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The Probability of Lava Inundation at the Proposed and Existing Kulani Prison Sites

by

J. Kauahikaua[1], F. Trusdell[1], and C. Heliker[1]

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[1]Hawaiian Volcano Observatory, Hawaii National Park, HI 96718

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Abstract

The State of Hawai`i has proposed building a 2,300-bed medium-security prison about 10 km downslope from the existing Kulani medium-security correctional facility. The proposed and existing facilities lie on the northeast rift zone of Mauna Loa, which last erupted in 1984 in this same general area. We use the best available geologic mapping and dating with GIS software to estimate the average recurrence interval between lava flows that inundate these sites. Three different methods are used to adjust the number of flows exposed at the surface for those flows that are buried to allow a better representation of the recurrence interval. Probabilities are then computed, based on these recurrence intervals, assuming that the data match a Poisson distribution. The probability of lava inundation for the existing prison site is estimated to be 11-12% in the next 50 years. The probability of lava inundation for the proposed sites B and C are 2-3% and 1-2%, respectively, in the same period. The probabilities are based on estimated recurrence intervals for lava flows, which are approximately proportional to the area considered. The probability of having to evacuate the prison is certainly higher than the probability of lava entering the site. Maximum warning times between eruption and lava inundation of a site are estimated to be 24 hours for the existing prison site and 72 hours for proposed sites B and C. Evacuation plans should take these times into consideration.

Introduction

Mauna Loa's most recent eruption began in its summit caldera at 0130 on March 25, 1984. In the next several hours, the eruption migrated into the southwest and northeast rift zones up to 10 km from the summit. At 1641, a new eruptive fissure opened 19 km from the summit and only 15 km from the Kulani medium-security correctional facility. By daybreak the following day, four flows had moved up to 9 km east and northeast (Lockwood and others, 1985); prison officials were placed on alert. By mid-morning, the flows moving eastward toward the prison had slowed, and officials decided against evacuation. The prison remained on "stand-by alert" for a few days, but the flows that had posed the most direct threat had stagnated by March 28, while the bulk of erupted lava continued to flow to the northeast away from the prison and toward Hilo (Hawaii Tribune-Herald, 1984). The eruption ended on April 15, 1984 (Lockwood and others, 1985), sparing both Kulani prison and Hilo. Only portions of a secondary road and power poles that supplied electricity to a meteorological observatory, and several communications relay stations, were destroyed (*Hawaii Tribune-Herald*, 1984).

The State of Hawai`i proposes to locate a new, approximately 2,300-bed medium-security correctional facility in the same general area as the existing approximately 100-bed medium-security correctional facility (Wilson, Okamoto & Associates, Inc., 1998). The events of the 1984 eruption demonstrate the reality of lava flow hazards in this area and underscore the importance of hazard awareness for future construction projects, such as a new prison.

Lava flow hazards for the Big Island have been estimated qualitatively, based on coverage rates (Mullineaux and others, 1987; Heliker, 1990; Wright and others, 1992), and quantitatively, based on probabilistic arguments for specific areas (Kauahikaua and others, 1995a and 1995b). The qualitative hazard maps are excellent for quickly judging relatively safe and unsafe areas island-wide, but their generalized nature and purposely

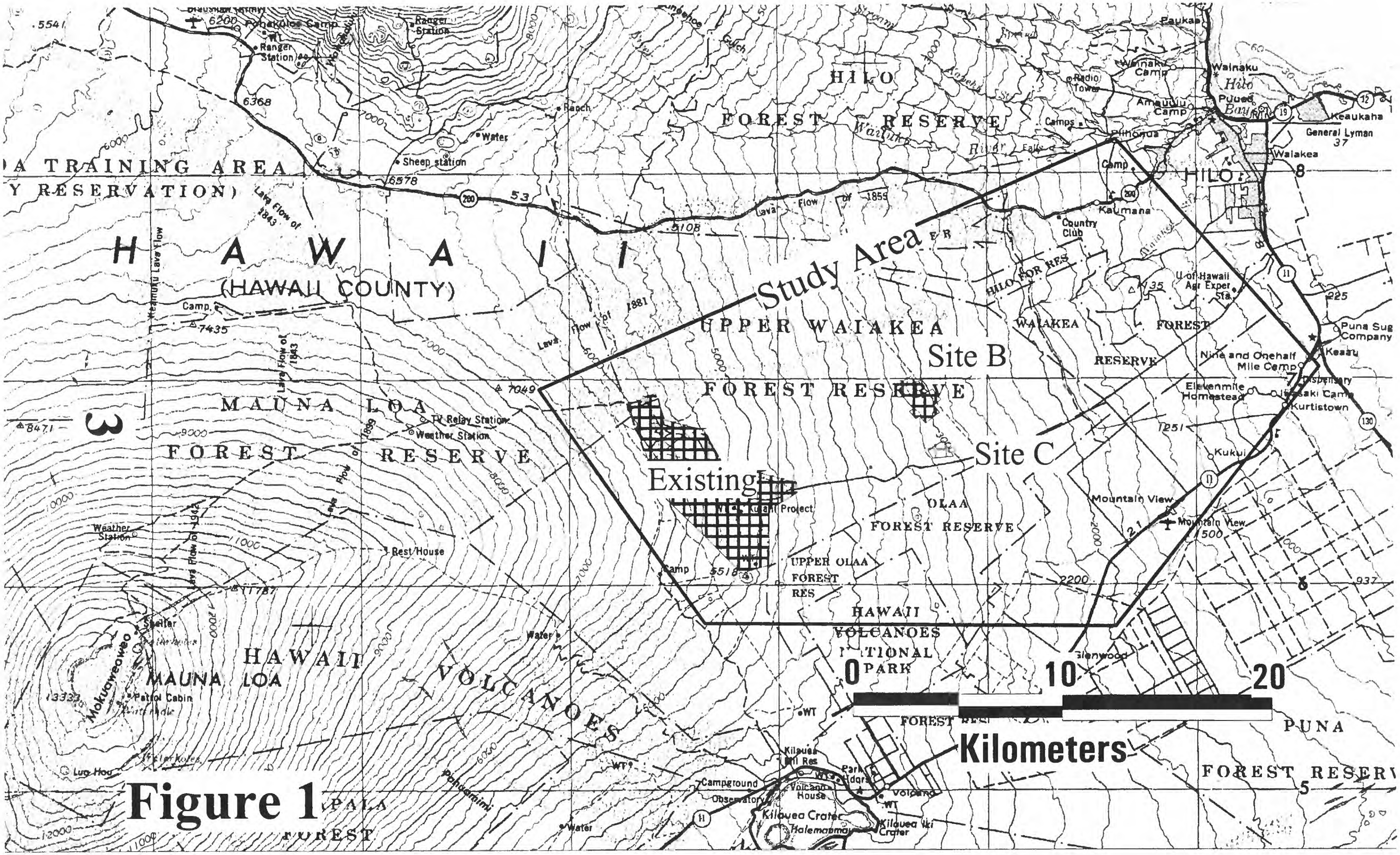


Figure 1

Study Area
Site B
Site C
Existing
0
10
20
Kilometers
HAWAII
(HAWAII COUNTY)
HILO
HILO FOREST RESERVE
UPPER WAIAKEA FOREST RESERVE
WAIAKEA FOREST RESERVE
OLAA FOREST RESERVE
UPPER OLAA FOREST RES
MAUNA LOA FOREST RESERVE
HAWAII VOLCANOES NATIONAL PARK
MAUNA LOA
Mokuaweoweo
Kilauea Crater
Volcano
Mountain View
Glenwood
Kurtistown
Keaau
Kaumana
Puna Sug Company
PUNA FOREST RESERVE
TRAINING AREA
RESERVATION)
3

vague boundaries make them difficult to use for evaluating hazards at specific project sites. On the other hand, probabilistic estimates of hazard can be computed for any project site, such as a prison, a hotel, or a geothermal development (e.g., Kauahikaua and others, 1995a), so long as the required input information is available.

