Appendix F

Slope Density

STATEMENT OF PURPOSE

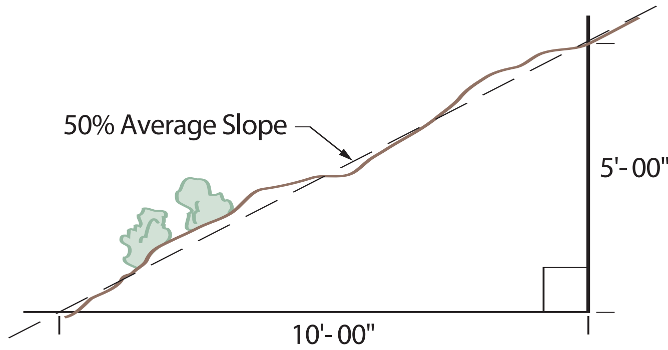
This document has been prepared with the intent of acquainting the general reader with the slope-density approach to determining the intensity of residential development. The slope-density approach was incorporated in the hillside plan in order to develop an equitable means of assigning dwelling unit credit to property owners. In addition to offering the advantage of equal treatment for property owners, the slope-density formula can also be designed to reflect property owners, the slope-density formula can also be designed to reflect judgments regarding aesthetics and other factors into a mathematical model which determines the number of units per acre on a given piece of property based upon the average steepness of the land. Generally speaking, the steeper the average slope of the property, the fewer the number of units which will be permitted.

Although the slope-density formula can be used as an effective means to control development intensity, the formula itself cannot determine the ideal development pattern. The formula determines only the total number of dwelling units, allowable on the property, based upon the average slope; it does not determine the optimum location of those units on the property. Exogenous factors not regulated by the slope-density formula such as grading, tree removal, or other environmental factors would be regulated by other means. The slope-density formulas do not represent by themselves a complete safeguard against development detrimental to the environment; but, together with other conservation measures, they are considered a valuable planning device.

DISCUSSION OF "SLOPE"

Steepness of terrain can be defined in several ways: As the relationship between the sides of the triangle representing a vertical section of a hill, or as the angle between the terrain and the horizontal plain, to name two. Unfortunately, the definitions of the terms "slope" "grade," "gradient," "batter," and of the expression "the slope is 1 to..." are not well known or uniformly applied, causing much confusion. For purposes of this section, the concept of steepness of terrain will be defined and discussed as a "percentage of slope."

"Percent of slope" is defined as a measurement of steepness of slope which is the ratio between vertical and horizontal distances expressed in percent. As illustrated below, a 50% slope is one which rises vertically 5 ft. in a 10 ft. horizontal distance.



One of the most common confusions of terminology relative to terrain steepness is the synonymous usage of "percent of grade" and "degree of grade." However, as the illustration below indicates, as percent of grade increases, land becomes steeper at a decreasing rate. The present slope-density formulas specified by the City of Cupertino require more land for development as the rate of percent of grade increases. Thus, the relationship between percent of grade and degree of grade is inverse rather than corresponding.

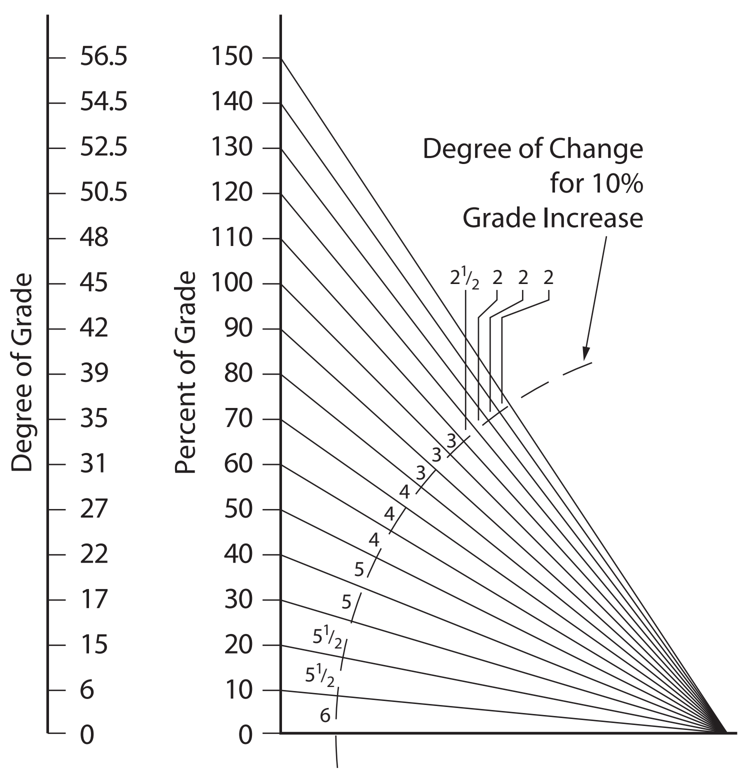
1 William Spangle & Associates Slope Density Study - Phase I. William Spangle and Associates was retained by County to assist the effort of Planning Policy Committee relative to Santa Cruz Mountain Study and Montebello Ridge Study.

