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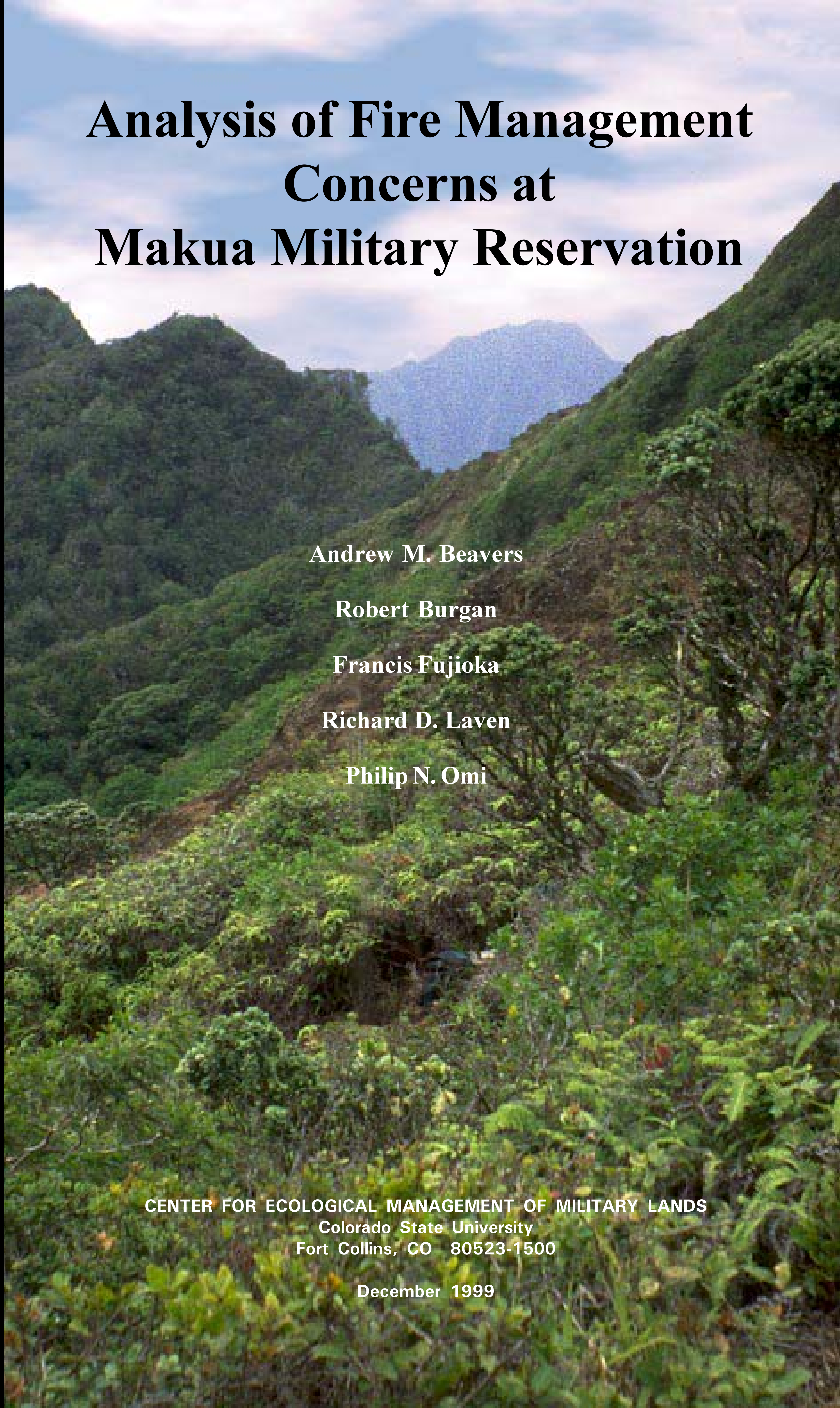
Analysis of Fire Management Concerns at Makua Military Reservation



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Introduction

Makua Military Reservation (MMR) is located on 4190 acres on the northwest leeward side of Oahu, Hawaii. The reservation is surrounded on the north, east, and south by high, precipitous valley walls and on the west by the Pacific Ocean. Surrounding cliffs reach heights of 2100 to 2900 feet. Numerous threatened and endangered plant and animal species reside on these cliffs.

MMR has been used since World War II as a live-fire training range by all branches of the military. This activity has resulted in the continuous introduction of a large number of ignition sources. When combined with the invasion of exotic species that are well adapted to the effects of burning, a highly fire prone environment was produced. A road network designed to contain fires that started on the range and a fire danger rating system were emplaced in the 1980's to reduce the number and extent of fires within the valley.

During the past decade a series of large fires, notably in 1995 and 1998, negatively impacted a portion of the native habitat and endangered species that occupy the high elevation ridges (map 1). In September 1998, Earth Justice Legal Defense Fund threatened to sue both the Army and the U.S. Fish and Wildlife Service (USFWS) unless the Army initiated consultations with the USFWS in accordance with section 7 of the Endangered Species Act within 60 days. Shortly thereafter, an errant mortar round started a fire that burned 800 acres outside of the south firebreak road. The commanding general of the U.S Army Hawaii Garrison shut down the range until Section 7 consultations are completed.

Part of the mitigation plan resulting from these consultations require the Army to provide a more effective wildfire management program. This report provides information about MMR's fire history, fuels, potential fire behavior, and fuel modification recommendations. Other information necessary for achieving more precise fire behavior prediction capabilities is being compiled by the U.S. Forest Service Pacific Southwest Research Station. The additions include high-resolution weather modeling and fire simulations using the FARSITE Fire Area Simulator. Though these supplements will provide further insights into fire behavior, they are not essential to fire prediction or fire control. These additions will be addressed in a separate report to be submitted by the Forest Service.

Fire History of the Makua Military Reservation

1.1 Summary

Pre-historic fire in the Hawaiian Islands was most likely rare and probably did not impact a significant area. The arrival of Europeans brought an increase in fire size and frequency. This trend has continued and the use of MMR as a live-fire range has induced a high fire frequency through consistent ignition sources.

1.2 Fire History Methods

A long-term history of fire in the Hawaiian Islands was compiled from the literature. Fire history at MMR was determined to the extent possible from existing literature and records obtained from the U.S. Army Hawaii Range Division, the Staff Judge Advocate's office, the Directorate of Public Works Environmental Division, and the Federal Fire Department at Lualualei. Some of these records were fire reports kept by the Army while others were fire response records kept by the Federal Fire Department.

1.3.1 Pre-Historic Fire Regime

The Hawaiian Islands have been subjected to infrequent fires throughout their history. The presence of an active volcano on at least one island at any one time suggests that fires from volcanic activity almost certainly occurred. However, fires caused by this ignition source within the frame of recorded history tend to be small and are oftentimes insubstantial when compared with the area affected by the lava flows themselves (Vogl, 1969)[1]. Lightning, the principal natural ignition source worldwide, is rare in Hawaii and when it does occur, fires of any significance are rarely started (Mueller-Dombois, 1981)[2]. Smith and Tunison (1992)[3] suggest that the lack of carbon in subsurface soils formed prior to human colonization and away from volcanically active areas indicates a low fire frequency. In addition, these authors believe that

[1] Vogl, R.J. 1969. The Role of Fire in the Evolution of the Hawaiian Flora and Vegetation. Reprint from *Proceedings Annual Tall Timbers Fire Ecology Conference*, April 10-11, 1969.

[2] Mueller-Dombois, D. 1981. Fire in Tropical Ecosystems. In *Fire Regimes and Ecosystem Properties. Proc. Of the Conf.*, 137-176. U.S. Forest Serv. General Tech. Rep. WO-26.

[3] Smith, C.W. and Tunison, T.J. 1992. Fire and Alien Plants in Hawaii: Research and Management Implications for Native Ecosystems. In: Stone C.P., Smith C.W., and Tunison J.T. (Eds) Alien Plant Invasions in Hawaii. Univ. Hawaii Press.

low fire frequency probably was a result of infrequent natural ignition sources, relatively moist non-flammable native vegetation, and discontinuous fuel beds. For these reasons, fires before the discovery of Hawaii by Polynesians 1600 years ago were most likely infrequent and of small scale.

1.3.2 400 A.D. – European Arrival

The introduction of anthropogenic influences brought an increase in the frequency and size of fires. These influences, particularly the use of slash and burn agriculture by native Hawaiians (Kirch, 1982[4], Cuddihy and Stone, 1990[5]), provided open areas free of vegetation for non-native pyrophytic (species that proliferate in the presence of frequent fire) grasses to take hold. The introduction of these grasses resulted in vegetation that was more prone to ignition and provided continuous fuel beds over which fire could propagate. These conditions led to a positive feedback cycle in which fire-adapted grass species increased the likelihood of fire, which in turn burned native habitat, allowing further invasion by fire-adapted grasses. Though it is clear that Makua valley was used by native Hawaiians, it is unknown whether they practiced the types of vegetation management that would produce a pyrophytic grass dominated landscape.

1.3.3 European Arrival – 1940

European arrival introduced a suite of plants and animals whose adaptations allow them to outcompete native Hawaiian species. Over the intervening years, hundreds of exotics have been introduced to the Hawaiian Islands. Eighty-six species are considered to pose a serious threat to native biota, the pyrophytic grasses being some of the most aggressive (Hughes et al., 1991)[6]. These grass species tend to rapidly colonize burned areas and, once established, are difficult to remove due to their sprouting abilities (Smith and Tunison, 1989). Because of their superior adaptation to fire, they can quickly outcompete Hawaiian species after a burn, resulting in extensive stands of exotic, fire-adapted grasses. The introduction of these grasses, combined

[4] Kirch, P.V. 1982. The impact of the prehistoric Polynesians on the Hawaiian ecosystem. Pac. Sci. 36(1):1-14.

[5] Cuddihy, L.W., and Stone, C.P. 1990. *Alteration of native Hawaiian vegetation: effects of humans, their activities and introductions.* Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit. Honolulu: Univ. Hawaii Pr.

[6] Hughes, F., Vitousek, P.M., Tunison, T. 1991. Alien grass invasion and fire in the seasonal submontane zone of Hawaii. Ecology 72(2) 743-746.

with the ever-increasing number of anthropogenic ignition sources, has resulted in significantly larger and more frequent fires.

1.3.4 1940 – Present

Smith and Tunison (1992) documented an increase in the frequency and size of fires at Hawaii Volcanoes National Park since 1968. They noted that this increase coincided with the spread and intensification of alien grasses. The resulting rise in grass biomass produced a fuel bed far more suitable to fire propagation. Introduced grasses, similar to those found in Hawaii Volcanoes National Park, may have found their way into Makua Valley far earlier. The conversion of the area to a military live fire range in the 1940's introduced seed spread vectors for exotics (via military vehicles and personnel) and a daily source of ignitions. These ignitions produced fires that allowed the encroachment of exotic pyrophytic grasses. While records before the late 1980's are highly fragmented and incomplete, the increase in fire frequency and size within MMR after 1940 was probably similar to that of Hawaii Volcanoes National Park after 1968. Currently, alien grasses, particularly Guinea grass (*Panicum maximum* Jacq.) and molasses grass (*Melinis minutiflora* Beauv.) heavily dominate the valley floor as well as C-ridge and the northern ridge (map 2). Molasses grass has encroached well into the forested areas within the northern valley lobe. These grasses have the ability to invade native systems without the aid of fire (Mueller-Dombois and Goldammer, 1990)[7] suggesting that even total removal of fire from the system may not stop their spread. However, these authors suggest that the occurrence of fire speeds the invasion by inducing an explosive colonization and densification of pyrophytic grasses.

1.3.5 Fire Records and Trend Analysis for Makua Military Reservation

All available records from the agencies mentioned in section 1.1 were compiled into the database in appendix 1. Large gaps in information are frequent and records prior to 1996 are incomplete in terms of both the existence of a record for every fire and the recorded information in the available records. Trend analyses were conducted on all 325 records for the time of ignition, month, size of average fires, fire danger rating index, and ignition source. The number

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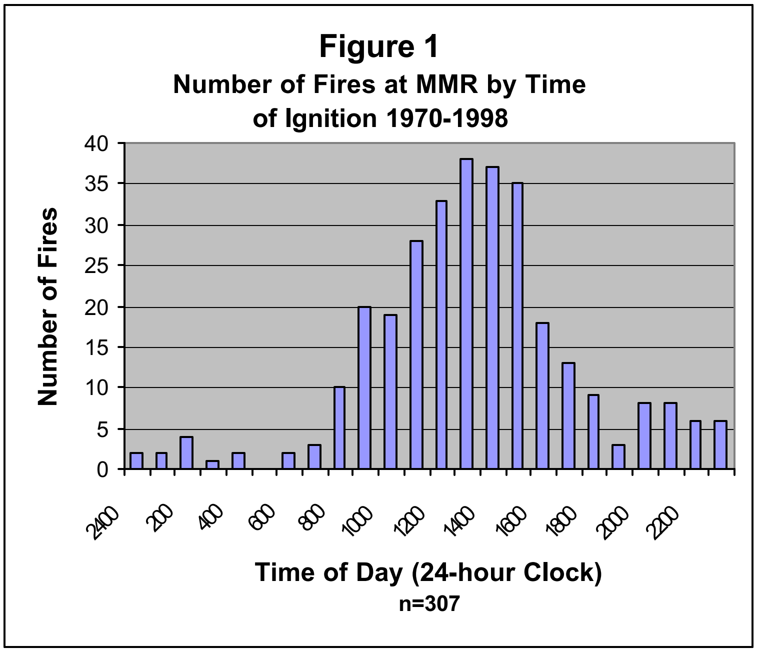
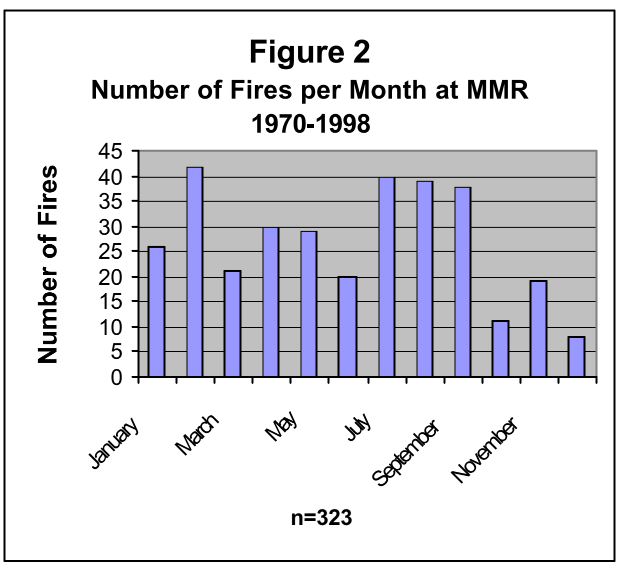
[7] Mueller-Dombois, D. and Goldammer, J.G. 1990. Fire in tropical ecosystems and global environmental change: An introduction. In: *Fire in the tropical biota: Ecosystem processes and global challenges.* Springer-Verlag Berlin Heidelberg.

of values (n) available for each analysis is noted in each figure. Due to the number of missing values and records, caution should be taken when attaching significance to any of these results.

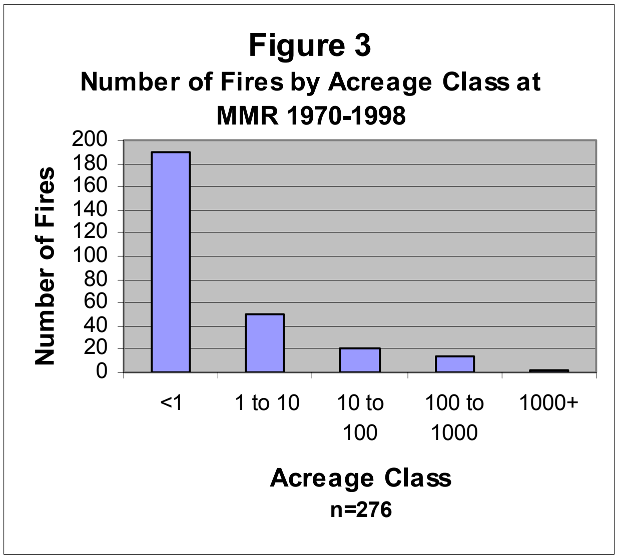


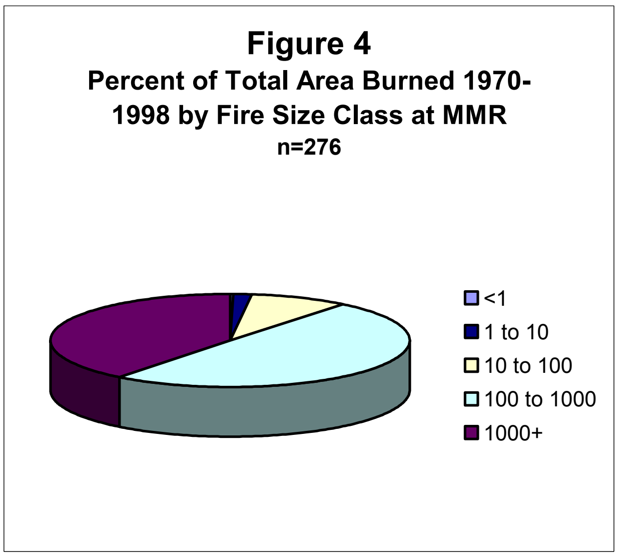
The existing fire records support the idea that fires at MMR follow patterns similar to those found on the mainland. Fires were most likely to occur during the peak burning period of 1000 to 1600 hours (Figure 1). One hundred ninety fires were recorded as starting during these six hours of the day from 1970 to 1998, far more than the number recorded during the remaining 18 hours of the day (117). Fires appear to be more frequent during the driest time of the year, July through September (Figure 2). However, February recorded 42 fires, the most for any month. This is intriguing because February is during the wet season (Block 1997)[8]. Climatic variation, number of training days for a given year, and differences in the types of weapons allowed from one year to the next precluded analysis of fire occurrence trends from one year to the next.