Our probabilistic estimates must be computed for specific project sites and require GIS digital maps and dates of individual lava flows and volcanologic structures in the area of interest. We use the best available geologic data for the general area, which includes the project sites and surrounding areas and is collectively referred to as the study area, to evaluate lava flow hazards specific to each project site. The three project sites are labeled "Existing," "Site B," and "Site C" (Wilson, Okamoto & Associates, Inc., 1998, written communication) in figure 1 within the boundary of the study area.

Specifically, the hazard we investigated is inundation by lava, defined as the entrance of an active lava flow into the boundaries of a project site. No distinction is made as to whether the lava flow enters from outside the project site or whether it is generated from a vent within the project site. Probabilities are calculated for at least one incident of lava inundation within arbitrary periods of 50 and 100 years. Probabilities for other periods may be calculated easily with the Poisson equation given in a later section. Probabilities are computed from estimates of recurrence interval or its reciprocal, event frequency.

Site-specific Recurrence

The probability of any event can be estimated from a time series of those events (e.g., Davis, 1986). Therefore the probability of lava inundation of a project site in the future can be based on a time series of lava inundation of that project site in the past. Specifically, we wish to estimate the average recurrence interval for lava flows reaching the project site. The average recurrence interval is the reciprocal of the average flow frequency. The most direct way to estimate either quantity is to excavate the site, date all flows found, and compute the average time interval between flows. The flows beneath the site are obviously the result of any eruption that could possibly produce a lava flow capable of reaching the site across any topographic obstacles now or in the past. One may think of the excavation findings as the result of the most realistic lava flow simulation experiment imaginable for this specific project site. Excavation is, of course, not practical, so we must search for the best alternative.

The most comparable data set can be obtained by detailed geologic mapping of the surface of the study area. Such a geologic map is shown in figure 2 (J.P. Lockwood and F.A. Trusdell, unpublished geologic mapping). The map portrays the contacts of 49 lava flow units within the study area, 19 of which have been dated by radiocarbon methods or observed. Ages for the remaining 30 units are estimated from stratigraphic relations. Based on all data regardless of quality, the average recurrence interval for lava flows found on the surface within the study area is about 260 years (3.8 flows per thousand years [table 1]). For the 19 dated flows (oldest is 10,400 years) composing 37% of the total number of mapped flows, the average recurrence interval is about 200 years (10,400 yrs * 0.37/19).

Specific recurrence-interval estimates for the three project sites can be estimated in a similar manner. First, all map units within each project site were selected and tabulated. In order to compensate for flows that are completely buried beneath a project

