Pacific Southwest Region | September 2023

ESF4 Burned Area Emergency Response Assessment
Technical Report
Hawaii Wildfires (CA-FE9-000005)

September 11, 2023

Kohala Fire (USDA FS)

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The USDA Forest Service staff deeply appreciate the warm hospitality of the people of Hawaii during the team's assessment of the 2023 wildfires. We value the dedication of the local staff and the opportunity to have technical exchanges related to post-fire assessment and treatments. This open and collaborative relationship allowed for a successful mission to aid post-fire response and recovery in Hawaii.

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Overview and Process

In early August 2023, a series of wildfires occurred in the state of Hawaii. These unprecedented, devastating fires grew quickly due to strong winds and dry conditions. On August 17th, the State of Hawaii requested the Federal Emergency Management Agency (FEMA) to staff a United States Department of Agriculture (USDA) Forest Service (FS) Burned Area Emergency Response (BAER) assessment team to evaluate six wildfires on the islands of Maui and Hawaii totaling 10,956 acres. The BAER team was on the islands from August 20th to September 5th, 2023, working with State, local, and other federal agency partners to develop recommendations to reduce the risk of post-fire damage to critical values from post-fire watershed response in undeveloped watersheds. This report describes the rapid characterization of post-fire watershed conditions and recommendations. We discuss the threats and risks to critical values and offer some recommendations on best approaches to burned area response for these fires, as well as on future wildfires. The focus of this report is the land, communities, and nearshore values within and downstream of the fire perimeters that may be at risk of damage or loss due to changed watershed conditions of the burned areas. The report does not discuss threats caused from the burned conditions in developed areas.

Picture 1. Ocean adjacent to the Mauna Kea Beach Resort Fire (USDA FS)

Burned area emergency assessments are rapid evaluations done to determine if critical values are at risk due to imminent post-fire threats and to develop appropriate actions to manage unacceptable risks. While this assessment followed the BAER process, it expanded beyond federal land management policy definitions of critical values and unacceptable risk. Critical values identified by the State of Hawaii for the BAER team to evaluate included life and safety, residential and transportation infrastructure, and critical nearshore ocean habitat (Picture 1). These assessments are not intended to provide a comprehensive evaluation of all fire or fire-suppression damages, nor to identify long-term rehabilitation or restoration needs.

The first step in a burned area assessment is to identify specific values that are potentially at risk from post-fire events. Once these critical values have been identified, each should be assessed for potential threats from post-fire conditions. To characterize post-fire threats, the BAER team makes field observations of soil and watershed conditions that are used in conjunction with analysis methods to estimate anticipated levels of post-fire damage from erosion, flooding, and geologic hazards. A post-fire emergency is identified as a critical value found to be at unacceptable risk of damage due to post-fire conditions. After defining the post-fire emergency, a response strategy that considers natural recovery is developed to mitigate the risk.

General Resource Setting

Cultural

The Hawaiian Islands are rich in history, culture, and traditions. Polynesians arrived at the islands more than 1,600 years ago by voyaging canoes, bringing with them their language, traditions, and lifestyles. The culture of the islands today is grounded in the Aloha Spirit, the Hawaiian language and traditions, and the beauty and spirit of the land. As a result of the Native Hawaiian history along with more recent multi-ethnic history, the islands are rich in archeological and historic sites, and the preservation of cultural landscapes are important to the maintenance of traditional practices. The cultural and historic heritage of the islands is intertwined with the natural resources and landscapes. These elements carry their full cultural significance when linked, protected, and interpreted together as a cultural landscape.

Landscape Alteration

Much of the landscape within and surrounding the fire perimeters has been heavily impacted by past management. Plantations for sugarcane, pineapple, and other tropical crops played a large role in the development and economy of the islands in the 19th and 20th centuries. Native forest was cleared for crops, grazing, and urban areas, introducing non-native and ornamental plants to the landscape. Drainage infrastructure was developed to irrigate crops, rock was removed from surface soils to enable agricultural development, and berms were constructed, some of which alter flow paths, confine channels, or terrace hillsides (Figure 1). In areas of west Maui north of Lahaina, a United States Geological Service (USGS) study showed that these modified landscapes contribute to ocean sediment plumes during runoff events (Stock et al. 2021).