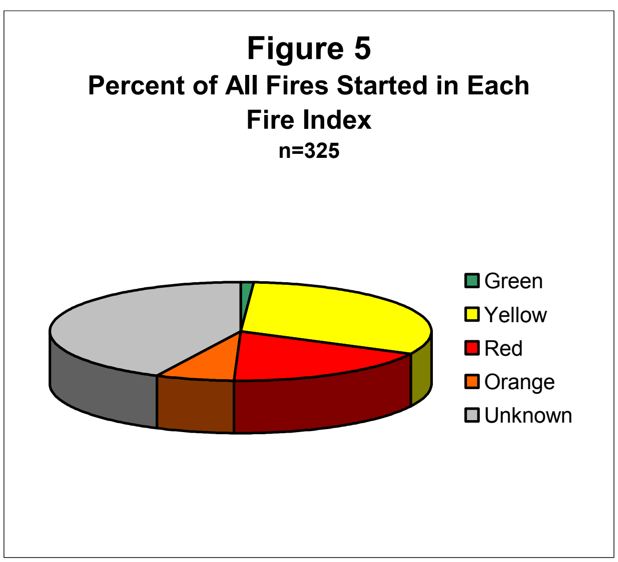


Fires were divided into size categories (<1 acre, 1 to 10 acres, 10 to 100 acres, 100 to 1000 acres, and 1000 or more acres). The relationship of the number of fires to fire size is an inverse J distribution, as would be expected (Figure 3). But the bulk of the area burned (50%) is by fires greater than 100 acres

[8] Block, Paul. 1997. Land Condition-Trend Analysis at Schofield Barracks and Makua Valley 1996 for the U.S. Army Garrison – Hawaii. Center for Ecological Management of Military Lands, Colorado State University, Fort Collins, CO.







in size (Figure 4). This suggests that a small number of fires are causing a large part of the resource damage. Controlling or eliminating these few large fires would greatly reduce the threat to MMR's resources.

The fire danger rating system that has been in place since the 1980s divided burning index values into four categories: Green, Yellow, Red, and Orange. The danger index was calculated from weather data collected from an on-site remote automated weather station (RAWS). All types of training were allowed under Green conditions but no training was allowed under Orange conditions. Various weapons systems, thought to pose too high a fire risk, were not allowed under Yellow conditions, and further weapons restrictions were imposed under Red conditions. The majority of fires recorded started under Yellow conditions (Figure 5). This suggests that perhaps this category was too liberal either in the weapons allowed or in its burning index cutoff value. Lowering the burning index (BI) threshold for this index (and, thus removing weapons from use at higher Yellow BIs) or removing fire prone weapons from use under Yellow conditions (particularly tracers), would result in fewer fires in this index categories and fewer fires overall. The acreage burned by fires started in each fire index category (Figure 6) suggests that, for fires with known fire

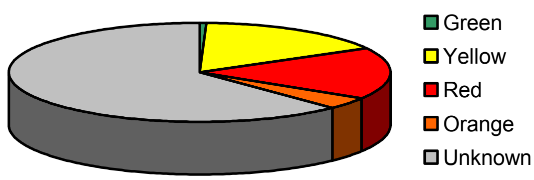


Figure 6
Acres Burned by Fire Index at Time of Fire Start
n=325

indices, the majority of acres (33%) were burned by fires that started under Yellow or Red conditions. This does not mean that these acres all burned under the yellow or red fire index, only that the fire ignition occurred under these conditions. The burning conditions after the time of ignition are unknown and may have played a major role in the number of acres burned. Use of the new fire danger rating system, described in section 4.3.2, will change the BI cutoffs as well as the weapons allowed under each fire index.

Historically, tracers have been the largest cause of fires at MMR (Figure 7)[9]. The Army decided in October, 1999 that tracers will no longer be allowed on the range. This will dramatically reduce the number of ignitions because tracers accounted for 49% of all ignitions in the fire history records. The elimination of tracers is a major step towards protecting the natural

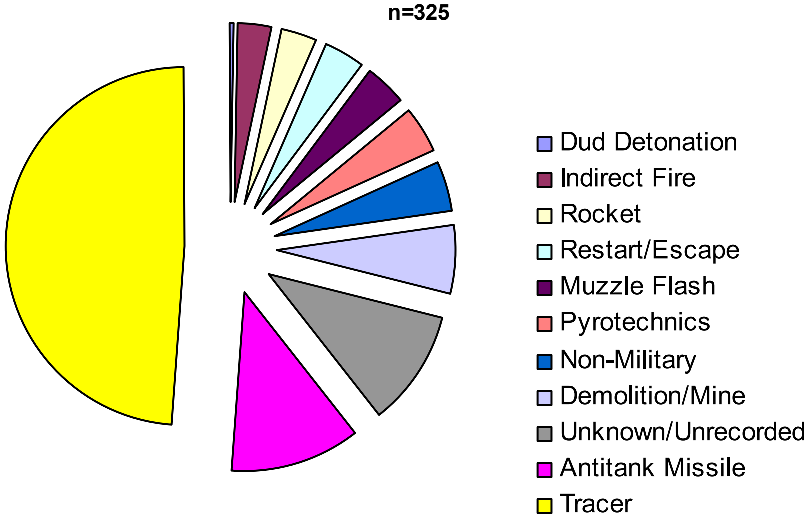


Figure 7
Fire Ignition Sources as a Percent of All Fires From 1970-1998
n=325

[9] Definitions for categories in Figure 7: 'Dud detonation'-Any fire started by spontaneous explosion of unexploded ordinance; 'Indirect Fire'-any fire started by mortars or artillery; 'Rocket'-any fire started by an unguided rocket propelled weapon (rockets are distinguished from missiles which are guided); 'Restart/Escape'- fires that were declared out and reignited to burn additional acreage or prescribed fire escapes; 'Muzzle Flash'-any fire started by the hot propellant gases escaping from the barrel of a gun when it is fired; 'Pyrotechnics'-any fire started by flares or weapons simulators (noisemakers or fireworks); 'Non-military'-any fire started by civilians or activities not associated with military training; 'Demolition/Mine'-any fire started by TNT, C-4 plastic explosives, or mines; 'Unknown/Unrecorded'-the cause of the fire is not known; 'Antitank Missile'-any fire started by a guided rocket propelled antitank weapon; 'tracer'-any fire started by the hot materials in a tracer round.

resources of MMR. Other weapons that should be considered for restrictions or usage modification during Yellow and Red fire index conditions are demolition explosives, mines, and pyrotechnics.

Antitank missiles, including Dragon and TOW missiles, account for 12% of all fires in the fire history records. However, Dragon missiles are no longer used on the range and these were responsible for 33 of the 38 antitank missile-caused fires. TOW missiles are rarely used on the range and pose a very small fire ignition threat. For these reasons, antitank missiles are not considered to be a major fire hazard.

Demolition explosives and mines account for 6% (20) of the fires in the fire history records. Because these weapons are placed rather than fired, the area in which the explosion occurs is known with great accuracy before detonation. By simply treating the site in which the explosives are to be used or choosing a site with little fire ignition risk, such as areas of bare ground, the ignition potential of these weapons can easily be reduced to nearly zero. Treatments can be as simple a cutting the grass to stubble height in areas where demolition charges or mines will be used.

Non-military ignitions accounted for 5% of fires (15) in the fire history records. Nearly all of these were caused by civilians. This is significant because most of these fires started on the highway and several of them are considered to be intentionally and/or maliciously set. In the end, this may be the greatest fire threat to MMR since the timing of military ignitions can be controlled, while civilian ignitions cannot. At this point there are few barriers to prevent fires started along the highway from quickly moving up valley. Improving fuel management along the highway could be vital to maintaining threatened and endangered species habitat (see section 5.3.1).

Other ignition sources each account for less than 5% of fires in the historical record and are therefore of minor concern. Mortars (included in the indirect fire category), thought by the Army to be one of the major ignition sources after tracers, account for only 4% (10 ignitions) of all fires in the fire history records. This indicates that mortars are not a primary ignition source and do not warrant any special attention or attempts at ignition control.

1.4 Recommendations

Fire records should be kept for every fire, regardless of extent or severity. These records should include:

- Date of ignition
- Time of ignition
- Ignition source
- Date declared out
- Time declared out
- Time of escape (if appropriate)
- Burning index and fire danger category (green, yellow, or red) at the time of ignition and every hour that the fire burns
- Resources used to suppress the fire (including number and type of equipment and personnel)
- Location of the fire (i.e. The ignition point and the burn boundary, preferably located with a GPS unit)
- Whether the ignition occurred outside of the firebreak road
- The number of acres that burned outside of the firebreak road
- The number of acres that burned inside the firebreak road
- The total number of acres burned
- Whether any of the known endangered species locations were burned

RAWS data during all fires should be retained with the fire records for future reference. The Makua Military Reservation Fire Report forms can easily be modified to include this additional information, with the possible exception of hourly fire danger ratings for long-lived fires. In addition, for those fires that escape initial attack and grow beyond a threshold size (approximately 100 ac), a wildland fire situation analysis and large fire narrative should be completed. These documents summarize daily fire danger, fire behavior, resources and values at risk (including endangered species habitat), and resultant management decisions and outcomes.

Vegetation Mapping Methods for the Makua Military Reservation

2.1 Summary

A vegetation map of MMR was created using digitized aerial photography and field data collection. The purpose of this map was to accurately ascertain vegetation cover for the entire valley, which is needed for fuel model determination and the high-resolution weather modeling being completed by the Forest Service. Eight vegetation classes and one non-vegetated class were delineated on a map that was then digitized. The final product was then reclassified into three fuel types: grass (for the valley bottom), forest (for the forested ridge areas), and kukui (*Aleurites moluccana* (L.) Willd) (for the wet gully areas dominated by kukui forest).

2.2 Vegetation Mapping Methods

One-meter resolution color infrared aerial photographs from February 1998 were assembled into a georeferrenced mosaic to provide a complete view of the area to be mapped. This image was then digitized into ArcView format and an unsupervised classification with six spectral signatures (classes) was run by Geographic Information Systems (GIS) technicians at Colorado State University (CSU), providing a preliminary vegetation map for improvement by field observations. The spectral classes were intended to distinguish six vegetation types and provide a starting point for the field portion of the vegetation classification.

A tour of MMR in early May 1999 provided an opportunity to determine likely classes for use in mapping. Vegetation classes suitable to the ecosystems within the mapping area were further refined with the help of botanists from the Army's Integrated Training Area Management (ITAM) program and the Directorate of Public Works Environmental Division (DPW Env). Ten classes were devised: grass, grass/shrub, shrub, ʻohiʻa (*Metrosideros polymorpha* Gaud) dominated forest, koa (*Acacia koa* A. Gray) dominated forest, wiliwili (*Erythrina sandwicensis* Degener) dominated forest, kukui dominated forest, savanna, vegetated cliffs, and intensively managed/denuded areas.

Initial data collection quickly proved the unsupervised classification to be unsatisfactory at distinguishing between vegetation types and was therefore not relied upon for the remainder of the mapping effort. 1:3200 scale images were used to delineate vegetation boundaries in the field. Because of constraints on groundwork outside of the firebreak road (virtually all of this area is inaccessible due to unexploded ordinance (UXO) concerns), the field mapping was accomplished by visually delineating vegetation boundaries from useful vantage points. Oftentimes this meant delineating boundaries from a distance of more than a mile. Because of the distance, it was difficult to differentiate between the ‘ohi‘a, koa, and wiliwili forests. Therefore, these forest types were lumped into a single category and termed “mixed forest”, resulting in eight vegetation categories. Additionally, fire behavior in these forest types is unlikely to vary noticeably because their litter is highly similar. Kukui dominated forest was left as a separate vegetation class because it tends to grow in particularly moist areas. Therefore fire behavior will likely be different from other forest types. Also, its light-colored canopy is easily distinguishable for mapping.

Ground truthing was not possible in the areas covered by UXO restrictions. Areas inside of the firebreak road were homogenous enough that truthing was deemed unnecessary for fire management purposes.

The final vegetation class boundaries were digitized into the ITAM GIS database. These maps were then reclassified into a fuels map (map 3) for MMR. Three distinct fuels were distinguished: grasses dominated by Guinea grass (*Panicum maximum* Jacq.), forest (including all of the forest vegetation with the exception of areas dominated by kukui), and kukui (representing the wet gully areas dominated by kukui). There are a considerable number of immature shrubs in areas of the grass fuel type that may warrant a fourth fuel type when they grow to maturity. However, at this point they will likely have little effect on fire behavior because the grass will be the primary carrier of the fire and past experience with fire at MMR has indicated that prescribed burning keeps the shrubs in check. For more information about the fuel types see section 4.

2.3.1 Vegetation Mapping Results

Eight vegetation classes and one non-vegetated class have been identified for mapping within the perimeter of the MMR. The final vegetation map is map 4. The following is a description of each vegetation category:

Grass

Alien grasses are generally greater than 1m in height, though grass in areas that have been burned or managed within the past year may shorter. The principal species are Guinea grass and molasses grass (*Melinus minutiflora* P.). The latter has been known to result in exceptionally high fire intensity, probably due to oils secreted from the base of leaf hairs onto the leaf surfaces. Heavy accumulations of dead biomass, nearing 100% of all grass biomass in the dry months, are common in the grass class. Pockets of shrubs, particularly haole koa (*Leucaena leucocephala* (Lam.) de Wit), exist within the grass vegetation class. Virtually no native species are present.

Grass/Shrub

Alien grasses grow in the understory or are codominant with shrubs. Grass biomass remains high and the influence of the shrubs is in the addition of larger diameter fuels to the fuel matrix as well as a firebrand source for spotting. There is some disagreement among personnel with fire experience at MMR about whether intensity and rate of spread of fires burning from grass into grass/shrub areas is reduced. However, at present, most shrubs (primarily haole koa) in the grass/shrub category have been repeatedly burned in the past several years and are therefore small and probably have little effect on fire behavior as the grasses will be the primary carrier of the fire.

Shrub

Alien (generally at middle elevations) and native (at higher elevations) shrub species dominate this class. Shrublands tend to occur at middle elevations in scattered patches and at high elevations on ridges unsuitable for the production of a forest stand of full stature. Many areas classified as shrub are occupied by species technically classified as trees that have taken on a shrubby growth form.

Mixed Forest

All tree species, with the exception of kukui, are included in this class. These forests are heavily dominated by the native species of ‘ohi‘a, wiliwili, and koa, though areas of alien infestation occur. Forested areas are almost exclusively located above 200 m. Where forested areas exist below this elevation they are limited to locations with favorable soils, moisture, and aspect.

Kukui Dominated Forest

Kukui dominated forest is any area where kukui canopy cover is greater than 50%. This class of vegetation occurs almost exclusively in moist gullies within the native forest class.

Vegetated Cliffs

This class includes any heavily to lightly vegetated cliff faces with a slope greater than approximately 75 degrees. Vegetation cover ranges from virtually none (in isolated areas) to complete cover of grasses and low stature shrubs. Individual trees are present but uncommon and closed canopy forests are absent.

Savanna

Grasslands with a tree canopy greater than 50% fall into this category. Grasses in the understory are consistently the alien species named above. Tree species include both native and exotic individuals.

Forest/Shrub

Shrublands with a tree canopy greater than 50% make up the forest/shrub category. Shrub and tree species include both native and exotic individuals. This vegetation class occurs only in one location along Farrington Highway.

Roads, Areas Around Buildings, and Bare Soil

This class includes roads, buildings and the surrounding landscaped vegetation, and areas with very sparse vegetation. Areas impacted enough by training exercises to remove continuous vegetation cover are included. This category is composed of areas where there is very little risk of fire ignition or spread. Locations that have been mowed and/or burned for fuel management are not included because they represent areas of higher fire ignition and spread risk.

2.3.2 Fuel Map Results

All vegetation classes with the exception of the mixed forest and the Kukui dominated forest classes were reclassified into a "grass" fuel class. The mixed forest was represented by a "forest" fuel class and the kukui dominated forest was reclassified into a "kukui" fuel class. A description of the associated fuel models can be found under section 4.3.1.

The Fire Effects Information System (www.fs.fed.us/database/feis), a national database of species-specific responses to fire, was checked for information about any of the species mentioned here. No information on any species was found.

2.4 Recommendations

The vegetation map should be updated as necessary in response to encroachment of pyrophytic grasses into native habitat, the maturing of shrubs within the grass category, or as events dictate. Improvements in vegetation mapping may be possible with further field work by botanists familiar with Hawaiian vegetation. However, the cost of remotely sensed data of the quality necessary to improve the map far outweighs any benefits that the increased vegetation map resolution would provide.