Figure 2a

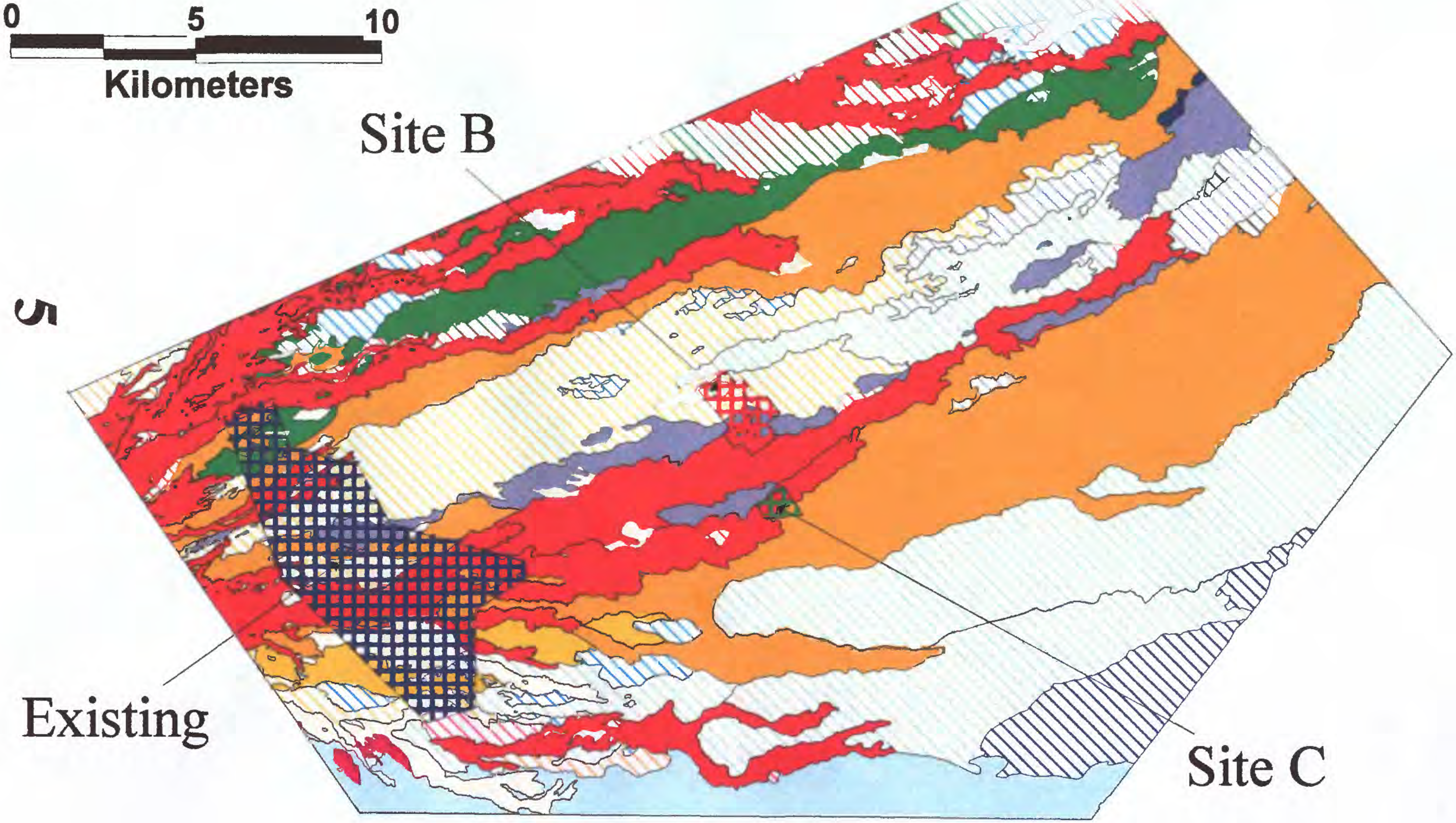


Figure 2b. Legend

🟥	0-1000 years, dated
▨	0-1000 years, age est.
🟧	1000-2000 years, dated
▨	1000-2000 years, age est.
🟨	2000-3000 years, dated
▨	2000-3000 years, age est.
☐	3000-4000 years, age est.
🟩	4000-5000 years, dated
▨	4000-5000 years, age est.
☐	5000-6000 years, age est.
▨	6000-7000 years, age est.
🟦	7000-8000 years, dated
☐	7000-8000 years, age est.
🟦	8000-9000 years,dated
▨	8000-9000 years, age est.
🟪	9000-10,000 years, dated
▨	9000-10,000 years, age est.
🟥	10,000-11,000 years, dated
▨	10,000-11,000 years, age est.
▨	11,000-12,000 years, age est.
☐	>12,000 years, age est.

site, all map units directly downslope from that site were also selected; the result is three expanded project sites (referred to here as the *downslope adjustment*; Kauahikaua and others, 1995a). Average recurrence intervals and areas are tabulated in table 1 (headings followed by "+" are the expanded project sites); the average number of flows per thousand years is plotted versus area in figure 3.

Table 1. Lava Flow Frequencies and other parameters for each project site.

interval, yrs	study area	existing	existing+	Site B	Site B+	Site C	Site C+	cumulativ fractional cover
0-1000	11	4	6	1	1	1	1	0.196
1000-2000	4	2	2	0	0	1	1	0.423
2000-3000	2	2	2	1	1	0	0	0.437
3000-4000	4	3	3	0	0	0	0	0.533
4000-5000	2	1	1	0	0	0	0	0.631
5000-6000	6	1	4	1	1	0	0	0.832
6000-7000	5	1	4	0	0	0	0	0.852
7000-8000	5	1	1	0	0	0	0	0.906
8000-9000	3	0	3	0	0	0	0	0.934
9000-10,000	2	1	2	1	2	1	1	0.988
10,000-11,000	3	1	1	0	0	0	0	0.995
11,000-12,000	1	0	1	0	1	0	0	1
>12,000	1	0	0	0	0	0	0	1
Ave. /1000 yrs	3.8	1.3	2.3	0.31	0.46	0.23	0.23	
STDev /1000 yrs	1.9	0.89	1.3	0.43	0.57	0.36	0.36	
TOTAL	49	17	30	4	6	3	3	
Area, sq. km	552.85	29.36	345.22	2.492	34.95	0.597	15.6	

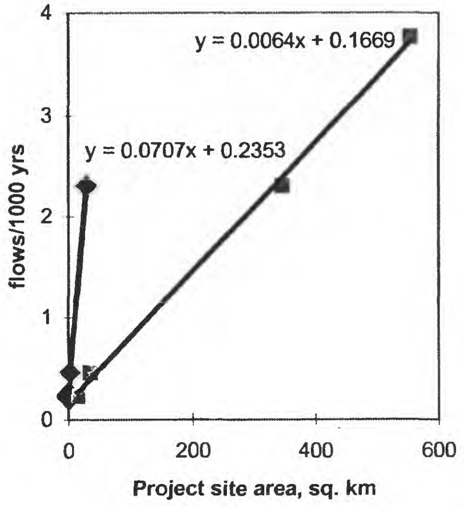


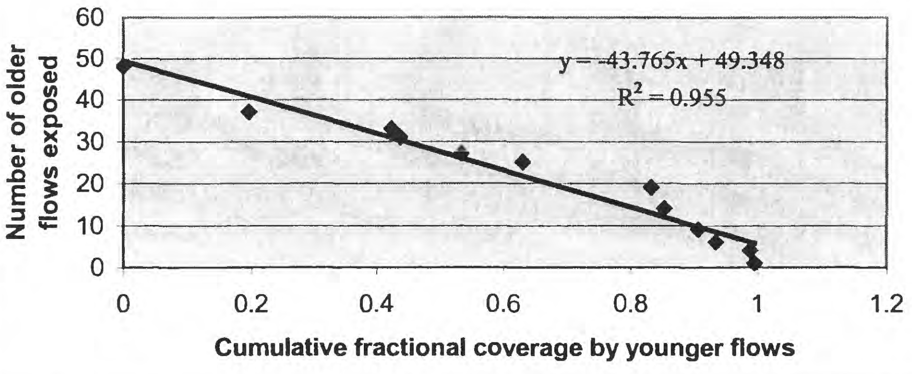
Figure 3. Project site area vs. flow frequency

The square symbols in figure 3 represent the three expanded project sites and the entire study area. The diamond symbols represent the three actual project sites, with the flow numbers obtained from the corresponding expanded sites. The number of flows exposed on the surface per thousand years shows a direct proportionality to the area over which they are exposed - approximately 0.64 flows per thousand years per 100 sq. km. The proportionality must be due to the random distribution of lava flow plan dimensions (width or length) in this region.

We are, however, more interested in the flow frequency for all flows not only exposed at the surface, but also buried beneath each project site for probability computations. The flow frequency for the expanded sites (as determined by the downslope adjustment) also shows a direct proportionality to project site area - 7.07 flows per thousand years per 100 sq. km. We again have the intuitive result that lava flow frequency (including exposed and buried flows) is approximately proportional to project site area, with the implication of random distribution of lava flow plan dimensions.

In the preceding analysis, we introduced the concept of downslope adjustment as one method of compensating for the under representation at the ground surface of older map units that are progressively covered by younger units. However, there is a problem with this method. For example, the surface of Mauna Loa is being covered at an approximately exponential rate of 40% in the first thousand years (Lipman, 1980; Lockwood and Lipman, 1987; Trusdell, 1995; see Kauahikaua and others, 1995b, for a discussion of exponential coverage rates). At this rate, more than 99% of Mauna Loa's surface older than 10,000 years is covered, and we can no longer get an accurate idea of the number of flows emplaced before that time. The picture gets increasingly foggy even after 1,000 years. We need a more general method than downslope adjustment to modify the frequency distribution of flows now at the surface for the number of flows that are completely buried by younger flows and no longer visible.