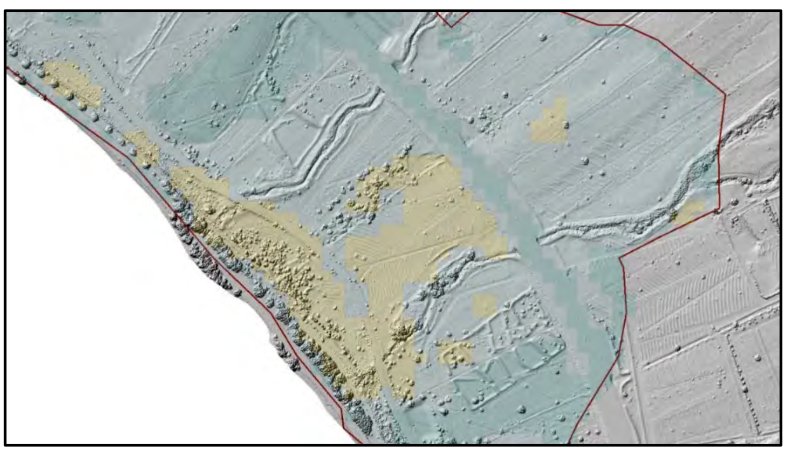

Figure 1. South Lahaina burn area. Berms line the main drainage, disconnecting surface flow from the lower slopes from the main channel. Other berms along roads and property boundaries also create storage depressions that trap runoff.

Along with other landscape change, the introduction and expansion of non-native, invasive species have reduced the prevalence of native plant communities. Currently, vegetation types within the burned areas are dominated by non-native species which tend to have a higher fire danger and more frequent fire return interval than native vegetation types. Multiple studies have found that habitat conversion to non-natives also reduces infiltration and thus increases runoff, though restoration to native plants was found to ameliorate these effects (Perkins et al. 2014, Perkins et al. 2018, Fortini et al. 2023).

Non-native ungulates such as pigs, cattle, deer, goats, and sheep have been introduced to Hawaii over time for various reasons as well. Lacking a local predator, many populations have grown exponentially and have negative impacts on landscapes. Multiple studies have examined the impacts of these ungulates on Hawaiian ecosystems and to a lesser extent, secondary effects to soils, hydrology, and restoration efforts, finding that the ungulates can create a negative feedback loop that promotes conversion of native forest to grasslands (Leopold and Hess 2017).

Geology and Soils

The islands of Maui and Hawaii are part of the Hawaiian Archipelago, having formed on the Pacific plate from a magma source deep in the mantle. The volcanic mountains of Hawaii have been built by the accumulation of basalt flows erupted over hundreds of thousands of years, as the Pacific Plate moved northwestward over a hot spot. There are two principal types of lava flows in Hawaii. Pahoehoe is characterized by smooth, ropy, or billowy surfaces, whereas aa has a very rough, spiny or rubbly surface, but a massive interior. These lava flows are sometimes found under a mantle of volcanic ash or alluvium (Lau and Mink 2006).

In many areas, especially on the Big Island, the geologically recent lava flows have not weathered into soils. Where mature soils have formed, they have developed from a combination of basaltic lava, volcanic ash, limestone from ancient corals, and alluvial material deposits. The soils within the burned areas are a combination of mollisols, andisols, and aridisols. Many of the soils have a high surface rock content as well as some natural hydrophobicity derived from the volcanic parent material; this natural water-repellent layer was observed to be strongest under forest vegetation types. Surface textures when exposed are dominantly silty clay loams, silt loams, and clay loams with lesser amounts of coarse-textured topsoil. The finer-textured soil types are susceptible to both wind and water erosion when surface cover has been removed, especially in areas where past land management practices have removed surface rock to facilitate agriculture. In general, the soils in the Hawaii Island fires had higher surface rock than those on Maui.