To more accurately assess the impact of steepness of terrain on the feasibility of residential development, it might be helpful to examine some of phenomena commonly associated with increasing percentages of slope steepness. 1

DESCRIPTION OF SLOPE-DENSITY

The "Foothill Modified" slope density

The "Foothill Modified" slope density is designed for application to those properties in the "Fringe" of the Hillside study area with average slopes less than 10%. The formula assumes availability of municipal services. Beginning at credit of 3.5 dwelling units/gr. acre, the formula follows a cosine curve of decreasing density credit with increase of slope, achieving a constant above 43% average slope.



Percent of Slope	Description of Slope; Problems
0-5%	Relatively level land. Little or no development problems due to steepness of slope.
5-15%	Minimum slope problems increasing to significant slope problems at 15%. 15% is the maximum grade often considered desirable on subdivision streets. Above 15%, roads must run diagonally to, rather than at right angles to contours increasing the amount of cut and fill. For example, the lower segment of San Juan Road in the Cupertino foothills averages 20% in grade,
15-30%	Slope becomes a very significant factor in development at this steepness. Development of level building sites requires extensive cut and fill in this slope category and the design of individual houses to fit terrain becomes important.
30-50%	Slope is extremely critical in this range. Allowable steepness of cut and rill slopes approach or coincide with natural slopes resulting in very large cuts and fills under conventional development. In some cases, fill will not hold on these slopes unless special retaining devices are used. Because of the grading problems associated with this category, individual homes should be placed on natural building sites where they occur, or buildings should be designed to fit the particular site.
50%+	Almost any development can result in extreme disturbances in this slope category. Except in the most stable native material special retaining devices may be needed.

The "Foothill Modified 1/2 Acre" slope density

This slope density is applied in the Urban Service Area to those properties where a full range of municipal utility services; are available. The formula begins at density of 1/2 acre per dwelling unit which holds constant at 22% average slope. From 22% to 43% average slope, the formula follows a cosine curve of decreasing density credit with increasing slope. The density credit above 43% average slope remains constant at 0.20 dwelling units/gr. acre.

The "5-20" slope density

This slope density is applied to those properties which lie west of the urban/suburban fringe.

See the following pages for the three slope density curves.

HOW TO CONDUCT A SLOPE-DENSILY ANALYSIS (MAP WHEEL METHOD)

The computation of density using a slope-density formula is relatively simple once the basic concepts are understood. This section of Appendix A describes the basic concepts in order to enable individuals to determine density. The City Planning staff will provide technical assistance however, it is the responsibility of the owner or potential developer to provide accurate map materials used in the slope-density investigation for a specific property.

The City has map material which is accurate enough to provide an approximate slope-density evaluation. Accurate information needed to evaluate a specific development proposal must be provided by the owner or developer.

Step 1: Selection of Map Material

To begin any slope-density investigation, it is important to select the proper mapping material. Maps on which measurements are made must be no small in scale than 1”=200’ (1:2400). All maps must be of the topographical type with contour intervals not less than 10 feet.