Figure 4. Coverage rate of older flows for entire study area



We can compute the coverage rate specifically for these flows within the study area. Figure 4 plots the cumulative fractional coverage at the beginning of each 1,000-year period (from Table 1) versus the total number of older flows that are still exposed beneath. The plot begins at the left with the total number of flows (49) plotted at 0% coverage and proceeds to the right with 38 flows older than 1,000 years plotted against the cumulative fractional coverage by the 0-1,000 year-old flows (0.196), and so on. If we hypothesize a random number of flows of random plan dimensions (as seems reasonable, based on figure 3) produced per unit time, then the number of older flows not covered by younger flows should be inversely proportional to the cumulative fractional coverage of the younger flows. This is similar to saying that you see fewer unpainted tiles as you paint over a tiled floor; the number of unpainted tiles is inversely proportional to the area of paint applied. A straight line ($y = -43.765x + 49.348$) fits the data well in figure 4, consistent with our hypothesis but not proving it. The number of flows exposed beneath younger ones is estimated by 49.348 – 43.765 * [cumulative fractional coverage] so the total number of buried flows can be estimated in turn as 43.765 * [cumulative fractional coverage]. Using this relation to estimate the number of unseen flows within each time interval, the adjusted estimate for the entire study area is 7.4 flows per thousand years, nearly twice the unadjusted estimate of 3.8 flows per thousand years (table 1). Figure 5 shows histograms of the exposed and adjusted flow frequencies in 1,000-year groupings. The adjustment (here termed the *burial adjustment*) is not perfect and may be better within the first 10,000 years than for the more distant past.

We derived the burial adjustment for the entire study area and have already shown that flow frequency (both exposed and buried [figure 3]) is proportional to area considered. Thus we feel confident that we can apply this general factor to subareas, such as the three project sites. That is, the estimated frequency of lava flows, including buried flows, is 1.95 times (7.4/3.8) the frequency of unburied flows now exposed at the surface in the study area. Using the burial adjustment, we get an estimate of 2.5 flows per thousand years for the existing project site, 0.6 flows per thousand years for Site B project site, and 0.45 flows per thousand years for Site C project site. Normalized by area, the adjusted estimate is 7.3 flows per thousand years per 100 sq. km (R^2=1.0). This compares well with the 7.07 flows per thousand years per 100 sq. km. (R^2=0.998) obtained by the *downslope adjustment*.

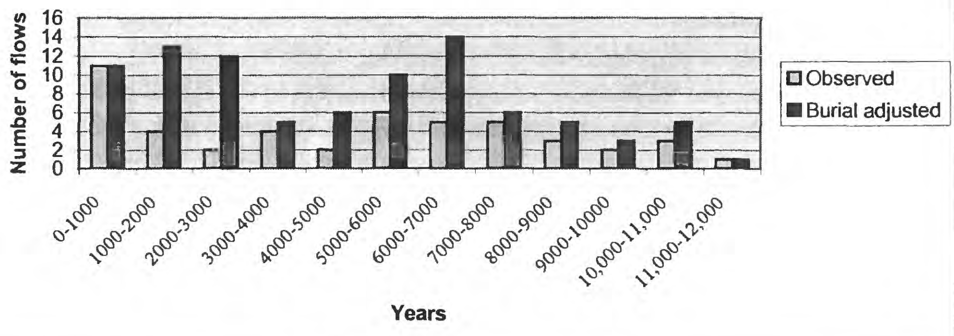


Figure 5. Lava flow frequencies for study area

A third method of flow frequency adjustment for the effect of under-representation by burial is to use only data from the most recent and best known period (here referred to as the *recency adjustment*; Kauahikaua and others, 1995a). Older periods are acknowledged as under-represented and therefore not included in any computation. The most recent period is recognized as the best known and least likely to be under-represented. For the present study, this would result in an estimated flow frequency of 11 per thousand years for the study area (based on the 0-1000 year row in table 1). The area-normalized flow frequency is 10.8 flows per thousand years per 100 sq. km (R^2=0.997) using project site entries in the 0-1000 year interval row of Table 1. We could also use the statistic of three flank eruptions since 1832 on the northeast rift zone near the project sites to estimate an equivalent flow frequency of 18 flows per thousand years. Kauahikaua and others (1995a) recognized that this simple method of adjustment generally yields the largest flow frequency estimate of any method, because every histogram of lava flow age distributions is shaped like the one labeled "observed" in figure 5. The number of flows exposed at the surface is generally highest in the most recent past and decreases backward in time.

This method also relies on a presumption that the most recent past is most representative of Mauna Loa's eruptive behavior in the near future. Discomfort with this method stems from its reliance on only a small part of the available data. How can we differentiate between a volcano whose eruptive frequency is changing with time and a volcano whose eruptive frequency is random and has had a recent period of more frequent activity? Even with a complete data set, the distinction may be difficult (Ho, 1996). The problem is compounded in our case by the increasing incompleteness of the data set further into the past. The dates on a lava flow sequence drilled through near Hilo form the only data set complete enough over several tens of thousands of years to assess the constancy of Mauna Loa's eruption rate. Beeson and others (1996) show that the rate at which lava flows overran the drill site in the last 86,000 years was fairly constant at about one flow per 4,000 years. While this is not definitive, it is the only indication available. It does not support a pattern of increasingly frequent eruptions for Mauna Loa; we believe, therefore, that the recency adjustment will underestimate recurrence intervals and should not be used if there are better options available.

Probability of Lava Inundation

We wish to estimate the probability of lava inundation for three project sites – the existing Kulani Prison site and proposed sites B and C (fig. 1). Our analysis and the data are consistent with production of a random number of lava flows per unit time for at least the last 10,000 years. The lava flows are reasonably independent of one another; while the presence of a previous lava flow can influence the flow path of a later lava flow, the terrain is entirely composed of lava flows all of which influence later flows. The random influence of all previous flows on a later flow path has the same effect as making the later flow path relatively independent of any one previous flow.

Therefore a Poisson equation is appropriate to compute probabilities (Kauahikaua and others, 1995b). The probability of occurrence of at least one lava flow within the time interval, *t*, is $1 - e^{-t/T}$, where T is the recurrence interval. Table 2 lists the recurrence intervals estimated by the three methods and the corresponding probabilities for t=50 and t=100 years for the three project sites (fig. 1). The italicized table entries for the recency adjustment are provided here only for comparison and are not intended as valid recurrence interval or probability estimates.

Table 2. Probability estimates for 50 and 100 years

		Probability	
	T, years	**t=50 yrs**	**t=100 yrs**
Existing site, downslope adjustment	435	0.11	0.21
Existing site, burial adjustment	400	0.12	0.22
Existing site, recency adjustment	*250*	*0.18*	*0.33*
Site B, downslope adjustment	2170	0.022	0.045
Site B, burial adjustment	1670	0.030	0.058
Site B, recency adjustment	*1000*	*0.049*	*0.095*
Site C, downslope adjustment	4350	0.011	0.022
Site C, burial adjustment	2220	0.022	0.044
Site C, recency adjustment	*1000*	*0.049*	*0.095*

For a period of 50 years, the estimated probability of lava inundation is 11-12% for the existing prison site, 2-3% for proposed site B, and 1-2% for proposed site C. The larger differences between probabilities estimated with different adjustment methods for Site B and Site C probably reflect the larger errors expected for estimates made in significantly smaller areas. Estimates for the smaller project sites are based on fewer data, so we expect larger errors in estimating the recurrence intervals. The significantly higher probability for the existing project site is due primarily to its larger area (see figure 3).