Distinct geologic and soil features were found in the Kula and Olinda fires. The channels are deeply entrenched with unstable gulch walls with slumping, sliding, and rockfall in pre-fire conditions. Interbedded lava flow layers exposed in the gulches have varying competency with aa clinker flows having less resistance than dense flows. Dense flows form resistant bedrock outcrops and waterfalls. Soils on the top edge of these gulches formed mostly from volcanic ash overlaying the lava flows. The soils are medium-textured, have relatively less rock content than the gulches, and are highly erodible when soil cover is lost. Homes have been constructed along the edge of the gulches.

Hydrology

Watersheds in the burned areas are generally steep, linear, and narrow, in most cases extending from the top of the ridge down to the ocean. They are characterized by an entrenched main channel with few short tributaries, minimal sinuosity, and steep gulch walls. High-energy, flashy flows occur in response to high-intensity rainfall (especially at higher elevations), often resulting in channels scoured to bedrock. Most upper reaches lack extensive fine sediment deposits, indicating sediment input from the surrounding landscape is transported out during common flow events. In wider, lower-gradient reaches, riparian vegetation may reduce flow velocities and facilitate deposition of sediment during floods. Floodplain development in lower reaches includes pockets of loosely consolidated alluvium with vegetative cover consisting of trees, shrubs, and groundcover.

Precipitation varies considerably on the Hawaiian Islands, including the watersheds that drain the 2023 burned areas. Precipitation is primarily associated with the predominant northeasterly trade winds, and a pronounced rain-shadow effect exists on the leeward western sides of the islands (Mitchell et al., 2023), where the 2023 fires occurred. The precipitation associated with the trade winds is greatest between roughly 2,000 and 6,000 feet of elevation and is lowest near sea level (Mitchell et al. 2023). For example, Mauna Kahalawai above Lahaina has average annual precipitation of roughly 360 inches in contrast to Lahaina which sees an average of 13-15 inches annually (Giambelluca et al. 2013). Lahaina, Pulehu, Mauna Kea Beach Resort and Kohala burned areas are on the lower flanks of the volcanos and have gentle slopes (Picture 2). The Lahaina and Pulehu burned areas on Maui are in the leeward lowlands characterized by a dry climate with generally lighter rains. The Olinda and Kula burned areas are located on higher-elevation volcanic terrain with generally steeper slopes than the other fires. Annual and storm-scale precipitation at these two higher-elevation burned areas is greater than at the lower-elevation fires. Mauna Kea Beach Resort and Kohala are located on the Kona Coast of Hawaii Island where summer rainfall is higher than winter rainfall but annual precipitation is still significantly lower than on windward slopes. General site characteristics on each of the burned areas are listed in Table 1. Whereas average annual rainfall totals are relatively low on most of the fires, the watersheds that pass through the burned areas generally extend to higher elevations, where average-annual and single-storm rainfall totals are considerably greater (Giambelluca et al. 2013). In the watersheds crossing the burned areas, most precipitation falls during the October to April rainy season. (Western Regional Climate Center (WRCC) website, Hawaii climate summary, [WRCC: Hawaii Climate (dri.edu)])

Picture 2. Pulehu Fire looking across the Maui landscape (USDA FS)

Table 1. General characteristics of the six 2023 burned areas.

Fire	Elevation range (ft asl)	Average annual precip (in)	Mean slope (%)	Pre-fire vegetative cover	Landscape alteration
Lahaina	0 - 240	13-15	7	Thick grasses on slopes, brush with tree-lined riparian corridors; urban areas	High: paved/developed areas, berms, sediment basins, ditches, tillage
Pulehu	150 – 1,300	12-15	6	Grass covered slopes, treelined riparian areas	Moderate: berms, furrows, surface rock removal
Kula	2,400 – 3,400	27-30	15	Entrenched, treelined gulches and grassy swales	Low: paved road, developed area
Olinda	1,950 - 3,800	44-63	19	Entrenched, treelined gulches and grassy swales	Low: ranch lands, fencing, minor development
Kohala	0 - 600	9-12	11	Grass and scattered trees with larger riparian areas treelined	Low: roads, culverts, paved/developed areas
Mauna Kea Beach	0 - 280	10-12	9	Grass and scattered trees with larger tree-lined riparian areas	Low: roads and paved/developed areas.