Fuel Load Information for Makua Military Reservation

3.1 Summary

Fuel loads, depths, and surface area to volume ratios (SA/V) were collected and analyzed to provide an indication of the worst case fuel scenario at MMR. Worst case fuels are defined here as mature stands that have reached their average maximum height and biomass (both live and dead). By sampling worst case fuels, predictions made by fire behavior models will tend to over-estimate fire behavior resulting in conservative management of the range. Once fuels in managed locations are measured, differences in estimated fire behavior and fuel loads between managed and unmanaged areas can be compared. The fuel sampling was limited to the grass fuel within the firebreak road due to UXO concerns elsewhere. Because there is no forest vegetation within the firebreak road, the forest and kukui fuel types were not sampled. Recommendations are made about fuel data collection in the future.

3.2.1 Fuel Load Data Collection Methods

Four 100 m transects were established within stands of mature grass fuels. Transects were located within mature stands of grass to represent the worst case fuel loading scenario for this fuel type. Transect orientation to the fuels and topography was random. Plots were established every 10 m along the transect with the first plot at 0m and the last at 90 m. A total of 40 samples was collected. Daubenmire frames (20 cm x 50 cm) were used to delineate each plot. All standing grass was cut as close to the ground as possible and placed in a garbage bag labeled with the transect number and the plot number. Dead fuel that was lying horizontally was cut where it intercepted the edges of the plot and was placed into the bag as well. Samples were then sent to CSU for drying and weighing. An overall fuel load was computed by averaging 39 sample dry weights (one outlier was removed, see section 3.2.3).

3.2.2 Fuel Depth Data Collection Methods

At each sample point on the transect, the fuel depth was estimated by measuring the height of the tallest fuel particle. Bob Burgan and Francis Fujioka, (USDA Forest Service, Pacific Southwest Research Station) recommended that maximum fuel depth be multiplied by 2/3 to provide an average fuel depth for the plot. An overall fuel depth was estimated by averaging all forty measurements.

3.2.3 Surface Area to Volume Ratio Data Collection Methods

At the end of each transect, the final plot location (at 100m) was used to sample SA/V for a total of four samples. This was accomplished by establishing a point at the end of the transect and collecting the 10 stalks of grass, closest to this point. The thickness of each sample was separately measured using the techniques outlined by Fujioka and Fujii (1980)[10]. Twenty-five measurements were taken from each sample for a total of 100 measurements. Weighting factors (to adjust for uneven fuel biomass distribution between stalks and leaves), and SA/V were calculated using equations described by Fujioka and Fujii. One SA/V measurement of 28,818

[10] Fujioka, F.M., Fujii, D.M. 1980. Physical characteristics of fine fuels in Hawaii – Some refinements on surface area-to-volume calculations. PSW Research Note PSW-348. 7 p., Pacific Southwest Research Station, Berkeley, CA.

1/ft was removed from the leaf data pool because it was clearly an outlier (defined here as more than three standard deviations from the mean). A final SA/V was determined by, first, averaging the 41 leaf and 58 stem SA/V measurements. These two averages were then multiplied by their respective weight correction factors and the results were added to produce a final SA/V.

3.3 Fuel Sample Results

The table below represents summary statistics for each fuel parameter measured.

	Depth *(In)* n=40	*SA/V Leaf** *(1/ft)* n=41	*SA/V Stem* *(1/ft)* n=58	*SA/V Ave.** *(1/ft)* n=99	*Loading** *(t/a)* n=39
Minimum	34.67	522.88	141.39	N/A	1.48
Maximum	68.67	5853.66	4783.36	N/A	24.78
Median	49.67	2162.16	621.37	N/A	7.70
Mean	**49.63**	**2333.44**	**781.63**	**1052.52**	**9.42**
Upper 95% CI	51.51	2746.08	986.81	N/A	11.27
Lower 95% CI	47.76	1920.81	576.45	N/A	7.57
Standard Error	0.93	204.17	102.46	N/A	0.91
Standard Deviation	5.86	1307.30	780.34	N/A	5.71

*One outlier was removed

3.4 Recommendations

Fuel data collection should continue using the methods described above to develop a model of the managed grass occurring inside the firebreak road. SA/V can be assumed to be the same as that calculated here, however depth and loading will have to be estimated for the managed fuels. Transects could be added to existing or future Land Condition Trend Analysis (LCTA) plots. These transects will have to be adjusted each time they are read so that fuel load data are not collected from the same plots that were used the time before, as the biomass may not have had enough time to recover in the interim. This can be accomplished by rotating the transect bearing by 45 degrees every time it is sampled and placing sample plot #1 at 5m instead of 0m (to avoid resampling the area at the base stake). Managed fuels should be sampled at the end of the cutting or burning cycle (i.e. when the fuels are oldest and tallest), probably at the end of one year's growth. Fuel sampling efforts should make every attempt to minimize the effects of recurrent trampling along transect locations.

Fire Behavior for Makua Military Reservation

4.1 Summary

Fire behavior fuel models for the grass, forest, and kukui fuel types were constructed and validated to the extent possible using fuel load estimates collected in the field and the best available subject matter experts. The local area expertise of Sammy Houseberg (Director of Installation Safety, 25th ID (L) USARHAW) and Don Studebaker (Fire Management Officer, Palomar District, Cleveland National Forest), complemented fuel observations and modeling recommendations made by Bob Burgan and Francis Fujioka. The resultant fuel models were validated to the extent possible using the experience of Mr. Houseberg and Mr. Studebaker. The National Fire Danger Rating System (NFDRS) fuel model[11] that is used for BI calculations was changed from L to N. A new fire danger rating system is created based on BIs associated with recommended flame lengths predicted by BEHAVE.

Fire prediction models were used because they provide precise quantitative information about anticipated fire behavior under given environmental conditions. The predictive capabilities of these programs are not perfect, but models are an indispensable tool used by fire managers throughout the world. Models provide managers with guidance on the extent of fuel reduction required to reduce flame lengths to controllable thresholds or predictions of fire growth during the next hour. The advantage to modeling is that we can evaluate many of the pros and cons of a particular course of action before anything is done on the ground.

4.2.1 Fuel Model Development

On August 17, 1999, Bob Burgan and Francis Fujioka visited MMR for the purpose of initiating the building of fuel models for the area. A document summarizing the comments of Mr. Burgan and Mr. Fujioka regarding fire prevention at MMR is included in appendix 2. The consensus of all present was that all of the lower valley vegetation types should be represented by a single grass fuel model. The fuel model that we developed is intended for use primarily as a

[11] Note: NFDRS fuel models are not to be confused with fire behavior fuel models. NFDRS fuel models are used to estimate fire danger. Fire behavior fuel models are used as inputs into a fire behavior prediction model such as BEHAVE (Andrews, P.L. 1986. BEHAVE: Fire Behavior Prediction and Fuel Modeling System – BURN subsystem, Part1. INT-GTR-194; Andrews, P.L. and Chase, C.H. 1989. BEHAVE: Fire Behavior Prediction and Fuel Modeling System – Burn Subsystem, Part 2. INT-GTR-260). NFDRS fuel models will be referred to as "NFDRS fuel models" while fire behavior fuel models will be referred to as "fuel models".

fire danger rating tool and will significantly overpredict fire behavior in most of the fuels inside the firebreak because it was designed for the heavier fuel accumulations that occur outside of the firebreak. The intent of this fuel model is to allow fire danger ratings based on the conditions outside of the firebreak. In this fashion, operations on the range will be controlled by the ability to control fire outside of the firebreak, where the risk posed by fire is the greatest. We entered rough estimates of fuel parameters into the TSTMDL[12] (Test Model) subsystem of BEHAVE as a starting point. With the guidance of both Mr. Houseberg and Mr. Studebaker the model was adjusted until it yielded results consistent with their substantial experience.

At a later date, the fuel model was used to run fire behavior simulations encompassing the full range of environmental conditions that occur at MMR. The results were given to Mr. Houseberg to compare to his experience with fire at MMR. Mr. Houseberg was utilized because he was the Facility Manager stationed at MMR for a number of years and has had more experience with fire at MMR than any other known individual. Adjustments were made to the fuel model to incorporate Mr. Houseberg's comments. We did not validate the fuel models because only two acceptable burn areas were located that would be available before the onset of the rainy season and the ensuing poor burning conditions. Two burns would only provide two data points, far fewer than necessary to provide a relevant validation, and therefore we decided the burns should be postponed until spring or summer 2000. By this time the roads within the south fuel break should be adequate to compartmentalize the area into five or six separate prescription areas (see section 5.4.2). Additionally, the use of Mr. Houseberg to test a wide variety of environmental conditions is more useful than a limited number of test burns providing data relating to only a couple of environmental conditions. All who helped develop the fuel models feel that, as long as they are used conservatively, the fuel models will be sufficient for the purposes of this study.

4.2.2 Fire Danger Rating System Development

The fire danger rating system that was in use through 1998 was revamped to reflect changes in the BI calculations and to incorporate the results of the fire history analysis. The BI calculations were changed because we decided that NFDRS fuel model N (sawgrass) better

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[12] Burgan, Robert E. and Rothermel, Richard C. 1984. BEHAVE: Fire Behavior Prediction and Fuel Modeling System – Fuel Subsystem. INT-GTR-167.

represents the fuels at MMR than NFDRS fuel model L (western perennial grass) which had been used in the past. The use of NFDRS fuel model L was based on the assumption that all fires would occur and be contained within the managed fuels inside the firebreak. This has not been the case and the use of NFDRS fuel model N reflects the fact that fires escape the firebreak roads. The BI's that are yielded by this change much better represent the fire behavior observed in the past according to Mr. Houseberg. NFDRS fuel model N more closely resembles the fuels outside of the firebreak, and is therefore more conservative because it will tend to overpredict fire spread within the firebreak. Thus, operations will be curtailed when burning conditions are less threatening, because the higher fire spread predictions for outside of the firebreak will be determining the cutoff values for training.

4.3.1 Fuel Model Results

The fuel model descriptors are as follows:

	Grass	*Forest*	*Kukui*
1 Hour Fuel Load (t/a)	4.00	1.00	0.10
10 Hour Fuel Load (t/a)	3.00	1.00	0.00
100 Hour Fuel Load (t/a)	0.00	0.00	0.00
Live Herbaceous Fuel Load (t/a)	4.00	0.00	0.00
Live Woody Fuel Load (t/a)	0.00	3.00	3.00
1 Hour SA/V (1/ft)	1200	1300	1300
Live Herbaceous SA/V (1/ft)	1100	0.00	0.00
Live Woody SA/V (1/ft)	0.00	1100	1100
Fuel Bed Depth (ft)	1.70	2.00	1.00
Heat Content (BTU/lb)	8000	8000	8000
Extinction Moisture (%)	40	40	35

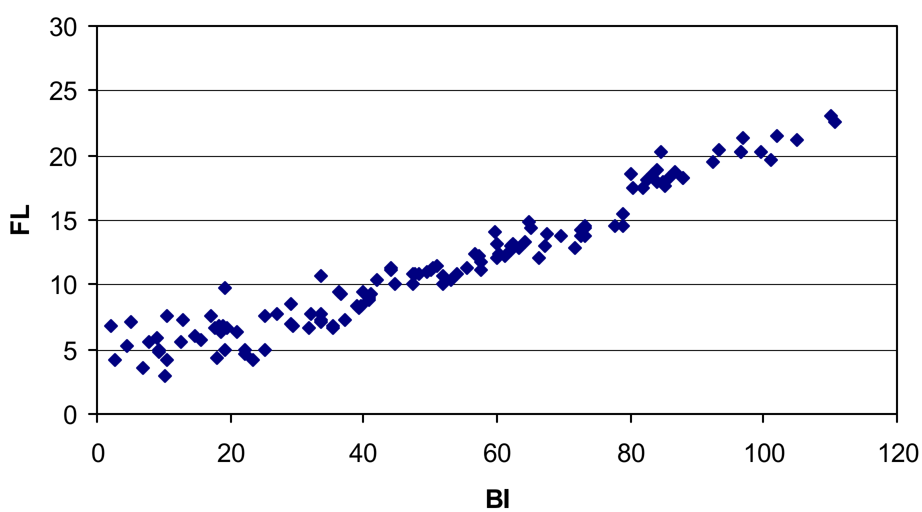
All three fuel models were constructed to be "static", meaning that the computer will not transfer herbaceous fuel loads to 1-hour fuel loads as conditions become drier. We considered making the grass fuel model "dynamic" (herbaceous fuel loads do transfer to 1-hour fuel loads with decreasing fuel moistures) but decided against this due to the fact that these models will be used primarily for fire danger rating. Because the NFDRS fuel models to which we are correlating our fuel models are static, we decided that our fuel models should be static as well.

Successful fire prevention and suppression will inevitably lead to an increase in biomass in areas outside of the firebreak. This condition will amplify the danger posed by any fire that does escape containment within managed areas inside the firebreak. Because there is no acceptable method to reduce fuel loads outside of the firebreak, there is little that can be done to alleviate this problem. However, the fuel models developed here were based on worst case fuel loads which should allow a sufficient margin of error for fire managers.

4.3.2 Fire Danger Rating System Results

The change in the NFDRS fuel model (L to N) used for BI calculation has yielded results that much more closely match the past fire behavior observed by Mr. Houseberg at MMR. Using NFDRS fuel model L generally resulted in BIs from 10 to 40. BIs are calculated to be approximately ten times the expected flame length. The new NFDRS fuel model results in BIs on the order of 30 to 100, which matches the typical flame lengths observed at MMR.

Figure 8
Flame Lengths vs BI Calculated by BEHAVE Using the Static Grass Fuel Model
n=125



Regression: BI=5.446*FL-11.614
r-square=.933 p=.0001

BIs were correlated with flame lengths predicted by BEHAVE using data from the lower RAWS (Figure 8) and the grass fuel model. Dead fuel moistures, windspeed, and wind direction were obtained from the Daily Fire Weather

Report from the lower RAWS. The slope was set to 20% for every run and the direction of the wind vector was set as degrees clockwise from due west (BEHAVE needs the direction of the wind in relation to the slope. For simplicity, the slope was assumed to face west). Calculations were made for the direction of maximum spread. These flame lengths were compared with the BI in a linear regression. The resulting regression equation is at the bottom of Figure 8.

The original fuel model used to regress flame length against BI was dynamic. This model was developed to best represent the fuels and predict fire behavior at MMR. However, the regression produced BI cutoffs that were too conservative based on our observation of the fuels at MMR and consultations with individuals experienced with the subject matter. Because our model is regressed against a static NFDRS fuel model and will be used primarily for fire danger rating, not fire prediction (at least at this point), it makes more sense for us to use a static model. For these reasons, the model was changed to the static model introduced in section 4.3.1.

4.3.3 Limitations of Fire Modeling

Mathematical fire models developed by Richard Rothermel in 1972[13] are the basis of virtually all fire prediction systems in use in the United States today. The BEHAVE fire prediction system that was used for this analysis is based on the mathematics worked out by Rothermel and has several inherent limitations. The model describes the conditions in the flaming front fire having a quasi-steady state spread rate within 6 feet of the ground, and under homogenous fuel and environmental conditions. Andrews (1986) [14] recommends limiting projection periods to 2 to 4 hours, even when environmental conditions are fairly constant. Additionally, Rothermel and Rinehart (1983)[15] provide a graphical interpretation of the greater accuracy of fire prediction in grass fuel types (like the ones at MMR) as compared to more complicated forest environments. For more information on the assumptions and limitations of this model, refer to Rothermel 1972 and Andrews 1986.

[13] Rothermel, Richard C. 1972. A Mathematical Model for Predicting Fire Spread in Wildland Fuels. USDA Forest Service Research Paper INT-115. Intermountain Forest and Range Experiment Station, Ogden, UT.

[14] Andrews, P.L. 1986. BEHAVE: Fire Behavior Prediction and Fuel Modeling System—BURN Subsystem, Part 1. Gen. Tech. Rep. INT-194, 130 p.

[15] Rothermel, Richard C. and Rinehart, George C. 1983. Field Procedures for Verification and Adjustment of Fire Behavior Predictions. Gen. Tech. Rep. INT-142. Intermountain Forest and Range Experiment Station, Ogden, UT, 84401.

The fuel models created here were validated to the greatest extent possible using currently available information. Our primary source has been Sammy Houseberg. While Mr. Houseberg provided us with many valuable insights, it is important to note that his input is based on the experiences of ten years ago. Mr. Houseberg has mentioned several times that his memory of these events may not be entirely accurate. In addition, the fuels at MMR have almost certainly changed in the meantime, possibly affecting the behavior of fires. The model must remain suspect to some degree until validation with replicated test burns can be accomplished.

4.4 Recommendations

The fuel models described in section 4.3.1 are intended as a starting point to be improved upon in the future. In no way should these be interpreted as the final fuel models. The models will have to be validated with test burns and through experience with unplanned ignitions, calibrated if necessary, and re-validated with further burns. The models here have been calibrated as well as possible using the available information. In addition, the grass model has been designed for fuels in their worst case scenario (mature stands) so that it will overestimate fire behavior somewhat. At some point in the future an additional fuel model should be developed that reflects the type of fire behavior typical of the new fuel bed created as the shrub species recover from the last large fire.