Estimated lava flow dynamics

Forecasts of any eruption dynamic at Mauna Loa, such as duration or flow length, can be based only on the record of Mauna Loa eruptions since recorded observations began in 1832. Basic physical parameters for the 39 observed eruptions of Mauna Loa are tabulated in Lockwood and Lipman (1987), Barnard (1995), and Decker and others (1995). The project sites will be affected only by flank eruptions on the northeast rift zone. Table 3 lists the pertinent facts for the 17 flank eruptions since 1832, sorted by duration. Figure 6 is a plot of the fraction of flank eruptions whose duration is less than, or equal to, a specified period. Figure 7 is a similar plot of the fraction of flank eruptions whose area is less than, or equal to, a specified size.

Table 3.

year	duration summit, d	duration flank, d		elev, m	repose, mo	Area, km^2	Volume, 10^6 m^3
1877	1	1	W flank	-55		1	8
1868	1	4	SW rift	1010	23	24	123
1916	0	12	SW rift	2260	16	17	31
1887	1	12	SW rift	1740	65	29	128
1942	2	13	NE rift	2800	20	34	176
1926	1	14	SW rift	2320	77	35	121
1907	1	15	SW rift	1890	37	28	121
1899	4	20	NE rift	3260	38	23	81
1852	1	20	NE rift	2560	6	33	182
1984	1	22	NE rift	2860	108	48	220
1950	1	23	SW rift	2440	12	112	376
1919	1	38	SW rift	2350	40	28	183
1935	6	40	NE rift	3690	23	33	87
1843	5	90	N flank	2990	126	45	202
1880	0	280	NE rift	3170	6	51	130
1859	1	300	N flank	2800	26	91	383

If we assume that future flank eruptions will be similar to the 17 between 1832 and 1984, then, using figure 6, we can forecast a probability of 0.5 (50%) that the next eruption will last 21 days or less, and 0.8 (80%) that it will last 50 days or less. We forecast a probability of 0.8 (80%) that the lava flow from the next eruption will have an area of 50 km^2 or less from figure 7. Some flow area information could be obtained from pre-1832 flows that have not been covered, but this has not been done for our estimate.

Figure 6. Flank eruption duration

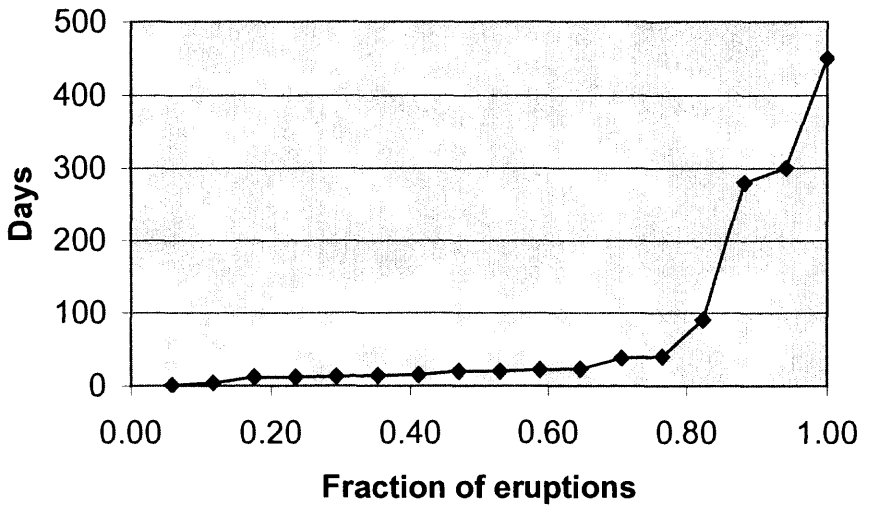
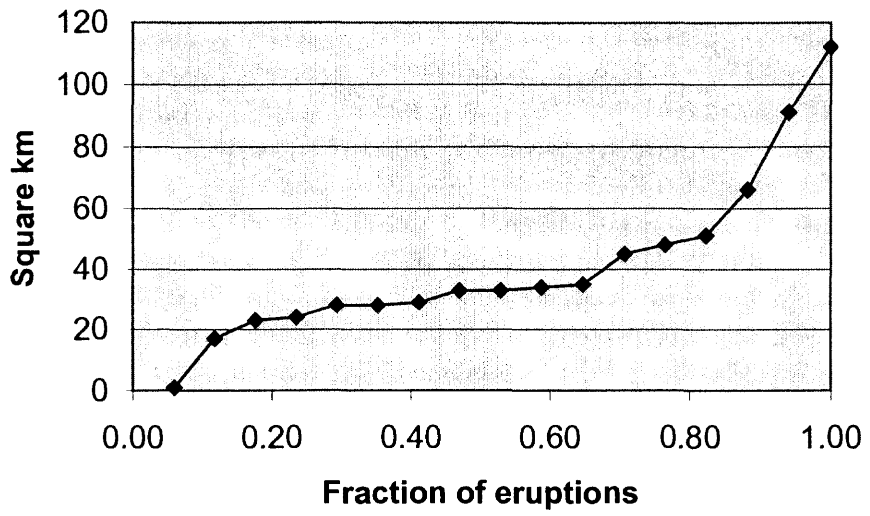


Figure 7. Flank eruption flow area



Terrain analysis – computation of lavasheds

The project sites are located on Mauna Loa's northeast rift zone, where 31% of eruptions since 1843 have been located (Trusdell, 1995). We can narrow down further the number of eruptive events that would affect a project site by delineating the "lavashed" of that site. A lavashed is the region that is uphill from each project site. The lavashed estimates included in this study were computed using the WATRSHED function in IDRISI for Windows (Eastman, 1997) on 30 m Digital Elevation Models (DEM) (USGS, 1987). The only input parameters for the operation of the WATRSHED function are the aspect of the DEM (azimuth of the slope vector) and the "angular region to either side of the uphill vector over which flow is accepted into an adjacent cell."

Lavasheds are computed from the project site uphill (rather than from the uppermost point downhill as with other geographic operators), and the angle parameter allows broadening of the acceptable uphill direction to include directions to either side of directly uphill (plus or minus half the angular parameter). If the DEM were a perfect representation of the terrain, then we could characterize a lavashed reliably with a small angular parameter. However, angular parameters of up to 90-degrees are required to smooth out errors and uncertainties in the DEM.

These errors and uncertainties are also evident by the presence of "holes" in the computed lavasheds. Lavasheds should have holes only where pits in the terrain occur. We ignore these holes, but we represent the lavashed with holes as computed in figures in this report.