If the map wheel method is used for measuring contours, or if a polar planimeter is used for measurement of an area, maps on which such measurements are made must not be smaller in scale than 1”=50’ (1:600); these maps may be enlarged from maps in a scale not less than 1”=200’. Enlargement of maps in smaller scale than 1”=200’, or interpolation of contours is not permitted.

Step 2: Layout of Standard Grid

The property for which area and slope are to be measured is divided into a network of “cells” constructed from a grid system spaced at 200 ft. intervals. In order to ensure a common reference point and to prevent the practice of “gerrymandering’ the grid system to distort the average slope of the property, the grid system must be oriented parallel to the grid system utilized by Santa Clara County’s 1”=500’ scale map series.

Figure I illustrates a hypothetical property divided into cells by a 200 ft. grid network. It is perhaps easiest to construct the 200’ x 200’ cells by beginning at an intersection point of perpendicular County grid lines (“Q” in Figure 1) and then measuring 200 ft. intervals along the two County grid lines until the entire property is covered with a network. After the grid lines have been laid out, it is helpful to number each 200 ft. square cell or part thereof. Whenever the grid lines divide the property into parts less than approximately 20,000 sq. ft., such areas shall be combined with each other or with other areas so that a number of parts are formed with the areas approximately between 20,000 and 60,000 sq. ft. Cells formed by combining several subareas should be given a single number and should be shown on the map with ‘hooks’ to indicate grouping (see area 2 on Figure 1). At this point, the investigator should obtain a copy of the “Slope-Density Grid Method Worksheet,” Figure 2 of this document. Under Column A (land unit), each line should be numbered down the page to correspond with the total number of cells on the property. (Figure 2).

Step 3: Measurement of Area and Contour Length

With the map material property prepared in Steps One and Two, we can now

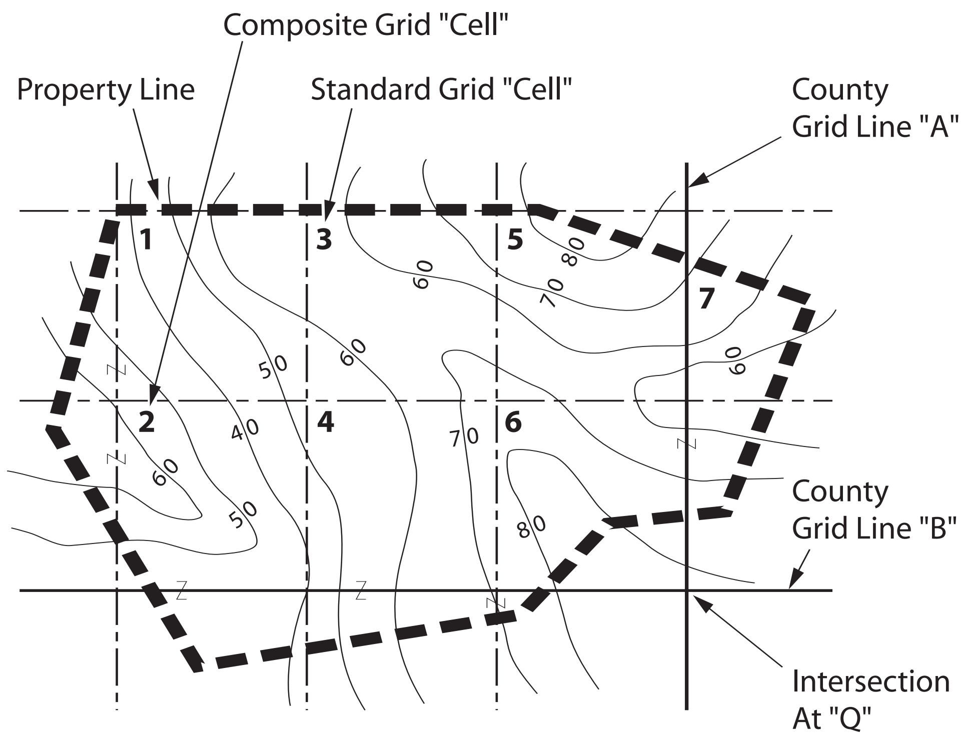


Figure 1

begin the actual mechanics of the slope-density analysis. The first task is to ascertain the acreage of the subject property. This acreage figure is obtained by measuring the area of each numbered cell divided by the 200 ft. grid, and then summing the results of the individual measurements. Since the standard grid cell measures 200' x 200,' it is only necessary to measure the area of any non-standard size cell. Referring once again to the worksheet, as each cell is calculated for area, the results should be entered in Column B (and Column C optional). See Figure 2.