Analysis and Results – Post-Fire Conditions

Soil Burn Severity

Assessment of soil burn severity is one of the first steps in the USDA FS BAER process. Post-fire soil burn severity is often mapped with the intention of identifying the degree to which the fire has affected soil characteristics that impact soil health and hydrologic function, and hence erosion rate and runoff potential. Soil burn severity is not a simple assessment of vegetation consumption, but rather an integration of vegetation loss, changes in soil structure and infiltration capacity, remaining vegetation and duff layers, ash, and soil color, all of which may indicate relative degrees of soil heating. From the soil burn severity map, geologists can predict debris flow hazards, hydrologists can predict changes to runoff and flood flows, and soil scientists can predict erosion potential.

Developed areas (both urban and rural) were not mapped for soil burn severity. This method has been developed for wildland vegetation and landscapes and therefore is not appropriate for describing the effects of fire on developed lands and burned structures. Thus, these areas were not visited or evaluated by the BAER team.

The final soil burn severity maps were developed with *ESRI ArcGIS* software using satellite-imagery-derived Burned Area Reflectance Classification (BARC) and field survey data (~172 field data points). Field work to document and confirm soil burn severity was completed from August 21st to 30th, 2023 (Picture 3). Field work included assessment of ash characteristics, ground cover, roots, soil structure, soil water-repellency, and vegetation burn severity as described in the *Field Guide for Mapping Post-fire Soil Burn Severity* (Parsons et al. 2010). Hydrophobicity was measured in the field but was not used as a determining factor of soil burn severity. In some forest vegetation types, strong surface hydrophobicity was found within and outside of the burned area in unburned conditions. In burned areas, it was often present in forested sites, but its severity was variable. Field assessment sites covered all six fire areas and as many burned conditions with each vegetation type as possible in the time available, however the process is still considered a rapid assessment and is not guaranteed to capture all variability. Field data were used to adjust the BARC map to produce the final soil burn severity (Figure 2).

Picture 3. USDA FS BAER team and agency partners discussing soil burn severity on the Lahaina Fire (USDA FS)

Picture 4. Unburned grass next to low soil burn severity on the Kohala Fire (USDA FS)

Pre-fire vegetation such as grasses or sparse shrubs usually experience extremely rapid consumption and spread rates, with very little heat having residence time at the soil surface (Picture 4, Picture 8). The result is very little alteration of soil organic matter and little or no change in soil structural stability. Water repellency, occasionally present under shrubs before the fire, may or may not be exacerbated by the fire. In the six mapped fires, very low and low soil burn severity was classified in areas where the surface organic material was charred or partly consumed. Roots close to the soil surface were usually still pliable, and soil structure was rarely changed. Most grassland areas burned at very low to low severity; however, low severity was found in all vegetation types. Vegetation recovery is anticipated to be rapid in these areas and sprouting was observed in some grasslands during the assessment. Post-fire erosion response in areas of low soil burn severity will be somewhat variable. Some low severity areas under forest vegetation will have litter and organic material additions before the wet season; however, some of the grasslands have little or no surface cover remaining except rock.

Dense vegetation, with a deeper litter and duff layer, results in longer duration heat on the surface soils, and thus, more severe effects on soil properties (Picture 5, Picture 8). For example, deep ash after a fire usually indicates a deeper litter and duff layer prior to the fire. This promotes loss of soil organic cover and organic matter, which are important for erosion resistance and the formation or exacerbation of water repellent layers at or near the soil surface. The results are increased potential for runoff and soil particle detachment, and transport by water and wind. In the six mapped fires, high soil burn severity was not widespread, but where it occurred, effects could be deep and severe. Most high burn severity had complete consumption of organic material with the surface layers of the soil resulting in a change to single-grain structure. Fine roots were commonly charred or consumed 3-5 cm deep. The volcanic ash-derived soils in the Olinda and Kula fires were particularly susceptible to deep soil heating. In these fires, soil structure was altered up to 20 cm deep and effects to roots occurred to 25 cm. The highest-severity areas often had a loose, dusty appearance, and no longer had any cohesion or soil strength. This condition was found where forested vegetation had accumulated enough fuel on the soil surface to cause high severity, or long-duration heat impact to the soil.

