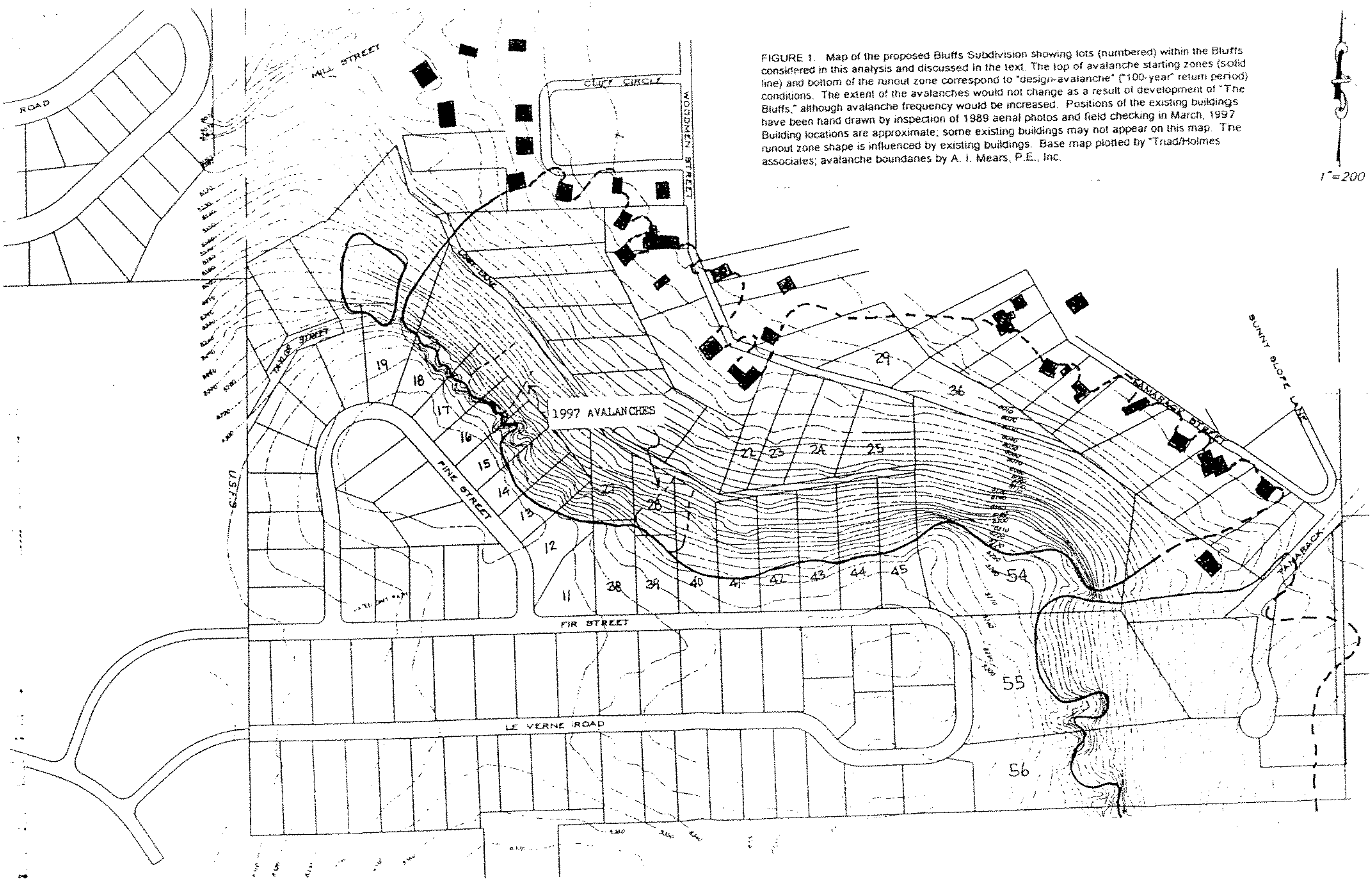

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