Irregularly shaped cells may be measured for area quickly and accurately by means of a polar planimeter. This device is an analog instrument which traces the perimeter of an area to be measured and gives the size in actual square inches. This measurement is then multiplied by the square of the scale of the map being used. For example, 1" - 200', the square of 200 ft. means 1" equals 40,000 sq. ft. The total square footage of each cell can then be converted to acreage by dividing by 43,560 sq. ft. More detailed instruction in the use of the planimeter may be obtained from the City Planning Department.

Areas of irregular shape can also be measured by dividing each part into triangles, for which areas are determined by the formula A - base x height + 2, if a planimeter is not available.

Having now determined the area of each cell, one must now proceed to measure the contour lengths of the property. Contour length and interval are both vital factors in calculating the average slope of the land. Each contour of a specified interval is measured separately within each standard cell or other numbered zone for which the area has been calculated. The map wheel is set at "zero" and is then run along the entire length of a contour within the boundary of the cell, lifted and placed on the next contour (with-out reseting the wheel to zero) and so forth until the total length of contours of the specified interval within the individual cell is determined. The map wheel will display a figure in linear inches traveled. This figure shown on the dial should then be multiplied by the map scale. (Example: map wheel reads – 14-1/2 inches, map scale is 1" - 50'. Contour length - 14.5 x 50 - 750'). The results should then be entered on the proper line of Column D (Figure 2).

Step 4: Calculation of Average Slope

Knowing the total length of contours, the contour interval, and the area of each numbered cell, one may now calculate the average slope of the land. Either of the two formulas below may be used to calculate average slope:

$$\frac{S= 0.0023\ 1\ L}{A}$$

S = average slope of ground in percent
I = contour interval in feet
L = combined length in feet of all contours on parcel
A = area of parcel in acres

The value 0.0023 is 1 sq. ft. expressed as a percent of an acre:

$\frac{1 \text{ sq. ft.}}{43{,}560}$ = 0.0023 ac.

$$\frac{S=I \times L \times 100}{A}$$

S = average slope of ground in percent
I = contour intervaling fcct
L = combined length in feet of all contours on parcel
A = area of parcel and square feet

The results should be entered on the appropriate line of Column E of the worksheet.

Step 5: Determination of Dwelling UnIt Credit

With. the average slope of the cell now determined, one can calculate the dwelling unit credit per cell by obtaining a factor frorn the appropriate slope-density table (Section 3 of this document) then multiplying that factor by the area of the cell in acres. Refer to Figure 4 to ascertain which formula applies to the property under investigation. The formula factor is found by first reading the table column "s" (slope) until reaching the figure corresponding to the average slope of the cell being studied; next, one reads horizontally to the "d" column (density D.U. / gr. ac.). This factor should be entered in Column F of the worksheet. The factor in Column F is now multiplied by the acreage in Column B and the result entered under the appropriate slope-density formula title (Column G, H, I or 1).

Step Six: Summation of Results

When all cells in the parcel have been analyzed in the manner previously described, the total for various components of the data may be derived and entered into the two bottom rows of the worksheet. Columns B, C (if used), and D should be summed at the bottom of the sheet. A mathematical average may be calculated for Column E. Columns G through J should be summed at the bottom of the page. The totals shown at the bottom of columns G through J represent the total number of dwelling units permitted on that property, based on the average slope. These totals should be carried out to a minimum of two decimal places.