Flamelengths calculated by the BEHAVE system were used to initially determine training cutoffs at MMR. These cutoffs have been correlated with BIs using the regression equation established in section 4.3.2 to simplify range control by allowing the range staff to control range operations using BI instead of flame length outputs from BEHAVE. The following table indicates the flame lengths, BIs, and their associated fire index color:

Flame Length (ft)	*Burning Index (BI)*	*Fire Index Color*
0-6	0-22	Green
6-11	22-50	Yellow
11+	50+	Red

Because of the conservative nature of the fuel model used to estimate these flame lengths and their associated BIs, these cutoffs provide a conservative estimate of when training should be allowed on the range. It should be noted that this table represents a baseline. Over the course of the next several years, the Army can expect the training restrictions to become more liberal because experience will be gained with ignition potential and the models will be validated.

The flame lengths in the above table equate approximately with standard cutoffs used by federal wildland fire agencies to estimate fire control difficulties. These cutoffs can be adjusted as experience is gained with the relationship between weather conditions and ignitions. If no fires are started under a set of conditions for a long period of time (months), the upper limit for each category can be increased. However, great caution should be taken when raising the limits of any index category. Sufficient experience must be gained first.

The BIs used for determination of the fire index color should be taken from the RAWS recording the highest BI. Particular attention should be paid to the RAWS on the ridge because high BIs at this station indicate a high probability that any fire that might occur in the native forest or enter this area from below will pose an unacceptable threat to the ridgeline habitat.

We recommend that the Army consider some restrictions to weapons use at MMR. These limitations are based on fire occurrence, which may have been influenced by past restrictions on specific weapons (restricted weapons would have caused fewer fires making them appear in the fire history to be safer than they really are). Therefore, no weapon system should be allowed for use in a fire danger category in which it was not allowed under the range restrictions in September 1998 (the last time the range was open for training). It should be noted that we are not weapons experts and recommendations regarding weapons restrictions are subject to approval by the Army.

Initially, weapons allowed on the range should be restricted to ball ammunition under Green and Yellow conditions. Red conditions will necessitate the closing of the range to training. The restriction to ball ammunition will allow the range staff time to adapt to the new calculations and cutoffs. The time necessary for the range staff to learn the new procedures cannot be estimated, but all systems should be running smoothly and the staff should be competent with all of the fire index determinations and fire suppression measures before any other ammunition is fired on the range.

Once the new operation procedures are well understood by the range staff, the following weapons restrictions should be considered. Under Green conditions all weapons that were authorized for use at MMR in 1998 (excluding tracers) should be allowed since the danger posed by any potential ignition is very low. Yellow conditions warrant the elimination of pyrotechnics, demolition charges, and mines. These weapons each resulted in more than 5% of fires while remaining ignition sources each account for less than 5% of ignitions. By restricting pyrotechnics and demolitions/mines and eliminating tracers, Dragon missiles, and rockets, which have already been voluntarily removed from use by the Army, the probability of fires should be reduced to less than 30% of the historic fire occurrence.

Ball ammunition and indirect fire caused the fewest fires in the past. While fires ignited by the muzzle flash of rifles have accounted for as many fires as pyrotechnics, rifle fire is far more common than pyrotechnics so we would expect more fires to be caused by this source. Also, all muzzle flash ignited fires start within the firebreak (all weapons are required to fire from within the firebreak at targets within the firebreak) and with proper pre-suppression preparation (see section 5) should pose little escape risk. Rockets and indirect fire should, at least initially, be restricted to Green conditions even though these weapons have both accounted for very few fires (3% each). This is based on the fact that these weapons had fairly stiff restrictions on their use in the past. Other weapons that are not included in this report but are used on the range should follow the same restrictions that were placed on them in 1998.

The grass fuel model should be validated using test burns and, if possible, observations made during wildfires. Because burning the forest fuel type is unacceptable, the forest and kukui fuel models will have to be validated using only information that can be obtained during wildfires. Access difficulties and the lack of safety zones for firefighters in forested areas may rule out any validation of the forest model. However, as the goal is to keep fire out of the forest, the inability to validate the forest fuel model is of little consequence. It should be noted that data collected during wildfires will be less reliable as fires at MMR tend to be of sufficient intensity to preclude data collection at the fire front because personnel cannot get close enough to make accurate measurements. Test burns allow personnel to pre-place any necessary measuring devices. This increases the accuracy of the measurements. Data from all types of fires should be collected using the methods outlined by Rothermel and Rinehart (1983).

Fuel Management Options for Makua Military Reservation

5.1 Summary

Fuel management options were discussed on site with Bob Burgan, Francis Fujioka, Pat Costales, Don Studebaker, Sammy Houseberg, Gayland Enriques, and Ron Borne. All existing fuel management techniques were considered for use at MMR, however, many were unacceptable due to the UXO and cultural resource concerns. Fuel modifications and treatments are shown on map 5. Long term refinement and prioritization of fuel treatments may be accomplished with a wildfire prevention analysis (WPA)[16]. There is currently not enough data to support a WPA as several years of reliable information are required. The longer the period of historical information, the better will be the results of the analysis. The fuel management options are listed by priority based on the best available information in regard to values and risks.

It is not the intent of this report to mandate fuel manipulations or other management policies and some of the options given here may exceed Army capabilities for engineering, environmental, cultural, or economic reasons. However, the first three treatments are considered to be of great importance to the preservation of the threatened and endangered species within MMR because they can be implemented immediately and provide significant protection to vulnerable areas.

5.4.1 Continue Current Treatments

Fuel loads within the south firebreak road have been kept down by mowing large portions of the area periodically. This should be continued barring the use of prescribed fire (discussed below) to accomplish the same objective. Helicopter landing zones, staging areas, and areas surrounding buildings and objectives should continue to be mowed as they are presently.

Herbicides are currently boom sprayed up to 10 feet out from the edge of most of the firebreak road. The lack of vegetation within this area is noticeable and this treatment should be continued as a method to widen the firebreak. However, the treatment area should be expanded to include the entire firebreak including the area along the north side of the south firebreak, a section not currently treated. (see section 5.4.5)

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[16] For more information about WPAs contact Pat Durland, Fire Management Specialist at the National Interagency Fire Management Center in Boise, ID.

The firebreak roads are currently in good condition but in several places are in danger of being washed out by erosion induced by heavy rains. The roadside ditches and the road itself should be improved to better dissipate water flow wherever possible.

5.4.2 Prescribe Burn Areas Inside of Firebreaks

Because of the efficiency of fuel removal, prescribed burning should be the primary method utilized to control fuel loads within the firebreak road. Using fire to reduce these fuels instead of mechanical reduction will save time and money. Prescribed fire can be used to treat areas that are impossible to treat with mechanical reduction which support high risk of escape during a wildfire, such as the forested southeast corner of the south firebreak road. The risk of escaped prescribed fires will most likely be counter-balanced by the fact that the entire area inside the firebreak road can be treated, resulting in fewer wildfire escapes.

The area within the south firebreak road should be compartmentalized by improving existing and abandoned roads. These roads should be cleared of all vegetation to a width of no less than 10 ft and graded to the extent necessary for use by both Humvee and standard civilian wildland fire engines. If possible, a single graded road 10 feet wide should be constructed within the north firebreak road to compartmentalize this area. The location of this road should split the north area approximately in half. In addition, the old bulldozer line north of the northernmost extent of the north firebreak road should also be improved. With such a road network in place, compartments can be burned one at a time which will allow much better control of the timing of the prescribed fire in relation to weather conditions and require fewer resources per burn. Each compartment should be burned no less than once per year and more frequently if necessary. The Army may also want to consider widening the existing firebreak in areas of higher escape risk such as the forested southeast corner of the south firebreak.

Prescribed burns outside of the firebreak road have been used in the past to reduce the fuels on and around C-ridge. However, in 1995 an escaped prescribed fire ignited for this purpose led to the decision to restrict prescribed burns to the fuels inside the firebreak. This escape eliminated the possibility of using fire for fuels management elsewhere in the valley.

5.4.3 Treatments Along Farrington Highway

The threat of an ignition along Farrington Highway, either accidental or malicious, is very real. Because the firebreak roads are constructed from a root road at the entrance to the range, any fire starting along the highway will always be outside of the firebreak, and thus, difficult to contain if the ignition occurs under high fire danger conditions. Because of this threat, the fuels along Farrington Highway should be cut as short as possible. In the area where the north ridge meets the highway and the terrain is too steep for mowing, fuels should be cut back as far as possible with weed-whackers. If the terrain is deemed too steep for weed-whacking, boom spraying of herbicide should be utilized to diminish fuel loads as far from the highway as this method permits. This will have to be continued for several years before existing vegetation begins to degrade and the corresponding fuel loads decrease. If an initial cutting of this area can be accomplished followed by consistent herbicide application, this problem will be reduced greatly.

Where the fenceline runs parallel to the highway, all vegetation between the fence and the highway and 10 feet inside of the fence should be cut as low as possible, including vegetation in drainages and low-lying areas. The area between the end of the fence and Makua Cave should be cut as low as possible within 25 feet of the highway. All areas that are cut should be maintained as often as is necessary to keep the vegetation less than 8 inches in height. A dozer line approximately 25 feet in from the highway and 10 to 15 feet wide should be constructed parallel to the highway wherever terrain, UXO, and cultural resources allow. The construction of this dozer line will provide a line of defense against wildfires starting on the highway and allow prescribed burning of the strip of vegetation between the dozer line and the highway. All of the recommendations made within this option assume that environmental and engineering obstacles can be overcome. At a minimum the fuels along the highway fenceline should be cut.

5.4.4 Construct a Firebreak to Protect C-Ridge

A second firebreak should be constructed to provide a second line of defense against fires moving up C-ridge. This area has been of particular concern for fire management because it provides a highly efficient pathway for fire to move into the native forest habitat at the top of the ridge. The firebreak should start at the Y intersection in the firebreak road, continue along the south flank of C-ridge, and tie in with the south firebreak road near its easternmost point (see map 5). Once this break is constructed, fuels within the compartment created between the existing firebreak and the new firebreak should be cut, burned, or grazed, depending on feasibility.

This recommendation assumes that creating a firebreak in this area is both technically possible and sensitive to cultural and environmental resources. A less intrusive fuelbreak could be constructed using handline that doesn't tie into the firebreak road. While this is less likely to stop a fire, it will certainly slow it down. The time gained may give suppression crews the extra advantage needed to contain the fire.

However, firebreak construction and maintenance may not be possible in this area, regardless of the construction techniques used because of steep terrain, UXO, and cultural resources. If this is the case, the Army should mow the flat area immediately surrounding and east of the upper dip pond and north of the south firebreak whenever interior areas are mowed. This will reduce the likelihood of spotting across the firebreak in the direction of C-ridge and thus offer further protection from fires originating within the firebreak.

Constructing a second firebreak road outside of the first (thereby producing a second line of defense) has been considered as an option for several years by the Army but has been repeatedly set back by safety issues, engineering difficulties, and high costs. Sending bulldozers into the impact area to construct a road is not feasible due to UXO and constructing a road across the terrain involved would be a major engineering undertaking. Finally, the cost of such a project, even if safety and engineering issues could be overcome, would most likely be far too expensive to justify.

5.4.5 Herbicide Along the Firebreak

The area between the easternmost end of the south firebreak and the junction with the north firebreak is not currently sprayed with herbicide. This length of road should be added to the herbicide application locations to increase the protection of C ridge from fires occurring within the south firebreak.

Use of herbicides on a larger scale is likely to fail approval of regulatory agencies because of concerns over water quality, contamination of the soil, and fears that the herbicide will drift into sensitive habitats. Additionally, while chemical agents can kill vegetation, the fuel load remains and the situation can actually be worsened since the dead fuel component increases to nearly 100% after application, thus decreasing average fuel moistures and increasing the fire danger. The resulting fuel matrix, if ignited, may very well result in an uncontrollable conflagration.

5.4.6 Grazing

If a livestock owner is willing to risk livestock loss to UXO detonation, cattle or sheep could be grazed at the east end of the north valley lobe and south of the south firebreak road. Because these animals are unlikely to move up slopes greater than 30 degrees, it is unlikely that they will be able to move into areas known to be inhabited by threatened or endangered species. Unfortunately, the biomass consumed by grazing animals may be patchy or inadequate to effectively reduce the fuel load. In addition, the logistics of moving livestock in and out of UXO restricted areas would have to be overcome. However, due to the low cost for this option (the Army would provide the land for free in exchange for the livestock owner assuming the risk of livestock loss), it should be considered as a viable alternative. This alternative would reduce fuel loads outside the firebreak road, and could be even more desirable if implemented in conjunction with burning or mowing in the north firebreak. For this option to be logistically possible the animals in the north valley lobe will probably have to be fenced within the north firebreak. This would negate the main advantage of grazing in this location, which is the ability to treat areas outside of the fuel break, making this option less attractive.

Cattle could graze the entire lower valley since they could be confined to the valley bottom by the topography. However, herding the cattle out of the range before each training session is prohibitively costly and time-consuming. Additionally, few ranchers are willing to accept the risk to their livestock posed by UXO and obtaining enough livestock to effectively reduce fuel loads valley-wide would be difficult.

Further Recommendations

Personnel Qualifications

One of the most frequently cited reasons for the decrease in fire prevention and suppression success in the 1990's has been the lack of a well-trained, devoted fire manager on site at MMR. We recommend that a fire specialist be on site at all times. This individual should be experienced in fire suppression, qualified through S-490 (Advanced Wildland Fire Behavior Calculations), and receive national level fire danger rating training. The individual could also perform other range duties (e.g. Facility Manager) if the Army doesn't want to create a position solely for the purpose of fire management at MMR. The individual would be responsible not only for maintaining the firefighting capabilities of MMR at their optimum levels, but also for the collection of data from wildfires (see sections 4.4 and 1.4). The individual would train those under his/her command in the tactics of wildland fire suppression (e.g. engines, pumps, saws, intermediate fire behavior, etc.). It is highly recommended that the term of this position extend over a multi-year period and that incentives are offered to retain competent individuals for as long as possible. Experience at MMR most likely will result in more effective firefighting and fire prevention capabilities. This position should be filled before any training occurs at MMR.

Operating Procedures

All of the recommendations made within this report assume that future fire managers at MMR will enforce the policies and guidelines suggested here and within the Wildland Fire Management Plan. Without proper enforcement of the BI training restrictions and improved firefighting readiness, fires will continue to burn large areas and threaten valuable natural resources. Additionally, effective data collection must be maintained in order to provide information for calibration of the fire danger rating system and the fuel models to provide the best fire management possible. The fuel models provided in section 4.3.1 are a beginning upon which improvements can certainly be made with information gathered during wild and prescribed fires. The fire danger rating system cutoff values may also be refined using the wildfire prevention analysis referred to in section 5.1. These improvements will further enhance the Army's ability to prevent and suppress wildfire at MMR.

Improved Coordination with Other Agencies

The Army should continue efforts to coordinate pre-suppression and suppression efforts with local, state, and federal agencies. The current agreements with the Federal Fire Department, the National Park Service, and state and local agencies should be strengthened wherever possible. Coordination should include fuels management, particularly with respect to adjoining state lands, as well as suppression efforts.

Conclusions

The challenges of fire management at MMR can be overcome with proper fuel management, effective data collection and analysis, and appropriate fire suppression training and preparedness. Improved fire prevention, resulting from recommendations made in this report combined with restrictions that the Army has already made on authorized weapons at MMR, should reduce fire occurrence to a fraction of historic levels. The Army's elimination of tracers alone will cut ignitions by 50%. The fire danger rating system, which has been greatly improved through fire modeling, will reduce fire starts even further. When combined with the fuel manipulations recommended above, fires that do occur will have little chance of causing any significant damage.

If fuel management (including appropriate future maintenance) is carried out successfully and guidelines from this report are enforced, the fires that do occur will burn under conditions that allow effective fire suppression before endangered species habitat is impacted. Although fire risk can never be eliminated completely, the Army will have improved capabilities for managing the fires that may occur.

Some of our recommendations will not be feasible for engineering, natural resource, cultural, or economic reasons, however, every improvement that is made will further reduce the chances of fires burning critical habitat. By initially proceeding with caution, monitoring conditions under which operations are conducted safely, and improving fire management techniques whenever possible, undesired fire impacts will be reduced and the Army will have the use of MMR as a live fire range for the foreseeable future.