To illustrate the utility of the concept, example lavasheds were calculated for a hypothetical project site consisting of the terminal lobe of flow 1 and 1A produced by the 1984 Mauna Loa eruption (Lockwood and others, 1985). The flow has already been emplaced, but, for the purposes of this example, we can pretend that it hasn't and that we

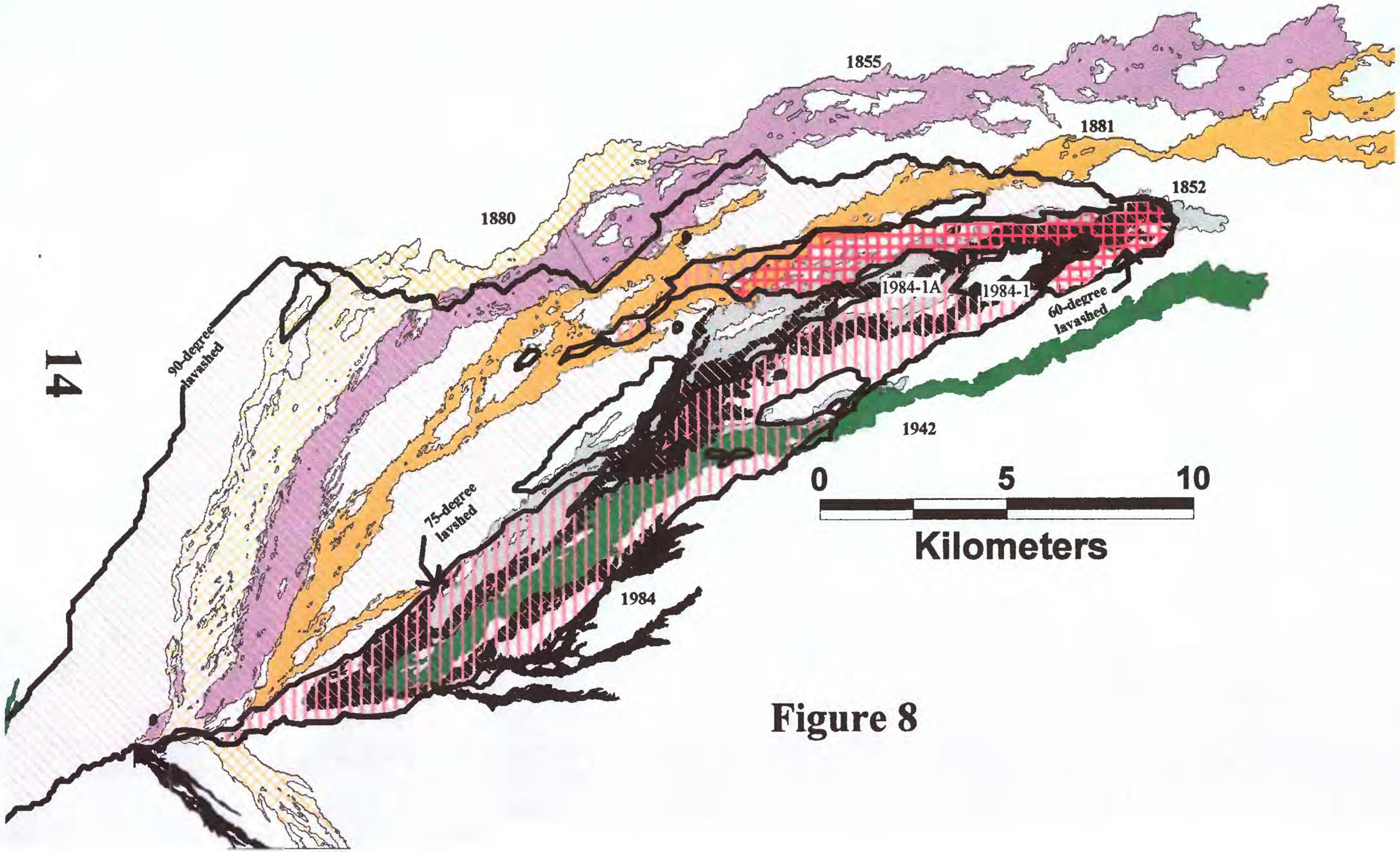

1855
1881
1852
1880
1984-1A
1984-1
60-degree
lavashed
90-degree
lavashed
1942
0
5
10
Kilometers
75-degree
lavshed
1984

Figure 8

are charged with evaluating the vulnerability of this small area that was covered by the flow. Three different lavasheds were computed for the same hypothetical project site using three different values of the angular region parameter. Figure 8 shows the nested lavasheds for values of 60, 75, and 90 degrees. The 60- and 75-degree lavasheds indicate that there are two main topographic paths to the project site, but DEM uncertainties preclude tracking them fully uphill. Only the 90-degree lavashed is sufficiently general to permit outlining both paths all the way to Mauna Loa's summit. The 90-degree lavashed is the most general and probably includes more area than is useful for our purpose. Our best choice for the angular parameter is between 75- and 90-degrees, but we will continue to use 90-degree lavasheds to err on the conservative side.

How have recent lava flows traveled compared to the computed example lavasheds? The outlines of the most recent lava flows in the area (1984, 1942, 1880, 1881, 1855, and 1852) are also plotted in figure 8. The 1855 and the 1880 flows begin within the 90-degree lavashed and flow out of it without ever entering the 75-degree lavashed. Neither enters the hypothetical project site. The 1881 and 1942 flows enter the 75-degree lavashed, and the 1881 flow also enters the 60-degree lavashed before departing all lavasheds; neither of these flows enters the hypothetical project site. The 1852 and the 1984-1 flows begin within the 75-degree lavashed, and a portion of each flow remains within it to finally enter the hypothetical project site. The 1984-1A flow is essentially a separate flow, starting at the channel breach outside the 75-degree lavashed and entering the 75-degree and 60-degree lavashed and finally the hypothetical project site. The reason that the 1984-1A flow must be considered a separate flow is that it is responding to the additional topography of the previously emplaced 1984-1 flow which changed the way a lavashed would be computed for the next flow. The DEM we used includes the topographic expression of all flows except the 1984 flow, because the DEM is based on air photos taken in the 1970s. In other words, flows earlier than 1984 did not respond to the same topography that was used to compute these lavasheds; they would have responded to the preflow topography, which we can no longer characterize.

Experience with lavasheds computed in the above way allows the following generalizations: Adjacent project sites can have overlapping lavasheds, i.e., lavasheds are not mutually exclusive. All lava flows that inundate the project site enter from the lavashed. Not all lava flows that begin within the lavashed will enter the project site. Lava flows that begin within the lavashed, then exit, do not seem to reenter; the one exception would be breakouts or channel breaches at the edge of lavasheds like the Mauna Loa 1984-1A flow. Such breakouts should be treated as separate flows that originate at the breach point. Hanley (1998) formulated similar generalizations in an application of ARC/Info FLOWDIRECTION and COSTPATH functions for lava flows produced by Pu`u `O`o. A lavashed is a reasonable means of using terrain to define the area from which lava flows can enter a project site.