Picture 5. Unburned forest and groundcover near the Olinda Fire (USDA FS)

The moderate class of soil burn severity is far more diverse in observed soil conditions and can include various vegetation types, ranging from forests to shrub communities, and in these fires included very dense grass vegetation in or adjacent to riparian areas (Picture 6, Picture 8). In the case forest types, the litter layer may be largely consumed, but scorched needles and leaves remain in the canopy and will rapidly become mulch. This is important in re-establishing protective ground cover and soil organic matter. Generally, there will be less destruction of soil organic matter, roots, and structure in an area mapped as moderate compared to high. In a shrub ecosystem, even where pre-fire canopy density was high, the litter layer is generally thin, and while the shrub canopy may have been completely consumed by the fire, the soil structure, roots, and litter layer may remain intact beneath a thin ash layer. In the six mapped fires, moderate soil burn severity was found in areas where the surface organic material was completely consumed by the fire, fine roots close to the soil surface were charred up to 3 cm deep, and the soil

Picture 6. Dense grasslands with high fuels loading near the Lahaina Fire (USDA FS)

structure was often altered at the surface. Moderate severity occurred under forest canopy or under particularly dense grassland vegetation. Some areas have potential for inputs of litter to increase ground cover, but more commonly no surface organic matter remains, which can increase post-fire erosion.

Picture 7. Evidence of post-fire wind erosion on the Lahaina Fire (USDA FS)

The wind-driven nature of most of these fires made soil burn severity determinations difficult. In most of the moderate and low soil burn severity, ash layers typically present at the soil surface were blown away. In some rare cases, burnt soil layers were also blown away, either lost completely, or deposited in drainages or along road cut-slopes. The absence of these wind-blown soil and ash layers was identified by seeing vegetation roots and basal rosettes present above the current soil surface (Picture 7). When observed, these areas were mapped as moderate or high burn severity.

Picture 8. Photos of the three classes of soil burn severity. On the left, low soil burn severity in the Lahaina Fire. In the center, moderate soil burn severity in the Lahaina Fire. On the right, high soil burn severity in the Kula Fire. (USDA FS)

The Soil Burn Severity product is used as an input for all the methods presented in this report; it is the basis for determining the anticipated level of post-fire watershed response. Combined, low (49%) and very low/unburned (34%) soil burn severity cover most of the fire areas with up to 15% moderate and high severity found in the Lahaina and Kula Fires (Table 2). The soil burn severity map for the Olinda and Kula fires is included here and a complete set of map products per fire are found in the Appendices (Figure 2, Appendix A-F. Map Products).

Table 2. Area within the fire perimeter by Soil Burn Severity (SBS) class. Areas classified as "Developed" were not assessed for SBS as this method is not appropriate for developed ground.

Fire	Soil Burn Severity (ac)					Total (ac)
	High	Moderate	Low	Unburned	Developed	
Lahaina	1	342	786	307	900	2,336
Pulehu	0	184	3,329	2,175	0	5,688
Kula	16	34	81	128	71	330
Olinda	14	179	341	926	25	1,486
Kohala	0	24	600	189	16	830
Mauna Kea Beach	<1	33	220	23	10	286
TOTAL	31	796	5,357	3,748	1,023	10,956