Fire History Records for Makua Military Reservation

Army Fire Report #	Start Date (YYMMDD)	End Date (YYMMDD)	MTC Objective	Grid Coordinates (6 digits only)	Time of Start	Time Out	Acres Burned	Fire Index Color	Burning Index	Escaped Firebreak	Suppression Aircraft Type	Ground Personnel	Ignition Source
.	700805	700807	.	.	900	1400	1525.00	.	.	.	.	17	.
.	750309	750312	.	.	930	1500	370.00	.	.	.	.	14	Incendiary
.	830129	N/A	.	.	.	.	.	.	.	.	.	.	.
.	870514	N/A	.	.	.	.	.	.	.	.	.	.	Rocket
.	870516	N/A	.	.	.	.	.	.	.	.	.	.	Rocket
.	870629	N/A	.	.	.	.	.	.	.	.	.	.	Rocket
.	870726	N/A	.	.	.	.	.	.	.	.	.	.	Tracer
.	870811	N/A	.	.	.	.	.	.	.	.	.	.	Prescribed Fire Escape
.	870919	N/A	.	.	915	1020	.	.	.	.	.	.	Fire Restart
.	871008	N/A	.	.	.	.	.	.	.	.	.	.	.
.	871015	N/A	.	.	1450	1530	.	.	.	.	.	.	.
.	880414	N/A	.	.	1130	1400	.	.	.	.	.	.	.
.	880526	N/A	.	.	905	1030	.	.	.	.	.	.	Flare
.	880526	N/A	.	.	.	.	.	.	.	.	.	.	Star Cluster
.	880607	N/A	.	.	2111	2219	.	.	.	.	.	.	Tracer
.	880623	N/A	.	.	1035	2030	.	.	.	.	.	.	Tracer
.	880702	N/A	.	.	1553	1630	.	.	.	.	.	.	.
.	880723	N/A	.	.	.	.	.	.	.	.	.	.	.
.	880810	N/A	.	.	1210	.	.	.	.	.	.	.	Rocket
.	880818	N/A	.	.	1801	1835	.	.	.	.	.	.	.
.	880827	N/A	.	.	.	.	.	.	.	.	.	.	Rocket
.	880828	N/A	.	.	1335	1920	.	.	.	.	.	.	Rocket
.	880829	N/A	.	.	.	.	.	.	.	.	.	.	Tracer
.	880831	N/A	.	.	1330	1400	.	.	.	.	.	.	Tracer
.	880908	N/A	.	.	.	.	.	.	.	.	.	.	Demolition
.	880922	N/A	.	.	.	.	.	.	.	.	.	.	Tracer
.	881022	N/A	.	.	1409	1627	.	.	.	.	.	.	Rocket
.	881103	N/A	.	.	.	.	.	.	.	.	.	.	Tracer
.	881205	N/A	.	.	2018	2159	.	.	.	.	.	.	Star Cluster
.	881211	N/A	.	.	.	.	750.00	.	.	.	.	.	.
.	890515	N/A	.	EJ804807	1330	2010	60.00	Green	.	No	UH-1, CH-47	70	Dud Detonation (60mm phosphorous)
.	890712	890713	.	EJ825812	955	1145	300.00	Red	.	Yes	UH-1, CH-46	40	Dragon Missile (HE)
.	890721	N/A	.	.	.	.	.	.	.	.	.	.	Pyrotechnics
.	890730	N/A	.	EJ822811	1200	1625	0.25	.	.	Yes	.	.	Pyrotechnics
.	890812	N/A	.	EJ827806	930	1055	2.50	Red	.	Yes	UH-1	20	Tow Missile
.	890816	N/A	DEER	.	1120	1130	0.03	Red	.	.	.	24	Mine
.	890816	890817	.	.	2315	45	.	.	.	.	.	.	Unknown (Highway)
.	890826	N/A	.	EJ797804	200	.	0.03	.	.	.	.	.	Unknown
.	890912	N/A	.	EJ815811	1208	1216	0.01	Red	.	.	.	.	Dragon Missile (HE)
.	890913	N/A	.	EJ816811	1225	1245	0.01	Red	.	.	None	3	Dragon Missile (HE)
.	890913	N/A	.	EJ812811	1425	1450	0.01	Red	.	.	UH-1	6	Dragon Missile (HE)
.	890915	N/A	.	EJ814812	1146	1300	0.01	Red	.	No	UH-1	3	Dragon Missile (HE)
.	890920	N/A	.	EJ805808	859	904	0.01	.	.	.	None	2	Bangalore
.	890920	N/A	.	EJ806808	1150	1159	0.01	Red	.	.	None	6	Smoke Grenade

Appendix 1

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Army Fire Report #	Start Date (YYMMDD)	End Date (YYMMDD)	MTC Objective	Grid Coordinates (6 digits only)	Time of Start	Time Out	Acres Burned	Fire Index Color	Burning Index	Escaped Firebreak	Suppression Aircraft Type	Ground Personnel	Ignition Source
.	890922	N/A	.	EJ820810	1453	1503	0.01	.	.	.	.	3	Demolition
.	890927	N/A	.	EJ817818	1200	1205	0.10	Red	.	.	None	20	.
.	891016	N/A	.	EJ810823	1230	1305	0.01	Red	.	.	None	3	5.56mm Ball Ammunition
.	891122	N/A	.	.	1030	1040	0.01	Yellow	.	.	None	5	Tracer
.	891127	N/A	.	.	1515	1600	0.40	Yellow	.	.	UH-1	20	Tracer
.	891128	N/A	.	EJ809817	1545	1700	0.01	Yellow	.	No	CH-47	20	Tracer
.	891128	N/A	.	EJ810816	1545	1700	0.01	Yellow	.	Yes	CH-47	20	Tracer
.	891128	N/A	.	EJ805814	1545	1700	0.01	Yellow	.	Yes	CH-47	20	Tracer
.	891208	N/A	.	EJ827806	930	1055	2.50	Red	.	Yes	UH-1	20	TOW Missile
.	900000	N/A	.	.	1330	1345	0.10	Red	.	.	None	3	Claymore Mine
.	900000	N/A	.	.	1535	1625	0.10	Red	.	.	UH-1	4	Demolition
.	900110	N/A	.	EJ809819	925	1130	5.50	Yellow	.	Yes	UH-60	0	Tracer
.	900110	N/A	.	EJ802811	1028	1300	1.25	Yellow	.	No	UH-60	20	Tracer
.	900110	N/A	.	EJ815812	1331	1800	225.00	Yellow	.	.	UH-60	30	Tracer
.	900110	N/A	.	.	1615	1810		.	.	No	.	.	.
.	900111	N/A	.	EJ807808	1400	1412	0.10	Yellow	.	No	UH-60	0	Dragon Missile (HE)
.	900111	N/A	.	EJ813805	1445	1800	0.60	Yellow	.	No	UH-60	.	Tracer
.	900204	N/A	.	EJ819811	1220	1230	0.01	Yellow	.	No	None	3	Tracer
.	900204	N/A	.	EJ820810	1220	1235	0.01	Yellow	.	No	None	1	Tracer
.	900204	N/A	.	EJ818811	1240	1245	0.01	Yellow	.	No	None	3	Tracer
.	900204	N/A	.	EJ819811	1240	1245	0.01	Yellow	.	No	None	3	Tracer
.	900204	N/A	.	EJ821810	1300	1315	0.10	Yellow	.	Yes	UH-1	13	Tracer
.	900204	N/A	.	EJ819811	1350	1405	0.01	Yellow	.	No	None	3	Tracer
.	900204	N/A	.	EJ819811	1418	1425	0.01	.	.	No	None	3	.
.	900205	N/A	.	EJ823818	1030	1045	0.15	Yellow	.	Yes	None	3	Tracer
.	900205	N/A	.	EJ819811	1110	1120	0.10	Yellow	.	No	None	3	Tracer
.	900205	N/A	.	EJ821810	1119	1128	0.10	Yellow	.	No	None	4	Tracer
.	900205	N/A	.	EJ819811	1145	1155	0.10	Yellow	.	No	None	3	Tracer
.	900205	N/A	.	EJ819810	1230	1240	0.10	Yellow	.	No	None	3	Tracer
.	900206	N/A	.	EJ818810	1232	1300	0.10	Yellow	.	No	UH-1	4	Tracer
.	900206	N/A	.	EJ820810	1326	1334	0.01	Yellow	.	No	None	1	Tracer
.	900206	N/A	.	EJ811811	1445	1500	0.10	Yellow	.	No	None	2	Tracer
.	900317	N/A	.	EJ809816	1340	1440	0.10	Yellow	.	Yes	UH-1	0	Tracer
.	900317	N/A	.	EJ806813	1540	1550	0.01	Yellow	.	No	None	2	Tracer
.	900318	N/A	.	EJ806813	1345	1440	0.10	Yellow	.	No	UH-1	5	Tracer
.	900330	N/A	.	EJ801811	.	1310	0.10	Yellow	.	No	UH-1	15	Dragon Missile (HE)
.	900330	N/A	.	EJ807808	.	1310	0.75	Yellow	.	No	UH-1	15	Dragon Missile (HE)
.	900411	N/A	.	EJ813812	1347	1400	0.10	Yellow	.	.	None	10	Tracer
.	900411	N/A	.	EJ817811	1348	1353	0.01	Yellow	.	No	None	1	Tracer
.	900411	N/A	.	EJ819811	1515	1550	0.10	Yellow	.	No	None	11	Tracer
.	900524	N/A	.	.	1438	1515	.	.	.	Yes	.	.	Unknown
.	900529	N/A	.	.	908	926	.	.	.	.	UH-1	.	Dragon Missile (HE)
.	900611	N/A	.	EJ805815	1240	1255	0.10	Red	.	No	Unknown	4	Tracer
.	900611	N/A	.	EJ800813	1330	.	9.00	Red	.	.	Unknown	50	Tracer
.	900704	N/A	.	EJ798850	1740	.	9.00	Red	.	Yes	Civilian	0	Unknown
.	900719	N/A	.	.	2113	2332	.	Red	.	.	UH-60	50	Tracer
.	900720	N/A	.	EJ819811	1055	1300	0.20	Red	.	.	UH-1, UH-60	47	Tracer

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Army Fire Report #	Start Date (YYMMDD)	End Date (YYMMDD)	MTC Objective	Grid Coordinates (6 digits only)	Time of Start	Time Out	Acres Burned	Fire Index Color	Burning Index	Escaped Firebreak	Suppression Aircraft Type	Ground Personnel	Ignition Source
.	900720	N/A	.	.	1156	1422	.	.	.	No	.	.	.
.	900801	N/A	.	.	1030	1040	0.01	Red	.	.	None	2	Dragon Missile (HE)
.	900802	N/A	.	.	1327	1340	0.01	Red	.	.	None	3	Claymore Mine
.	900810	N/A	.	.	1400	1415	0.01	Red	.	.	UH-1	1	Claymore Mine
.	900816	N/A	.	.	1020	800	0.01	Red	.	.	UH-1	120	Smoke Grenade
.	900820	N/A	.	EJ819811	1510	1545	0.10	Red	.	No	None	20	Demolition
.	900829	N/A	.	EJ803811	1220	1310	0.10	Red	.	No	.	9	Ball Ammo
.	900829	N/A	.	EJ806812	1500	.	800.00	Red	.	.	Unknown	.	Ball Ammo
.	900902	N/A	.	.	1130	1135	0.01	Red	.	.	None	2	Dragon Missile (HE)
1	901020	N/A	.	.	115	630	15.00	Red	13	Yes	Hughs 500	6	Non-Military
.	901020	N/A	.	.	851	1445	.	.	.	.	.	.	.
11,0	901103	901104	.	.	2355	20	2.00	Red	15	Yes	None	6	Off Post
11,1	901104	N/A	.	.	1930	2205	12.00	Orange	20	Yes	Hughes 500	23	Non-Military
11,2	901105	901106	.	.	1422	300	0.50	Red	11	Yes	None	8	Non-Military
11,3	901105	N/A	.	.	1440	1730	240.00	Red	11	Yes	UH-60, CH-47, Unknown	80	Non-Military
.	901105	N/A	.	.	1525	1920	.	.	.	.	.	.	.
11,4	901107	N/A	.	.	600	1100	0.50	Red	13	Yes	UH-1, UH-60, Hughes 500	6	Restart
11,5	901109	901110	.	.	1520	1230	47.00	Red	17	Yes	CH-47, Unknown	16	Restart
.	901109	901110	.	.	2051	111	.	.	.	.	.	.	.
.	901110	N/A	.	.	654	900	.	.	.	.	.	.	.
91-01	910116	N/A	.	.	1010	1015	0.01	.	.	No	None	2	Dragon Missile (HE)
91-02	910207	N/A	.	.	2045	2055	0.02	.	5	Yes	None	4	Tracer
91-04	910227	N/A	.	.	1501	1543	0.54	.	8	Yes	Unknown	3	Tracer
91-05	910330	N/A	.	.	1520	1615	0.49	.	3	No	None	1	Tracer
91-06	910330	N/A	.	.	1720	1753	0.07	.	3	No	None	4	Tracer
91-07	910401	N/A	.	EJ814816	1545	2030	20.00	.	3	Yes	2 UH-1, CH-47	17	Tracer
91-03	910414	N/A	.	.	2120	2224	3.00	.	5	No	UH-60	7	Tracer
91-08	910423	N/A	.	.	1350	1358	0.01	.	8	No	Unknown	2	Ball
91-09	910430	N/A	.	.	1341	1354	0.04	.	23	Yes	None	5	Ball
91-09	910501	N/A	.	EJ826812	1341	2320	71.66	.	19	Yes	UH-1, UH-60, CH-47	47	Tracer
91-10	910501	N/A	.	EJ825809	1341	1800	14.83	.	19	Yes	UH-1, CH-47	.	
91-11	910507	N/A	.	.	1240	1249	0.01	.	3	Yes	None	2	Tracer
91-12	910529	N/A	.	EJ801810	1305	1310	0.00	.	14	No	None	1	Tracer
91-13	910530	N/A	.	EJ803811	951	1002	0.00	.	25	No	None	4	Tracer
91-14	910530	N/A	.	EJ802810	1259	1313	0.00	.	25	No	None	2	Tracer
.	910622	N/A	.	.	1530	1645	.	.	.	.	.	.	.
91-16	910715	N/A	.	EJ801811	1545	1620	0.02	.	47	No	None	3	Tracer
91-17	910715	N/A	.	EJ804811	1548	1625	0.10	.	47	No	None	3	Tracer
91-18	910715	N/A	.	EJ806812	1553	1630	0.06	.	47	No	None	3	Tracer
91-19	910715	N/A	.	EJ803810	1710	1730	0.12	.	47	No	None	2	Tracer
91-20	910716	N/A	.	.	1122	1137	0.00	.	47	No	None	None	Tracer
91-21	910716	N/A	.	.	1123	1136	0.00	.	47	No	None	None	Tracer
91-22	910716	910717	.	EJ826808	1240	100	75.00	.	47	Yes	2 UH-1, CH-47, Hughes 500	17	Tracer
91-23	910717	N/A	.	EJ839803	1226	1240	0.10	.	34	No	UH-1	8	Gunship (Tracer)
91-24	910717	N/A	.	EJ806811	1530	1615	1.11	.	46	No	UH-1	23	Tracer
91-25	910718	N/A	.	.	1007	1011	0.00	.	46	No	None	3	Tracer
91-26	910723	N/A	.	.	1355	1415	0.10	.	39	No	None	None	Ball

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91-27	910724	N/A	.	.	1335	1415	0.25	.	39	No	UH-1	8	Tracer
91-28	910725	N/A	.	.	1251	1255	0.00	.	28	No	None	3	Tracer
91-29	910725	N/A	.	.	1421	1510	0.03	.	22	No	None	3	Tracer
91-30	910725	N/A	.	EJ818807	1422	1900	400.00	.	22	No	UH-1	3	Demolition
.	910727	N/A	.	.	1452	1844	.	.	.	.	.	.	.
91-31	910731	N/A	.	.	1527	1841	1.00	.	25	Yes	UH-1, CH-47, Hughes 500	15	Off Post
91-32	910801	N/A	.	.	450	1010	1.00	.	25	Yes	UH-1, CH-47, Unknown	12	Ball
.	910801	N/A	.	.	1400	1745	.	.	.	.	.	.	.
91-33	910802	N/A	.	.	1030	1045	0.02	.	34	No	None	2	Demolition
91-34	910822	N/A	.	.	1320	1410	0.10	.	30	No	None	22	Tracer
91-33	910822	N/A	.	.	1515	1600	0.25	.	30	No	None	3	Tracer
.	910827	N/A	.	.	300	450	.	.	.	.	.	.	.
91-35	910828	N/A	.	.	245	.	0.10	.	40	Yes	None	None	Non-Military
.	910828	N/A	.	.	1230	1550	.	.	.	.	.	.	Restart
.	910902	N/A	.	.	1644	1702	.	.	.	.	.	.	.
91-36	910903	N/A	.	.	1410	1425	0.05	.	24	No	None	17	Demolition
91-37	910903	N/A	.	.	1531	1757	7.00	.	22	No	UH-1, CH-47	40	Demolition
91-38	910904	N/A	.	.	1329	1905	3.50	.	23	No	UH-1	14	Dragon Missile (HE)
91-39	910904	910905	.	.	1627	600	75.00	.	23	No	UH-1, UH-60	11	Indirect Fire
.	910909	N/A	.	.	804	1130	.	.	.	.	.	.	.
91-40	910909	N/A	.	.	1105	1200	9.25	.	52	Yes	UH-1	6	Tracer
91-41	910909	N/A	.	.	1450	1630	0.50	.	37	Yes	UH-1	5	Non-Military
91-42	910912	N/A	.	.	855	1345	98.00	.	14	Yes	UH-1, CH-46	26	Tracer
91-43	910912	N/A	.	.	2205	2330	2.00	.	14	Yes	None	1	Non-Military
91-44	910917	N/A	.	.	1518	1620	0.25	.	27	No	UH-1	6	Ball
91-45	910923	N/A	.	EJ815813	1040	1102	0.01	.	24	No	None	2	Tracer
91-46	910924	N/A	.	.	1710	1725	0.25	.	26	Yes	UH-60	6	Unknown
91-47	910924	N/A	.	.	1734	1825	5.00	.	26	Yes	UH-60	None	Unknown
91-48	911010	N/A	.	.	1210	1220	1.00	.	25	No	None	6	Pyrotechnics
91-49	911010	N/A	.	.	1405	1412	0.00	.	28	No	None	2	Ball
91-50	911010	N/A	.	.	2240	2315	0.25	.	26	No	None	22	Dragon Missile (HE)
91-51	911107	N/A	.	.	1216	1230	0.00	.	37	Yes	None	3	Off Post
91-52	911217	N/A	.	.	1045	1235	0.05	.	39	No	None	9	Tracer
91-53	911217	N/A	.	.	1310	1400	0.17	.	17	No	None	4	Tracer
91-54	911217	N/A	.	.	1310	1400	0.01	.	17	No	None	4	Tracer
91-55	911217	N/A	.	.	1310	1400	0.15	.	17	No	None	4	Tracer
.	920604	N/A	.	.	1800	1835	.	.	.	.	.	.	.
93-01	930114	N/A	.	.	1434	1439	0.00	Red	22	No	None	4	Non-Military (Charcoal)
93-02	930119	N/A	.	.	1410	1422	0.01	Yellow	19	No	None	2	Dragon Missile (HE)
93-03	930119	N/A	.	.	1418	1434	0.00	Yellow	19	No	None	1	Tracer
93-04	930119	N/A	.	.	1550	1610	0.06	Yellow	19	No	None	1	Tracer
93-05	930119	N/A	.	.	1620	1638	0.00	Yellow	19	No	None	2	Tracer
93-06	930120	N/A	.	.	1408	1416	0.01	Orange	30	No	None	2	Dragon Missile (HE)
93-07	930120	N/A	.	.	1408	1422	0.00	Orange	30	No	None	2	Dragon Missile (HE)
93-08	930123	N/A	.	.	1350	1359	0.00	Yellow	19	No	None	1	Tracer
93-09	930123	N/A	.	.	1443	1458	0.01	Yellow	18	No	None	1	Tracer
93-10	930124	N/A	.	.	1206	1210	0.00	Yellow	18	No	None	1	Tracer