Slope Density "Grid-Method" Work Sheet

PROPERTY DESCRIPTION: EXAMPLE						DWELLING UNIT CREDIT FROM SLOPE/DENSITY TABLES				
A	B	C	D	E	F	G	H	I	J	K
LAND UNIT	(acres) AREA	(sq. ft.)	CONTOUR	Av. SLOPE	FACTOR	FOOTHILL MOD	FOOTHILL MOD 1/2 ac.	SEMI-RURAL	COUNTY	
1 Compos.	1.14	49600	750	15.3	0.545			0.621		
2 Compos.	1.18	51300	680	13.3	0.572			0.675		
3 Std.	0.92	40000	320	8.0	0.625			0.575		
4 Compos.	1.17	51000	490	9.6	0.606			0.709		
5	0.86	37600	470	12.6	0.572			0.492		
6 Compos.	0.92	40100	190	4.8	0.660			0.607		
7	0.56	24300	210	8.6	0.616			0.345		
TOTALS BY GRID METHOD	6.75	293366	3110	10.3	X			4.02		
TOTAL BY SINGLE AREA										

Figure 2

"Rounding" of Dwelling Unit Credit Results

The City Council, during its meeting of March 7, 1977, adopted the following policy regarding the rounding up of a numerical dwelling unit yield resulting from application of a slope-density formula:

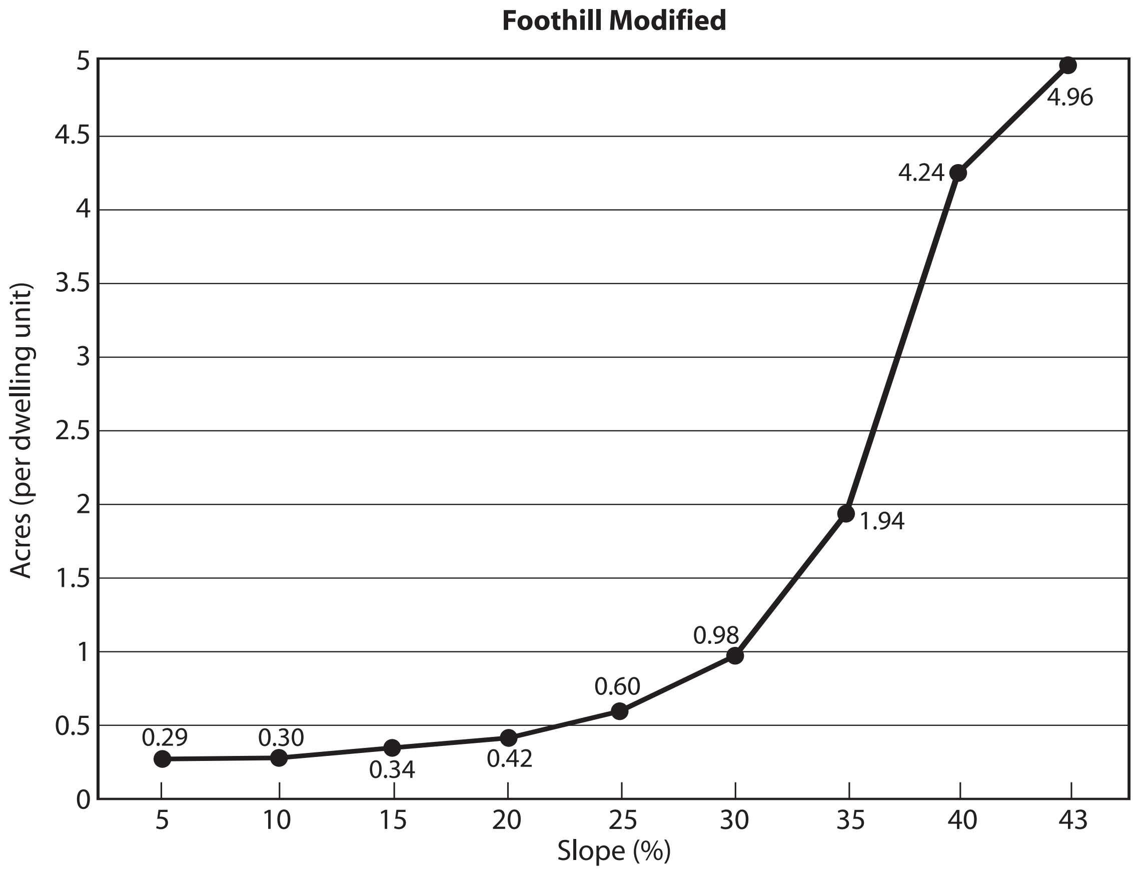
"The rounding up of the numerical yield resulting from application of a slope-density formula may be permitted in cases where the incremental increase in density from the actual yield to the rounded yield will not result in a 10% increase of the actual yield. In no case, shall an actual yield be rounded up to the net whole number unless the fractional number is .5 or greater."