Finally, we can use the nearly identical flow advance rates for the 1942 Finch (1942) and 1984 (Lockwood and others, 1985) flows to estimate probable advance rates for flows in the lavasheds of the three project sites. Figures 9 and 10 show the estimated 9-, 24-, 48-, and 72-hour warning lines based on these advance rates for each of the project sites. Lavashed maps with these warning lines can be used to estimate how much lead time is available to respond to a flank eruption that begins within the lavashed. For example, using figure 9 we can estimate that a flow produced by a vent that opened on

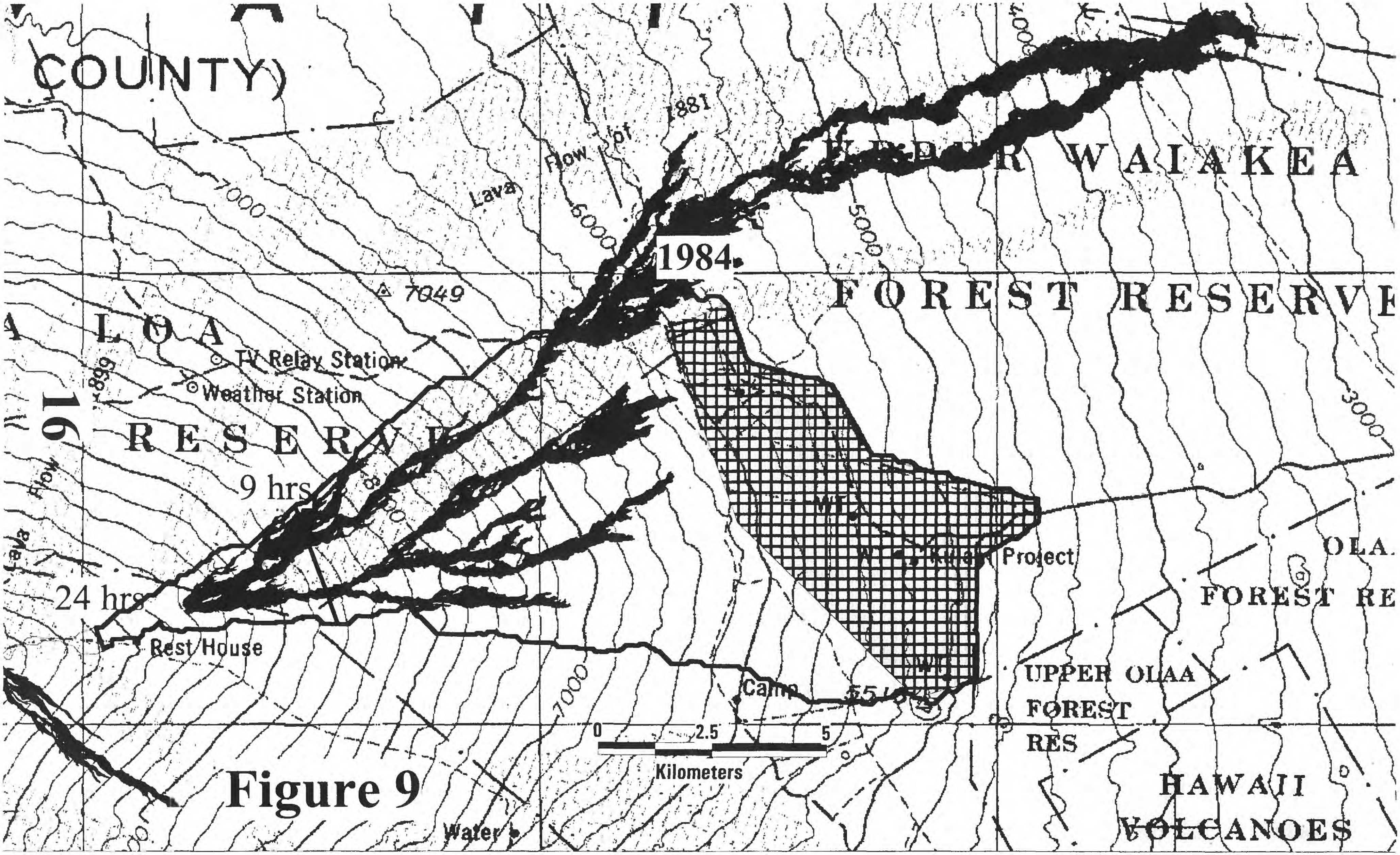

COUNTY)
WAIAKEA
FOREST RESERVE
Lava Flow of 1881
7000
6000
5000
4000
3000
1984
7049
LOA
TV Relay Station
Weather Station
899
RESERVE
9 hrs
24 hrs
Lava Flow
Rest House
Camp
Kulani Project
WT
UPPER OLAA
FOREST
RES
OLA
FOREST RE
HAWAII
VOLCANOES
0
2.5
5
Kilometers
Water