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93-11	930124	N/A	.	.	1215	1222	0.00	.	.	No	None	1	Tracer
93-12	930124	N/A	.	.	1345	1400	0.25	Yellow	18	No	UH-1	3	Tracer
93-13	930216	N/A	.	.	1418	1420	0.00	Red	21	No	None	5	Pyrotechnics
93-14	930218	N/A	.	.	1525	1530	0.00	Red	23	No	None	3	Tracer
93-15	930218	N/A	.	.	1720	1730	0.01	Red	23	No	None	8	Tracer
93-16	930223	N/A	.	.	1325	1415	2.00	Orange	32	No	UH-1	7	Tracer
93-17	930225	N/A	.	.	2308	2340	0.01	Orange	32	No	UH-1	3	Dragon Missile (HE)
93-18	930302	N/A	.	.	1420	1450	0.20	Orange	39	No	UH-1	6	Dragon Missile (HE)
93-19	930304	N/A	.	.	1230	1500	11.12	Orange	39	No	UH-1	24	Mortar
93-22	930309	N/A	.	.	1132	1215	6.40	Yellow	30	No	UH-1	None	Pyrotechnics
93-20	930311	N/A	.	.	915	948	1.30	Red	22	No	UH-1	5	Tracer
93-21	930314	N/A	.	.	1859	1910	0.01	Yellow	21	No	None	1	Dragon Missile (HE)
93-22	930412	N/A	.	.	1415	1730	123.58	Orange	34	No	UH-1, CH-46	23	Tracer
93-23	930412	N/A	.	.	1415	1425	0.10	Orange	34	No	None	2	Tracer
93-24	930412	N/A	.	.	1415	1735	20.00	Orange	34	Yes	UH-1	38	Off Post (Malicious)
93-25	930413	N/A	.	.	1250	1515	46.27	Orange	34	No	UH-1	25	Demolition
93-26	930420	N/A	.	.	900	905	0.25	Yellow	18	No	None	4	Ball
93-27	930421	N/A	.	.	1120	1700	9.00	Orange	42	No	UH-1	2	Mortar
93-28	930422	N/A	.	.	1145	1430	100.00	Orange	42	No	UH-1	18	Dragon Missile (HE)
93-29	930423	N/A	.	.	1600	1800	0.30	Red	22	No	None	2	Dragon Missile (HE)
93-30	930428	N/A	.	.	1645	1715	0.25	Yellow	15	No	UH-1	3	Dragon Missile (HE)
93-33	930510	N/A	.	.	1505	1508	0.30	Red	28	No	None	2	Dragon Missile (HE)
93-34	930511	N/A	.	.	1420	1430	0.09	Orange	34	No	None	2	Dragon Missile (HE)
93-35	930512	N/A	.	.	1615	1621	0.01	Red	23	No	None	6	Dragon Missile (HE)
93-36	930525	N/A	.	.	1605	1705	3.95	Orange	33	No	UH-1	5	Indirect Fire
93-37	930526	N/A	.	.	1522	1543	0.25	Yellow	15	No	UH-1	6	Tracer
93-38	930526	N/A	.	.	1522	1600	0.17	Yellow	15	No	UH-1	6	Tracer
93-39	930616	N/A	.	.	1950	2020	0.22	Red	27	No	UH-1	5	Mortar, 81mm
93-40	930617	N/A	.	.	35	140	0.50	Red	27	Yes	UH-1	4	Tracer
93-41	930626	N/A	.	.	1245	2330	5.35	Red	23	Yes	UH-1, UH-60, CH-53	48	MK19 TPT
93-42	930718	N/A	.	.	2225	2335	0.25	Yellow	11	No	UH-60	4	Dragon Missile (HE)
93-43	930818	N/A	.	.	1210	1220	0.25	Yellow	16	No	None	3	Practice SMAW
93-44	931014	N/A	.	.	815	830	0.02	Red	21	No	UH-1	17	Dragon Missile (HE)
93-45	931115	N/A	.	.	1800	1825	0.26	Yellow	16	No	UH-60	2	Tracer
93-46	931116	N/A	.	.	1030	1039	80.92	Yellow	16	No	UH-1	None	Tracer
93-47	931213	N/A	.	.	1641	1732	0.25	Yellow	16	Yes	UH-1	6	Tracer
94-01	940106	N/A	.	.	1613	1715	1.00	Yellow	19	No	UH-60	5	Tracer
94-02	940204	940205	.	.	2020	30	18.00	Yellow	14	No	UH-60	34	Tracer
94-03	940206	N/A	.	.	2205	2350	7.40	Yellow	17	No	UH-60	28	Tracer
94-04	940208	N/A	.	.	2255	2325	0.03	Yellow	18	No	UH-60	4	Tracer
94-05	940210	N/A	.	.	240	310	0.01	Yellow	15	No	UH-60	3	Dragon Missile (HE)
94-06	940211	N/A	.	.	1220	1240	0.90	Yellow	17	No	UH-60	4	Tracer
94-07	940211	N/A	.	.	1805	1900	2.50	Yellow	18	No	UH-60	23	Tracer
94-08	940211	940212	.	.	2343	27	0.22	Yellow	18	No	UH-60	4	Dragon Missile (HE)
94-09	940308	N/A	.	.	1735	1809	0.90	Yellow	16	Yes	UH-60	3	Tracer
94-10	940329	N/A	.	.	1800	1845	0.25	Green	10	No	None	3	Tracer
94-11	940330	940331	.	.	2315	35	1.10	Green	7	Yes	UH-60	6	Tracer

Note: Unavailable Information indicated by "."

Army Fire Report #	Start Date (YYMMDD)	End Date (YYMMDD)	MTC Objective	Grid Coordinates (6 digits only)	Time of Start	Time Out	Acres Burned	Fire Index Color	Burning Index	Escaped Firebreak	Suppression Aircraft Type	Ground Personnel	Ignition Source
94-12	940406	N/A	.	.	1145	1845	6.79	Yellow	18	No	3 UH-60, 2CH-47	65	Tracer
94-13	940406	N/A	.	.	1155	1845	217.50	Yellow	18	Yes	3 UH-60, 2CH-47	65	Tracer
94-14	940407	N/A	.	.	1152	1352	0.90	Red	24	No	None	3	Indirect Fire
94-15	940414	N/A	.	.	733	820	1.40	Yellow	20	No	None	12	Tracer
94-16	940414	N/A	.	.	2029	2055	0.02	Yellow	19	No	None	8	Tracer
94-17	940523	N/A	.	.	858	931	1.70	Yellow	15	Yes	UH-60	4	Tracer
94-18	940608	940609	.	.	2130	220	0.11	Yellow	19	No	2 UH-60	9	Tracer
94-19	940609	N/A	.	.	1940	2200	13.00	Red	29	No	UH-60	9	Demolition
94-20	940620	N/A	.	.	852	1130	88.98	Yellow	15	No	2 UH-60	30	Tracer
94-21	940620	N/A	.	.	1225	1320	3.56	Yellow	15	No	UH-60	7	Tracer
94-22	940706	N/A	.	.	1555	1800	0.00	Orange	35	Yes	UH-60	51	Off Post (Malicious)
94-23	940712	N/A	.	.	2250	2310	0.05	Yellow	15	Yes	None	3	Tracer
94-24	940819	N/A	.	.	1045	1744	181.00	Red	26	Yes	2 UH-60, CH-53	61	TOW Missile
94-25	940915	N/A	.	.	2020	2027	0.05	Yellow	15	No	None	3	20mm Tracer
95-01	950201	N/A	.	.	1615	1642	0.25	Red	24	No	UH-60	10	Dragon Missile (HE)
95-02	950202	N/A	.	.	1641	1655	0.00	Red	21	No	None	12	Dragon Missile (HE)
95-03	950212	N/A	.	.	925	1020	0.25	Yellow	17	No	None	2	Tracer
95-04	950222	N/A	.	.	1515	1800	0.26	Red	22	No	CH-47	6	Demolition
95-05	950316	N/A	.	.	205	240	0.01	Green	9	Yes	UH-60	None	Tracer
95-06	950601	N/A	.	.	2042	2100	0.20	Red	29	No	UH-60	8	Dragon Missile (HE)
.	950614	950616	.	.	115	605	2400.00	.	.	Yes	.	.	Escaped Prescribed Fire
95-07	950716	N/A	.	.	1340	1500	2.02	.	.	No	None	2	Tracer
95-08	950813	N/A	.	.	910	1045	7.41	Yellow	19	No	UH-60	49	Tracer
95-09	950815	N/A	.	.	910	1055	0.00	Yellow	13	No	None	21	Tracer
.	951006	N/A	.	.	1120	1830	350.00	.	.	.	3 Unknown	331	.
.	960423	N/A	.	EJ185811	1831	2000	0.25	.	.	.	.	.	Tracer
.	960508	N/A	.	EJ804807	1015	1405	0.15	Yellow	17	.	2 UH-60	9	20 mm TPT
.	960527	N/A	.	.	1130	1430	.	.	.	.	.	.	.
.	960530	N/A	.	EJ816809	1100	1145	0.25	Yellow	11	.	None	9	Tracer
.	960531	N/A	.	.	915	1035	0.50	Yellow	15	No	CH-47	1	Tracer
.	960604	N/A	.	.	1010	1130	0.25	Yellow	15	No	CH-47	2	Tracer
.	960605	N/A	.	EJ814811	455	528	0.25	.	.	.	.	.	Tracer
.	960724	N/A	.	EJ804807	1600	1635	0.25	Yellow	20	.	None	9	Tracer
.	960724	N/A	.	EJ804807	1645	1655	0.25	Yellow	20	.	None	9	Tracer
.	960724	N/A	.	EJ804807	1720	1735	0.26	Yellow	20	.	None	9	Tracer
.	960814	N/A	.	EJ818800	1735	1810	0.25	Red	27	.	UH-60	6	TOW Missile
.	960918	N/A	.	EJ802809	1540	1840	0.25	Yellow	18	No	CH-53	6	Ball
97-01	970128	N/A	.	EJ812805	1205	1252	0.25	.	.	No	None	.	Tracer
97-02	970128	N/A	.	EJ807805	1530	1711	0.50	.	.	No	CCH-53	.	Tracer
97-03	970129	N/A	.	EJ809802	1105	1230	0.25	.	.	No	None	.	Tracer
94-04	970211	N/A	.	EJ807805	1330	1410	0.25	.	.	No	None	.	Tracer
94-05	970211	N/A	.	EJ806804	1458	1653	0.25	.	.	No	UH-60	.	Tracer
94-06	970228	N/A	.	EJ808805	1510	1845	2.96	.	.	No	None	.	Tracer
94-07	970331	N/A	.	EJ808804	1350	1400	0.00	.	.	No	None	.	Grenade Simulator
94-08	970401	N/A	.	EJ813801	805	915	0.25	.	.	No	CH-46	.	Tracer
94-09	970401	N/A	.	EJ812802	1105	1215	0.25	.	.	No	CH-46	.	Tracer
94-10	970401	N/A	.	EJ811801	1320	1402	1.00	.	.	No	CH-46	.	Tracer

Note: Unavailable Information indicated by "."

Appendix 1

Army Fire Report #	Start Date (YYMMDD)	End Date (YYMMDD)	MTC Objective	Grid Coordinates (6 digits only)	Time of Start	Time Out	Acres Burned	Fire Index Color	Burning Index	Escaped Firebreak	Suppression Aircraft Type	Ground Personnel	Ignition Source
94-11	970417	N/A	.	EJ806807	1130	1200	0.50	.	.	No	None	.	Tracer
94-12	970417	N/A	.	EJ807807	1130	1200	0.50	.	.	No	None	.	Tracer
94-13	970417	N/A	.	EJ811807	1130	1200	0.25	.	.	No	None	.	Tracer
94-14	970417	N/A	.	EJ822811	1140	1320	1.00	Yellow	15	No	UH-60	None	Tracer, Spot Fire
94-15	970513	N/A	.	EJ811807	901	936	1.50	.	.	No	None	.	Tracer
94-16	970516	N/A	.	EJ812804	920	1020	0.50	.	.	No	None	.	Tracer
94-17	970517	N/A	.	EJ818808	1350	1410	1.50	.	.	No	None	.	Mortar (HE)
94-18	970525	N/A	.	EJ818808	1010	1042	0.25	.	.	No	None	.	Tracer
94-19	970525	N/A	.	EJ807813	1400	1430	0.25	.	.	No	None	.	Tracer
94-20	970627	N/A	None	EJ820806	1800	1845	2.00	Red	26	No	UH-60	.	Demolition/Explosives
94-21	970725	N/A	.	EJ817815	1100	1200	1.00	.	.	No	None	.	Demolition
94-22	970725	N/A	.	EJ806816	1345	1415	0.50	Red	21	No	UH-60	.	Demolition
94-23	970729	N/A	.	EJ820804	1450	1820	20.00	Yellow	19	No	3 UH-60	12	Ball
94-24	970731	N/A	.	EJ818804	1455	1535	10.00	Yellow	19	No	2 UH-60	2	Ball
94-25	970731	N/A	.	EJ821806	2153	2248	0.25	Yellow	14	No	UH-60	5	Tracer
94-26	970805	N/A	.	EJ821807	820	945	2.00	Yellow	18	No	UH-60	.	Tracer
94-27	970805	N/A	.	EJ819812	2110	2145	0.25	Yellow	17	No	None	2	Tracer
94-28	970809	N/A	.	EJ819806	746	810	0.25	Yellow	10	No	None	2	Tracer
94-29	970809	970810	.	EJ824803	2125	25	2.00	Yellow	14	Yes	2 UH-60	9	AT-4
94-30	970813	N/A	.	EJ822806	2111	2142	1.00	Yellow	17	No	None	.	Tracer
94-31	970819	N/A	.	EJ812802	1820	1850	0.25	Red	24	No	None	3	Mortar 60mm
94-32	970906	N/A	.	EJ805807	1340	1640	5.00	Yellow	15	No	CH-46, 2 UH-60	20	Tracer
94-33	970907	N/A	.	EJ806804	1400	2000	3.00	Orange	35	No	UH-60	4	Restart
94-34	970908	N/A	.	EJ824803	925	1225	3.00	Yellow	14	Yes	2 UH-60	9	AT-4, Tracer
97-34	970925	N/A	.	EJ820808	52	110	0.50	Yellow	18	Yes	None	3	Tracer
97-35	971112	N/A	.	EJ816804	2052	2116	0.30	.	.	No	.	.	TPT, 20mm
98-01	980123	N/A	DEER	EJ818807	1700	1724	0.50	Yellow	19	No	None	.	AT-4
98-02	980130	N/A	COYOTE	EJ809806	2320	2345	1.00	Yellow	17	No	UH-60	.	Tracer
98-03	980211	N/A	ELK	EJ818805	1245	1351	0.25	Red	23	No	UH-60	.	Tracer
98-04	980225	N/A	DEER	EJ814808	1605	1615	0.25	Yellow	16	No	None	.	Tracer
98-05	980225	N/A	DEER	EJ819802	1630	1645	0.25	Yellow	16	No	None	.	Tracer
98-06	980227	N/A	DEER	EJ817806	1441	1520	2.00	Yellow	20	No	UH-60	.	Tracer
98-07	980227	N/A	DEER	EJ820808	1535	1550	0.25	.	.	No	None	.	Tracer
98-08	980227	N/A	DEER	EJ819808	1630	1642	0.25	Yellow	18	No	None	.	Tracer
98-09	980307	980308	.	EJ802821	1730	1000	100.00	Yellow	20	Yes	UH-60	2	Off Post
98-10	980318	N/A	.	EJ803805	1040	1430	50.00	Orange	40	Yes	CH-47, UH-60, CH-53	62	Tracer, Grenade Simulator
98-11	980318	N/A	.	EJ825806	1750	2218	30.00	Red	26	Yes	UH-60	3	TOW Missile
98-12	980618	N/A	DEMO PIT	EJ819805	1030	1033	0.01	Orange	32	No	None	.	Demolition
98-13	980722	N/A	.	EJ798814	1345	1445	1.00	Orange	32	Yes	None	3	Off Post (Malicious)
.	980805	N/A	.	.	1645	1810	.	.	.	.	.	.	.
98-14	980914	N/A	FP	EJ801807	915	1200	4.00	Red	26	No	CH-53	.	Mortar, 81mm (HE)
98-15	980914	N/A	.	EJ801807	1755	1900	.	Orange	46	No	None	.	Restart
98-16	980915	N/A	.	EJ801807	700	745	0.01	Yellow	21	No	None	.	Restart
98-17	980915	N/A	.	EJ816811	1310	1350	0.75	Orange	38	No	None	.	Restart
98-18	980916	N/A	FP	EJ815815	840	2200	800.00	Yellow	19	Yes	CH-47, UH-60, CH-53, 2 CH-60	71	Mortar, 60mm (HE)
98-19	980917	N/A	.	EJ825814	1254	1634	0.01	.	.	Yes	CH-47	None	Restart

Note: Unavailable Information indicated by "."