Slope Density Formula: "Foothill Modified"

$$d = 1.85 + 1.65 \cos \{ (s-5) \times 4.8\}$$

$$0 < s < 44$$

SLOPE %	Density D.U. per gross ac.	Gr. Acres per D.U.	Average lot area gr.sq.ft.	SLOPE %	Density D.U. per gross ac.	Gr. acres per D.U.	Average lot area gr.sq.ft.
s	**d**	**1/d**	**43560/d**	**s**	**d**	**1/d**	**43560/d**
5	3.500	0.286	12,446	27	1.406	0.711	30,975
6	3.494	0.286	12,466	28	1.275	0.784	34,169
7	3.477	0.288	12,528	29	1.147	0.871	37,962
8	3.448	0.290	12,633	30	1.025	0.976	42,498
9	3.408	0.293	12,781	31	0.908	1.101	47,957
10	3.357	0.298	12,975	32	0.798	1.253	54,569
11	3.296	0.303	13,216	33	0.696	1.438	62,626
12	3.224	0.310	13,510	34	0.601	1.664	72,484
13	3.143	0.318	13,859	35	0.515	1.941	84,562
14	3.053	0.328	14,269	36	0.439	2.280	99,305
15	2.954	0.339	14,746	37	0.372	2.688	117,073
16	2.848	0.351	15,297	38	0.316	3.166	137,905
17	2.734	0.366	15,932	39	0.270	3.698	161,081
18	2.614	0.382	16,661	40	0.236	4.236	184,532
19	2.489	0.402	17,498	41	0.213	4.695	204,497
20	2.360	0.424	18,459	42	0.201	4.964	216,235
21	2.227	0.449	19,562	43	0.201	4.964	216,235
22	2.091	0.478	20,832				
23	1.954	0.512	22,297				
24	1.815	0.551	23,994				
25	1.678	0.596	25,967				
26	1.541	0.649	28,271				


Foothill Modified
Acres (per dwelling unit)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.29
0.30
0.34
0.42
0.60
0.98
1.94
4.24
4.96
5
10
15
20
25
30
35
40
43
Slope (%)