Figure 9

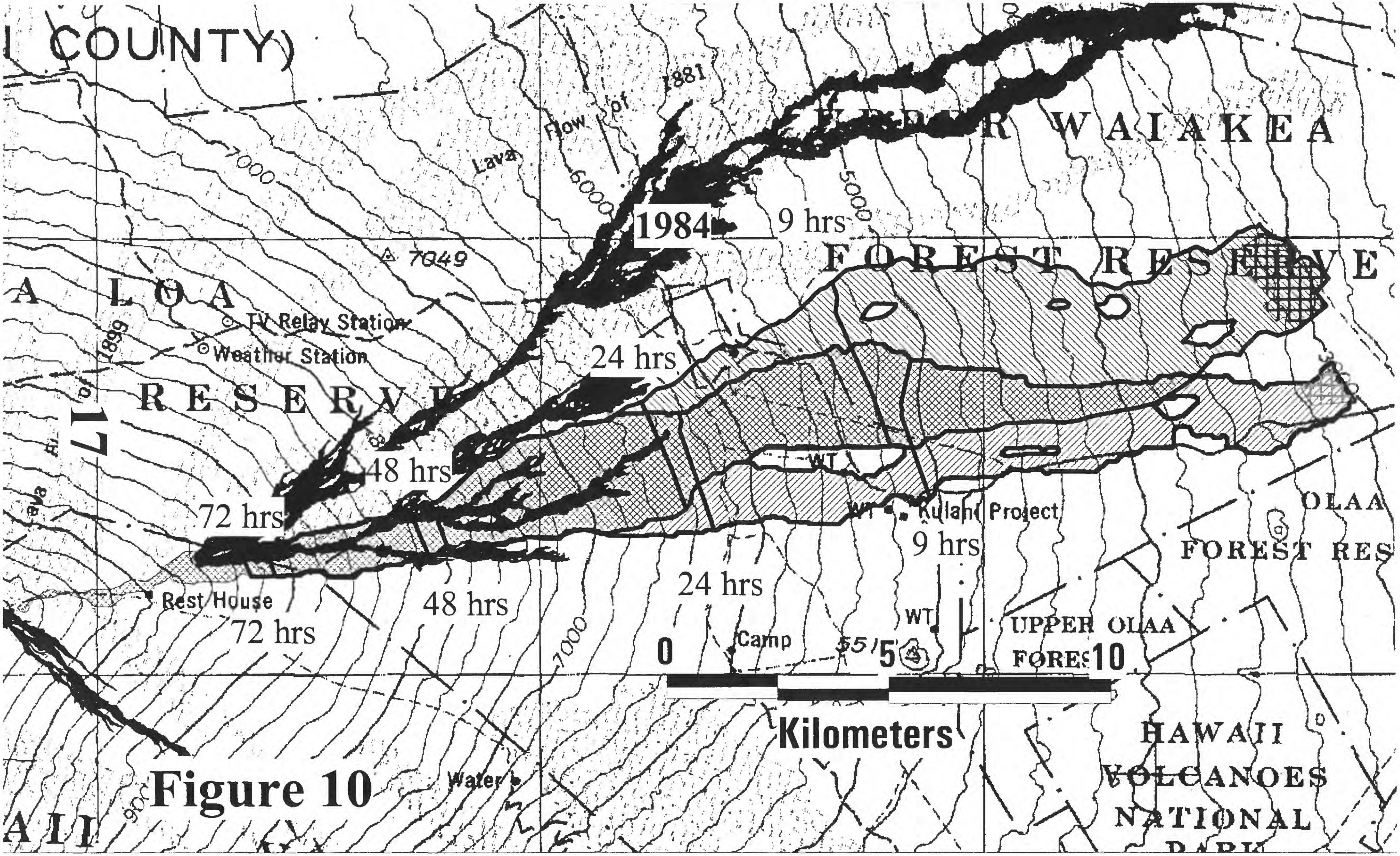

(COUNTY)
Lava Flow of 1881
7000
6000
5000
R WAIAKEA
1984
9 hrs
FOREST RESERVE
7049
A LOA
TV Relay Station
Weather Station
1899
RESERVE
24 hrs
48 hrs
72 hrs
WT
WT
Kulani Project
9 hrs
OLAA
FOREST RES
Rest House
72 hrs
48 hrs
24 hrs
7000
Camp
0
5
10
WT
UPPER OLAA
FOREST
Kilometers
HAWAII
VOLCANOES
NATIONAL
PARK
Water
AII

Figure 10

the 9-hour warning line could enter the existing prison project site 9 hours later. Maximum warning times can also be determined from figures 9 and 10. The existing prison project site would have no more than 24 hours warning for a flank eruption that started within its lavashed. Sites B and C could have as much as 72 hours warning for a flank eruption that started within their respective lavasheds.

Conclusions and recommendations

The flow frequencies estimated in this study are proportional to the size of the area considered. The probabilities for a 50-year period are 11-12% for the existing prison site (29.4 km^2), 2-3% for proposed site B (2.5 km^2), and 1-2% for proposed site C (0.6 km^2). Thus the higher probability of lava flow inundation at the existing site reflects primarily the relatively large size of the project site. Defining a large project site that includes a buffer zone beyond the immediate boundaries of the facility is a more realistic approach however, considering the difficulties of evacuating a 2,300-inmate prison. A lava flow that passes well outside the project areas defined for sites B and C may still necessitate evacuation if the flow threatens roads and utility lines leading to the site.

Not included in the probability calculation is the significantly shorter maximum warning time of 24 hours for the existing prison site reflecting its proximity to potential vent areas. The decision to evacuate the prison will have to be made well before it is possible to determine whether the site is directly in the path of an oncoming lava flow or not. The warning lines depicted in figure 9 show that if another eruption occurs near the 1984 vents, lava flows could reach the existing site within 9 to 24 hours. Locating the prison farther downslope at site B or C increases the possible warning time by about 48 hours (figure 10). In either case, the probability of having to evacuate the prison is significantly higher than the probability of lava actually covering the site.

The estimates and forecasts reported here are based on the best information currently available. Some of the estimated quantities, possibly the probabilities, will change as new information becomes available. Updated mapping, and more radiometric dates, which result in identification of new flows or consolidation of one or more flows into a single eruptive unit, will have a significant effect, because it will change the total number of exposed flows and therefore the recurrence interval estimates. Better models of variations in Mauna Loa's eruptive rate with time will also change estimates of the currently appropriate recurrence interval; we assume a random eruptive rate with no time dependence in this report. More accurate DEMs may change the computed lavasheds. We recommend further mapping and dating in order to improve hazard estimates in the future.

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Don Swanson, scientist-in-charge at the Hawaiian Volcano Observatory, suggested that this project as soon as the State of Hawai`i announced its intention to construct a new prison on the slopes of Mauna Loa. The authors thank Asta Miklius and Paul Okubo for very useful reviews.

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Figures

1. Map showing the existing Kulani Prison site, as well as Site B and Site C, proposed for the new prison. Also shown is the extent of the study area for which mapping and dating of individual flows is used for the probabilistic calculations.
2. a) Geologic map (J.P. Lockwood and F.A. Trusdell, unpublished mapping) of the area surrounding the three project sites shown in figure 1. The lava flows are color-coded into 1,000-year intervals and represent ages from 14 years to 14,000 years before present. b) legend for the geologic map.
3. Number of flows per thousand years is proportional to the area of the project sites listed in Table 1.
4. Plot showing the number of exposed flows equal to, or older than, a specified age versus the fractional coverage by younger flows. The linearity of these data suggest that we can use coverage rate to estimate the number of flows covered during each thousand year period. A histogram of adjusted flow frequencies is also plotted in figure 5.
5. Histogram of observed and burial-adjusted flow ages found within study area, 1,000-year intervals.
6. Plot showing the fraction of Mauna Loa flank eruptions of equal or shorter duration than a specified period.
7. Plot showing the fraction of Mauna Loa flank eruptions of equal or smaller area than a specified size.
8. Map showing the nested 60-, 75-, and 90-degree lavasheds computed for the terminal lobes of the Mauna Loa 1984-1 and 1984-1A flows. For comparison, the 1852, 1855, 1880, 1881, 1942, and 1984 lava flows are also shown. Flow lobes 1984-1 and 1984-1A are referenced in the text. The blank areas within the lavasheds are the "holes" mentioned in the text.
9. Map of the lavashed for the existing prison site showing the 9- and 24-hour warning lines. Note that any eruption beginning within this lavashed would produce a lava flow that could enter the existing prison project site in less than 24 hours. The 1984 lava flows are shown for comparison. The short southern lobes slowed within 15 hours.

10. Map of the lavashed for future prison Site B and Site C showing the 9-, 24-, 48-, and 72-hour warning lines. The 1984 lava flows are shown for comparison.

Tables

1. Number of flows within 1,000-year intervals for each of the project sites considered. Data are derived from J.P. Lockwood and F.A. Trusdell (unpublished mapping).
2. Probability estimates over arbitrary periods of 50 and 100 years for the three project sites adjusted in three ways for the effects of under-represented (buried) flows. The italicized, recency-adjusted estimates are less reliable than the others and are not used in this paper.
3. Parameters for the 17 flank eruptions of Mauna Loa between 1832 and present sorted by duration.