US Army Hawaii (USARHAW)
Fire Behavior Modeling/Danger Rating Consultation*

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September 17, 1999

Francis Fujioka (USDA Forest Service, PSW) and Robert Burgan (USDA Forest Service, IFSL, retired) visited the Makua Military Reservation, Oahu, on August 13, 1999, in the company of Gayland Enriques (USAR Hawaii), Pat Costales (DOFAW, Oahu Branch Manager), and Andy Beavers (CSU fire ecologist). The purpose of this visit was to review the Army's efforts toward managing and minimizing the wildland fire risk.

Our first stop was the Remote Automatic Weather Station (RAWS) site on Makua Ridge. This is an excellent location for a RAWS unit to monitor the conditions in the forested areas. It also provided an excellent vantage point from which to discuss the wildland fire situation. It was immediately obvious to Fujioka and Burgan, and certainly not news to the others, that it is not possible to make a 100 percent guarantee that all fires can be confined to the lower valley. However this report does discuss minimizing the risk.

We discussed not only the ignition potential from military activities, but also the potential of fire starts from civilian activity along the highway. While civilian ignition sources are not as frequent as military sources, neither are they under any sort of control. Thus they may occur at a time of very high fire danger and when suppression capability is at a minimum. We could not define a strong defense against this threat. The obvious solution of building a firebreak parallel to the highway was not acceptable for archeological and social reasons. Neither was the option of grazing. The potential for fires to burn into the Makua Training Area from outside was summarized with the comment that about all the Army can do is respond the best they can when a fire occurs.

We also noted lanes of grass passing through the upper forested areas from below. These grasses apparently invaded because of damage from past fires. At this point there doesn't seem to be much that can be done other than to minimize further burning and encroachment. The high elevation RAWS station should be very useful for determining the potential for fire to enter the forest from below, thus providing key information on when field exercises would pose an unacceptable risk to the forest.

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* Note: In the period between the writing of this consultation and the finalization of the Analysis of Fire Management Concerns at MMR report, a number of changes were made to the recommendations within this consultation because of changes in Army policy and the discovery of new information. For these reason, recommendations made in this consultation may not appear or may differ from those in the Analysis of Fire Management Concerns at MMR report.

After completing discussions at the upper RAWS site, we met Ron Borne at the range officers' building near the highway. Ron gave us a good history of how the current situation developed and of the importance of getting training exercises established. We then drove the firebreak road around the training area, stopping to look at the midvalley water reservoir, the micro-RAWS, and the vegetation. Gayland pointed out the areas that have been mowed in the past, and the areas where the vegetation is not treated because of unexploded ordinance. These areas are obviously of great concern because fires within them can only be fought from the air. Unfortunately, successful protection from fire for long periods results in increased biomass so the potential for damaging fires increases over time. There are no obvious solutions other than the current practice of maximizing the effective width of the firebreak road by using herbicides to kill adjacent vegetation. The problem of ricochets or errant rounds is difficult to guard against other than by strict control of the live fire exercises.

Gayland said the Army has spent about $300,000 per year in the past on fuels management (mowing, herbicide application). He also pointed out some older roads within the interior of the primary training area, suggesting that these roads could be cleaned and improved to serve as interior firebreaks, thus partitioning the training area into smaller parcels that could be more easily prescribe burned. This is a good idea and should provide a large cost-savings over mowing. It would be important to burn annually to keep the biomass down and the prescribed fires manageable.

Finally we went to Schofield Barracks to look at the vegetation map produced by Andy Beavers. Andy advised us that he has defined four primary vegetation types – grass, grass/shrub, shrub, and forest. The shrub component of the grass/shrub type appeared to be small enough that it can be ignored for fuel modeling purposes because the grass will be the primary carrier of fires. Andy's map should be most useful for doing FARSITE simulations using custom fuel models. Although NFDRS fuel models are not normally "customized" because there is no specialized software for this purpose, NFDRS fuel models could also be assigned to Andy's vegetation map if there were ever an effort to map fire danger at high resolution for the Makua Valley.

On August 17, Don Studebaker (USFS, Cleveland NF) and Mr. Sammy Houseberg joined us and we built custom fire behavior fuel models for the unmanaged grass and forest types outside the firebreak.

An additional fire behavior fuel model should be developed for the MMR -- a "managed grass" fuel model to represent the "worst case" managed grass type – probably 1 year of growth. This model can be built by Burgan in telephone and email consultation with Sammy Houseberg and Gayland Enriques. It is not critical that this model be built immediately because it will not be used for current operations, but rather is needed for use in the FARSITE program. It is needed for FARSITE because the "unmanaged" grass model will overpredict fire spread rate and flame length for the managed grass stands. When using FARSITE, the grass areas cut down to stubble, and the bare earth areas can be considered to be firebreaks.

On completion of this effort, we discussed the advisability of doing some test fires to help assess the capability of the unmanaged grass fuel model to predict rate of spread (ROS) and flame length (FL). We drove to the MMR to look for suitable test plots, and found two candidate areas. On returning to Schofield, we further discussed the urgency of doing test burns. The consensus opinion, shared by Burgan and Fujioka, was that rushing to do test burns by the end of September when the weather would likely become unfavorable, was not wise. That is, it is not necessary to do the test burns prior to commencement of training because these burns would only provide two data points.

We felt that a better assessment of the grass fuel model could be obtained by having Sammy Houseberg and Don Studebaker each spend sufficient time using BEHAVE to determine whether or not the fire behavior predicted by the fuel model over a wide range of fuel moistures and wind speeds, matched their considerable experience. If not, it will be adjusted and re-tested. For initial use of a fuel model it is more important to know that it is going to produce reasonable fire behavior predictions over a wide range of environmental conditions than it is to match the results of a limited number of test burns, because this guards against unpleasant surprises. Testing of the unmanaged grass fuel model should be completed before training starts.

Fuel model verification data (flame lengths and spread rates) should be taken as a matter of course whenever prescribed burns are conducted, or during fires resulting from unplanned ignitions, if possible. This should provide for improvement of all fuel models over time – a process that should continue for years.

Recommendations

1) Get an account with the Weather Information Management System (WIMS) before starting training exercises. The Army has already begun this effort and expects the account to be established in the next week or two. This will provide a sanctioned method to calculate NFDRS indexes for the MMR, and provide for permanent storage of the weather data so it is not inadvertently discarded. It will also make the weather data easily available for future research. Because the NFDRS is a “bookkeeping” system, requiring continuous tracking of weather, it is critical to take weather observations every day, not just when exercises are held.

2) Code the RAWS station to use NFDR fuel model N before starting training. NFDR fuel model L (western perennial grass) has been used in the past to represent the grass fuels at the MMR. This model was apparently chosen to represent the managed fuels within the firebreak roads. The current philosophy is to represent the older grass stands outside the firebreak roads. NFDR model N (sawgrass) is recommended for this.

   The old philosophy of using fuel model L makes the inherent assumption that all fires will occur and be contained within the firebreaks. This has not been the case. The new philosophy of using model N is more conservative because it implies that operations will be curtailed when burning conditions in the unmanaged grass outside the firebreaks are such that the fires could not be controlled. The managed fuels within the firebreaks should present a much less serious fire potential in the same burning conditions.

3) Burning index has been used in the past for estimating fire potential. This is a good index for this purpose and its use should be continued. The only other NFDRS index that we recommend is the Ignition Component because, with future research, it may provide additional insight into the probability of an ignition, given the type of ordinance. Capability to calculate the BI and IC daily must be in place before training starts.

4) We recommend, that at least initially, the BEHAVE System be used as the primary system to control operations. Thus BEHAVE needs to be running on the computer (PC) at the MMR before training starts. Live and dead moistures needed for BEHAVE can be obtained from the NFDRS calculations for the lower RAWS site. Because we have changed from NFDRS model L to model N, the range of BI values associated with the current precaution levels will be different. Normally, the breakpoints for precaution levels are set by doing an historical analysis of fire occurrence and size associated with the NFDRS indexes. Sufficient historical weather and fire occurrence data are apparently not available. Personal experience can also be used to set the breakpoints, as Sammy Houseberg did, but this requires a considerable period of time (years). We specifically built a fuel model to represent the older grass stands, so using it in BEHAVE to calculate flame lengths provides the best foundation for starting operations. Flame length/fire control situations described in Rothermel's "How to Predict the Spread and Intensity of Forest and Range Fires", provide a mechanism to translate the current precaution classes to fire behavior flame lengths:

Precaution Class	Flame Length (ft)	Control Options
Green	0 - 4	Hand crew can control
Yellow	4 – 6	Equip req'd to control
Red	6 – 8	Serious control problems
Orange	8+	Head fire can't be controlled

The flame length breakpoints in Rothermel's publication are: 0-4 feet, 4-8 feet, 8-11 feet, and 11+ feet. Rothermel's standard breakpoints have been modified in the above table, for application at the MMR, on the advice of Mr. Houseberg. These are more conservative than the standard breakpoints, but the authors agree that is a good way to start. These breakpoints can be relaxed if experience so indicates.

Division of the NFDRS fuel model N burning index values by 10 provides an estimate of flame length, providing a mechanism to relate BI values for this fuel model, to the precaution levels. After sufficient fire occurrence data has been gathered (50-100) fires, FIREFAMILY PLUS should be used to refine the association between BI, IC, and fire size and occurrence.

5) More severe burning conditions may be tolerated if the wind is blowing down valley than up valley. We recommend that exercises not be permitted if the wind is blowing up the valley and the flame length for the unmanaged grass model is greater than 6 feet. This corresponds to a BI of 60. These are probably conservative values that will need to be adjusted. Going beyond an 8 foot flame length (BI=80) with up valley winds would be questionable. Implement this recommendation before starting training.

6) Fire occurrence records need to be kept and entered into the National Interagency Fire Management Integrated Database (NIFMID). This can be done through the WIMS account. The standard Forest Service fire report can be used, with the exception that some local notes will have to be kept to define the types of ordinance that started each fire. These records will be useful for future research. This recommendation doesn't have to be implemented before training starts, but every effort should be made to implement it sometime in 1999.

7) An experiment is suggested to not only determine flame lengths at which fires start to become a concern, but also to determine the associated NFDRS burning index and ignition component values. This experiment should be conducted in September 1999, if possible. It needs to be accomplished before training starts.

   This experiment would require that grass mowing in part of the main training area be modified, just this one time, to provide a patchwork of small (100 foot square) stands of unmowed grass. About 50 such grass patches should be sufficient. They should be in locations where fire suppression will be easy. Live fire can be directed into these test plots under various weather conditions to determine when ignitions begin to occur. Much data can be gathered quickly and safely in this manner, and the testing can begin as soon as the mowing is complete. The test firing should begin about noon, when the vegetation is relatively dry, then continue during the day until the fuels moisten as the humidity rises in the evening. The reason for starting at noon is that actual fuel moisture tends to lag values predicted from just relative humidity and temperature. That is, vegetation is likely to be slightly wetter than predicted when the humidity is falling, and slightly drier than predicted when the humidity is rising.
   Thus, afternoon tests are more conservative in that actual dead fuel moistures will be at least as dry as predicted, perhaps slightly drier.

   Utilize one test plot at a time, progressing from ball ammunition to explosives, to tracers--that is, from weapons least likely to start a fire to those most like to cause a fire. Record the weather data and the BI, IC, and calculated fire behavior flame length at each test firing, as well as whether or not a fire is actually started. For custom fire behavior fuel models requiring live moisture inputs, use values calculated by the NFDRS for the valley bottom RAWS station. This effort could help refine the BI guidelines, and could probably be completed before Sept. 30, 1999. A study plan should be written to guide this effort.

8) Determine how well the valley bottom RAWS represents weather conditions in the main training area, where the micro-RAWS is currently located. NFDRS and fire behavior calculations should initially be made using weather from the valley bottom because the conditions there are warmer and drier than further up the valley, thus giving a conservative assessment of fire potential. However, the mid-slope RAWS station may be more appropriate, if it observes weather parameters, particularly windspeeds and directions, significantly different that those recorded for the valley bottom station. Comparison of the weather readings between the two stations does not need to be accomplished prior to starting training, but on completion, it may permit use of the mid-valley RAWS for fire potential estimates, and gain some additional training days.

9) Training exercises should not be permitted when the ridge-top weather station indicates high fire danger according to the precaution level guidelines. Implement this recommendation immediately.

10) Continued refinement of burning index and flame length guidelines should be a goal. Mr. Houseberg only had the valley bottom station to work with. Having 3 RAWS stations provides a great opportunity to refine the conditions under which exercises can be conducted. Rothermel and Rinehart provide a method for field verification of fire behavior predictions (Rothermel and Rinehart 1983). Implementation of this recommendation can only occur with active training.

11) Make national level fire danger rating training, and at least 400 level fire behavior training, as well as operations and incident management training, a prerequisite for the position of range safety officer. Because training takes time, it is not reasonable to expect this recommendation to be implemented prior to commencement of training, but it should be actively pursued. In the meantime, make sure the most knowledgeable people are at the MMR making decisions regarding the risk of training under the current weather conditions.

12) It is suggested that 1 hour timelag fuel moistures be set to 10 hour fuel moistures for both fire danger and fire behavior calculations. Research by Anderson (1985) indicates that only very fine vegetation actually has a 1-hour timelag response. Vegetation meeting this criteria does not exist at the MMR. Implement prior to starting training.

The authors of this report are not qualified to say what kind of training should occur at the start and when should it increase. This can be better answered by the military experts than us, other than to say "be conservative" in the beginning and shoot only ball ammunition on the drier days and explosives or tracers on the wetter days, but test the limits a bit as experience is gained.

The authors also leave recommendations on suppression equipment or tactics to people who are more experienced in fire suppression.