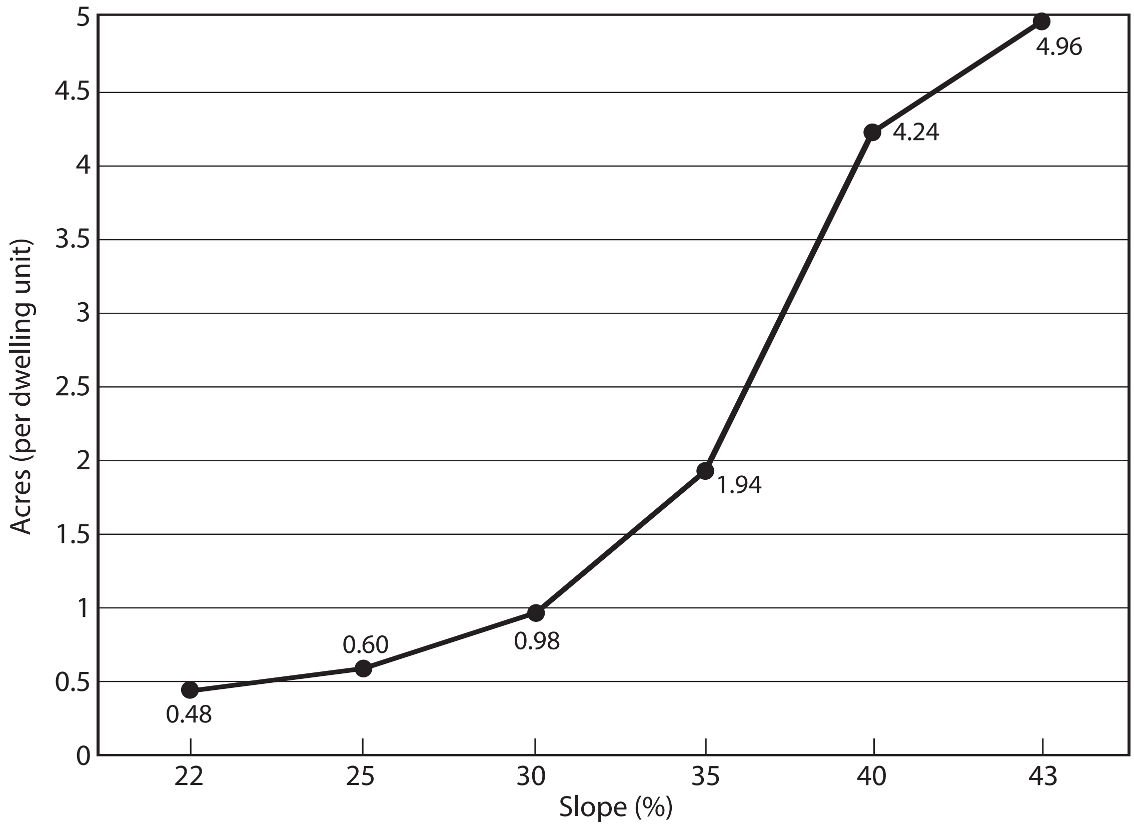
Slope Density Formula: "Foothill Modified 1/2 Acre"

$d = 1.85 + 1.60' \cos\{(s-5) \times 4.8\}$

$5 < s < 44$

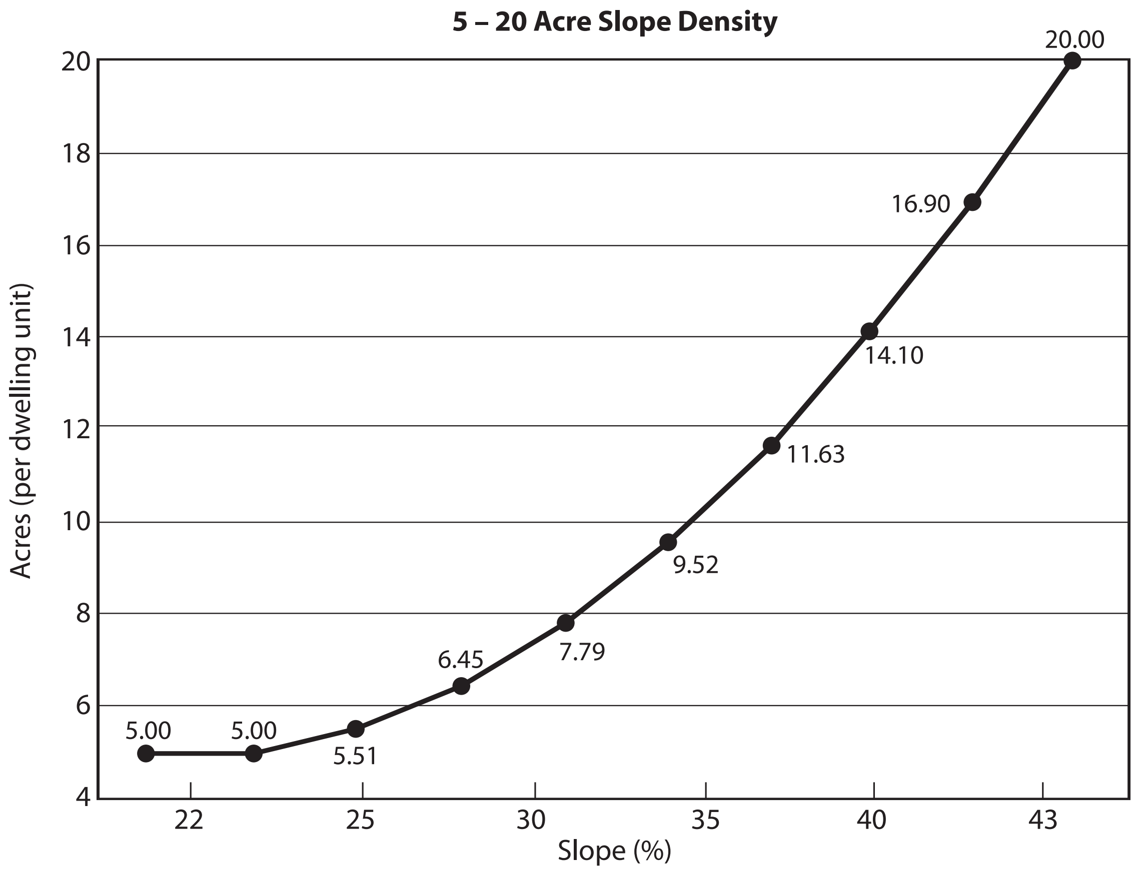
SLOPE %	Density D.U. per gross ac.	Gr. Acres per D.U.	Average lot area gr.sq.ft.
s	**d**	**1/d**	**43560/d**
22	2.091	0.478	20,832
23	1.954	0.512	22,297
24	1.815	0.551	23,994
25	1.678	0.596	25,967
26	1.541	0.649	28,271
27	1.406	0.711	30,975
23	1.275	0.784	34,169
29	1.147	0.871	37,962
30	1.025	0.976	42,498
31	0.908	1.101	47,957
32	0.798	1.253	54,569
33	0.696	1.438	62,626
34	0.601	1.664	72,484
35	0.515	1.941	84,562
36	0.439	2.280	99,305
37	0.372	2.688	117,073
38	0.316	3.166	137,905
39	0.270	3.698	161,081
40	0.236	4.236	184,532
41	0.213	4.695	204,497
42	0.201	4.964	216,235
43	0.201	4.964	216,235