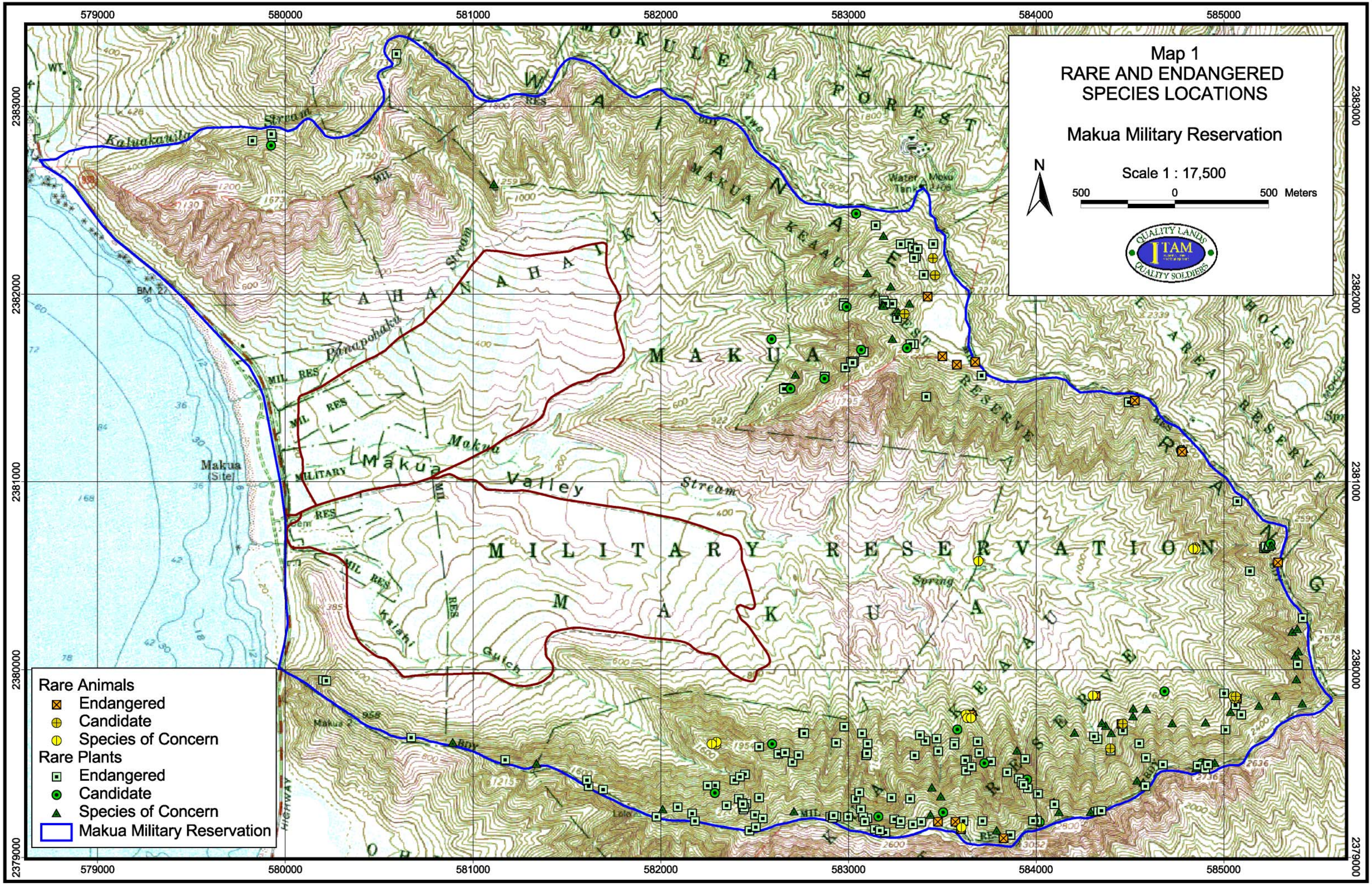
Because it is not possible to build an impervious fireline around the training area, limitation of fire risk through awareness of fire potential is critical. We believe the Army has the tools to limit the risk, and the will to do so, but again, it must be recognized that fire risk cannot be forced to zero. Even closing the MMR will not eliminate fire risk, and in fact would likely make it worse because responsible people with fire fighting equipment would no longer be "on site" and the vegetation biomass would build up to dangerous levels due to lack of vegetation management. An ignition from the vicinity of the highway could then be very serious.

In terms of assessing fire potential, it is obvious the Army is doing everything it can to minimize fire damage to the endangered species in the MMR.

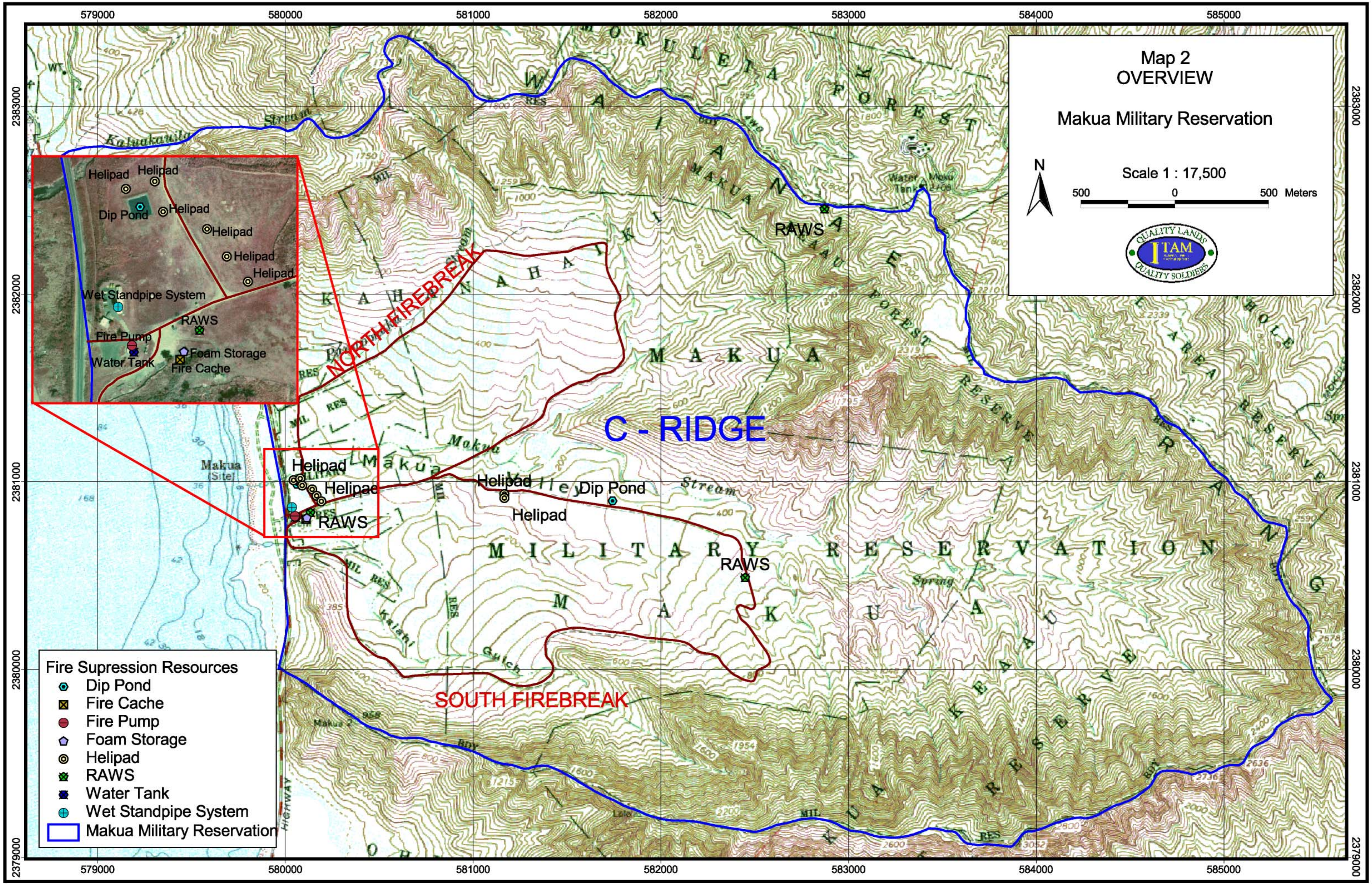
References

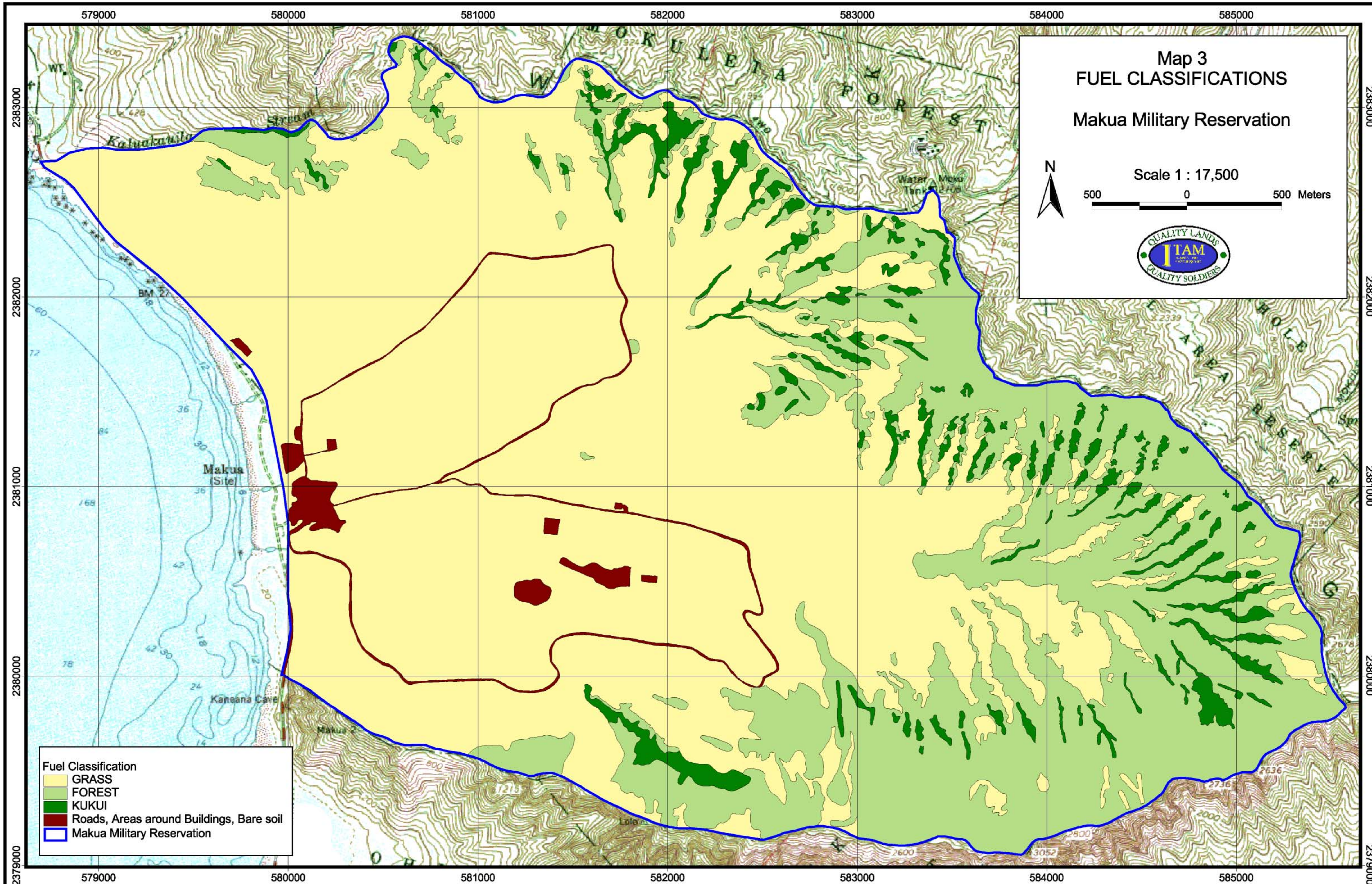
Anderson, H.E. 1985. Moisture and fine fuel response. IN: Eigth Conf. On Fire and Forest Meteorology, Detroit Michigan, April 29 – May 2, 1985.

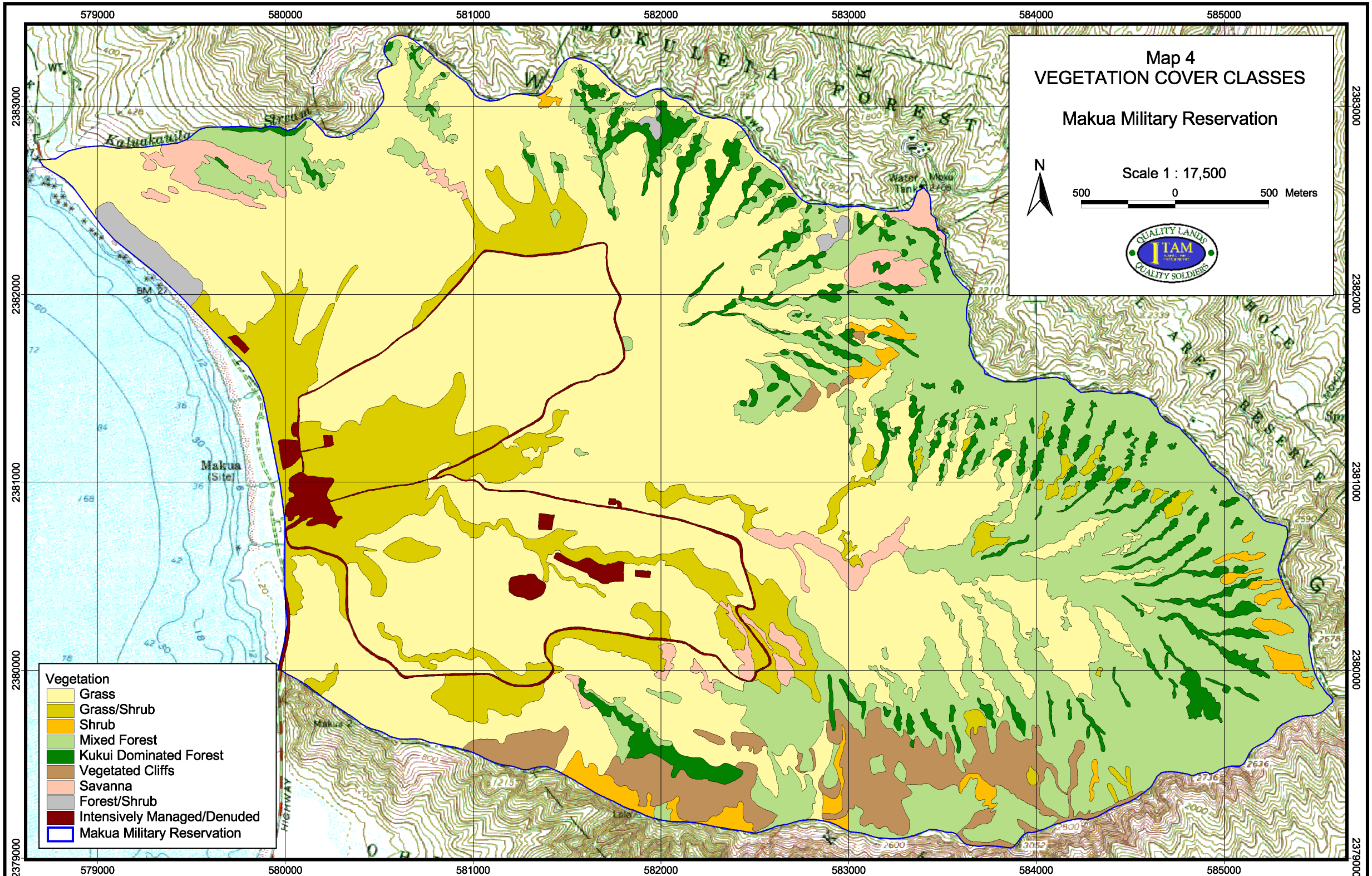
Rothermel, Richard C., and George C. Rinehart. 1983. Field procedures for verification and adjustment of fire behavior predictions. USDA Forest Service, Intermountain Forest and Range Experiment Station, GTR INT-142. 25p.



Map 1
RARE AND ENDANGERED
SPECIES LOCATIONS
Makua Military Reservation
Scale 1 : 17,500
500 0 500 Meters
N
QUALITY LANDS
ITAM
QUALITY SOLDIERS
Rare Animals
Endangered
Candidate
Species of Concern
Rare Plants
Endangered
Candidate
Species of Concern
Makua Military Reservation
MAKUA MILITARY RESERVATION
Makua Valley
KAHANAHAIKI
MAKUA KEAAU FOREST RESERVE
Makua (Site)
579000
580000
581000
582000
583000
584000
585000
2383000
2382000
2381000
2380000
2379000


Map 2
OVERVIEW
Makua Military Reservation
N
Scale 1 : 17,500
500 0 500 Meters
QUALITY LANDS
ITAM
QUALITY SOLDIERS
C - RIDGE
NORTH FIREBREAK
SOUTH FIREBREAK
Helipad
Dip Pond
Wet Standpipe System
RAWS
Fire Pump
Water Tank
Foam Storage
Fire Cache
Fire Supression Resources
Dip Pond
Fire Cache
Fire Pump
Foam Storage
Helipad
RAWS
Water Tank
Wet Standpipe System
Makua Military Reservation
579000
580000
581000
582000
583000
584000
585000
2379000
2380000
2381000
2382000
2383000
MAKUA
MILITARY RESERVATION
MOKULEIA FOREST
Makua Valley
Makua Stream


Map 3
FUEL CLASSIFICATIONS
Makua Military Reservation
N
Scale 1 : 17,500
500 0 500 Meters
QUALITY LANDS
ITAM
QUALITY SOLDIERS
Fuel Classification
GRASS
FOREST
KUKUI
Roads, Areas around Buildings, Bare soil
Makua Military Reservation
579000
580000
581000
582000
583000
584000
585000
2383000
2382000
2381000
2380000
2379000
Makua
(Site)
Kaneana Cave
Kaluakauila
Stream
BM 27
MOKULEIA FOREST
Water Tank
Moku



Map 4
VEGETATION COVER CLASSES
Makua Military Reservation
N
Scale 1 : 17,500
500 0 500 Meters
QUALITY LANDS
ITAM
QUALITY SOLDIERS
Vegetation
Grass
Grass/Shrub
Shrub
Mixed Forest
Kukui Dominated Forest
Vegetated Cliffs
Savanna
Forest/Shrub
Intensively Managed/Denuded
Makua Military Reservation
579000
580000
581000
582000
583000
584000
585000
2383000
2382000
2381000
2380000
2379000
Makua
(Site)
Kaluakauila
Stream
MOKULEIA FOREST
Water Tank
BM 27
HIGHWAY
Makua 2

Map 5
FUEL MANAGEMENT RECOMMENDATIONS

Makua Military Reservation