Foothill Modified - 1/2 Acre



5–20 Acre Slope Density

Slope %	Density D.U. per gross ac.	Gr. Acres per D.U.	Average lot area gr. sq.ft.	Slope %	Density D.U. per gross ac.	Gr. acres per D.U.	Average lot area gr.sq.ft.
s	d	1/d	43560/d	s	d	1/d	43560/d
10	0.20	5.00	217,800	31	0.10	9.92	431,964
11	0.20	5.07	220,786	32	0.10	10.32	449,722
12	0.19	5.15	224,518	33	0.09	10.75	468,121
13	0.19	5.26	228,992	34	0.09	11.18	487,154
14	0.19	5.38	234,204	35	0.09	11.63	506,814
15	0.18	5.51	240,153	36	0.08	12.10	527,093
16	0.18	5.67	246,835	37	0.08	12.58	547,982
17	0.17	5.84	254,245	38	0.08	13.07	569,475
18	0.17	6.02	262,381	39	0.07	13.58	591,563
19	0.16	6.23	271,238	40	0.07	14.10	614,238
20	0.16	6.45	280,811	41	0.07	14.63	637,491
21	0.15	6.63	291,096	42	0.07	15.18	661,313
22	0.14	6.94	302,089	43	0.06	15.74	685,696
23	0.14	7.20	313,784	44	0.06	16.31	710,630
24	0.13	7.49	326,176	45	0.06	16.90	736,106
25	0.13	7.79	339,260	46	0.06	17.50	762,115
26	0.12	8.10	353,030	47	0.06	18.10	788,648
27	0.12	8.44	367,481	48	0.05	18.73	815,694
28	0.11	8.78	382,606	49	0.05	19.36	843,244
29	0.11	9.15	398,399	50	0.05	20.00	871,288
30	0.11	9.52	414,854	50>			


5 – 20 Acre Slope Density
Acres (per dwelling unit)
Slope (%)
20
18
16
14
12
10
8
6
4
22
25
30
35
40
43
5.00
5.00
5.51
6.45
7.79
9.52
11.63
14.10
16.90
20.00