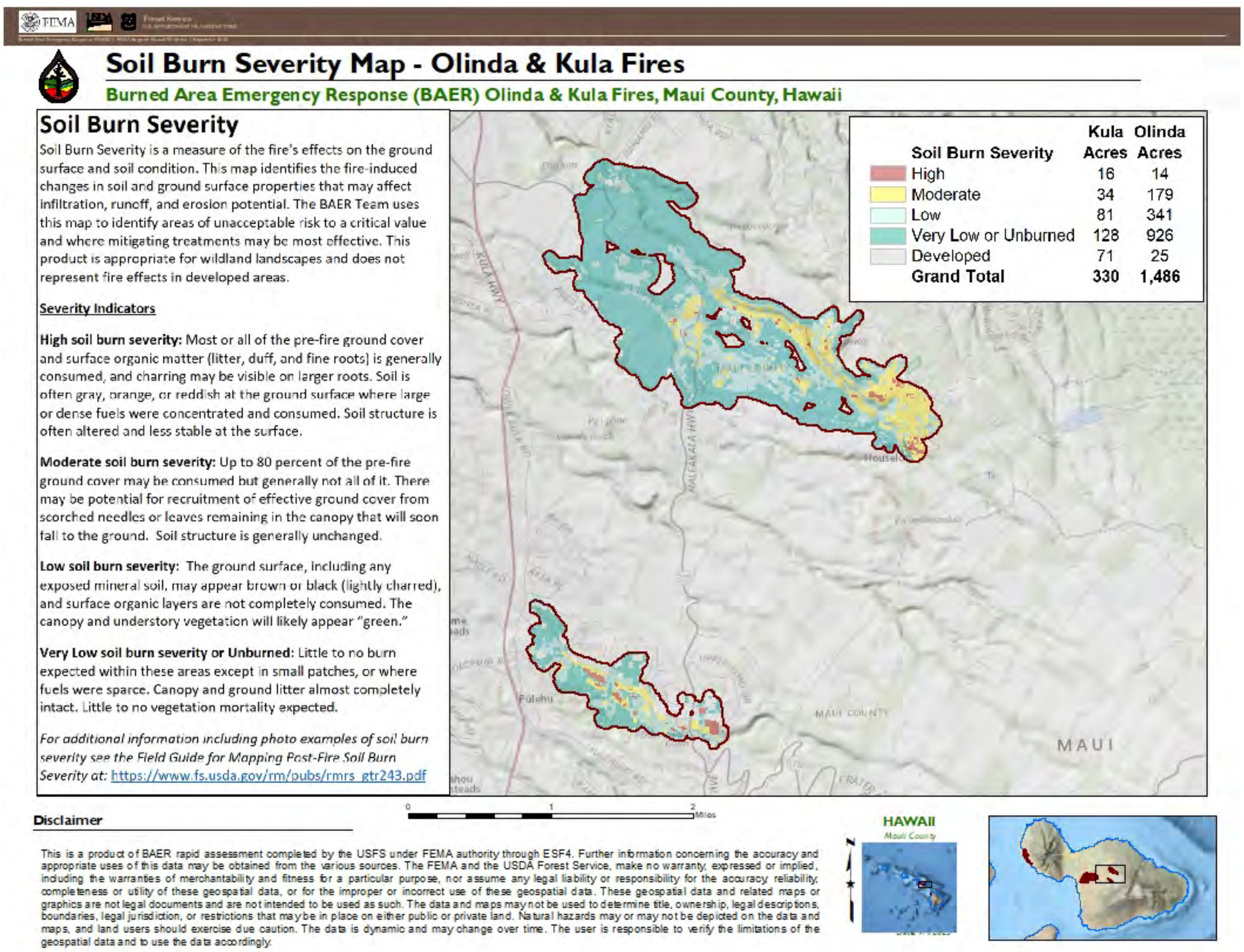

Figure 2. Soil burn severity map for the Olinda and Kula Fires.

From a distance the low and moderate burn severities in parts of these fires look similar, especially in grassland vegetation. In some areas of low soil burn severity, there is almost no ground cover due to loss of ash to the winds, but these areas had almost no soil heating, roots below the surface were not affected, infiltration is likely to be close to normal levels, and resprouting vegetation should recover quickly. Little or no groundcover is evident in areas of moderate soil burn severity as well, but below-ground effects to roots and soil structure occurred due to a longer duration of heating. Infiltration is likely to be lower in these areas due to pore sealing and loss of pore space at the surface, sprouting vegetation may recover more slowly or at lower density, and watershed response should be higher.

Soil Erosion

Soils within the burned areas have variable wind and water erosivity levels (Appendix A-F. Map Products). Erosion hazards are developed assuming a surface with little ground cover, similar to moderate and high soil burn severity levels. Most soils with low surface rock content have moderate to severe water erosion hazards and high wind erosion hazards. For this assessment, wind erosivity indices of over 38 tons/acre/year were considered a high hazard with rates of over 86 tons/acre/year as very high. Soils with high surface rock content in the fires have moderate to high water erosion hazards but

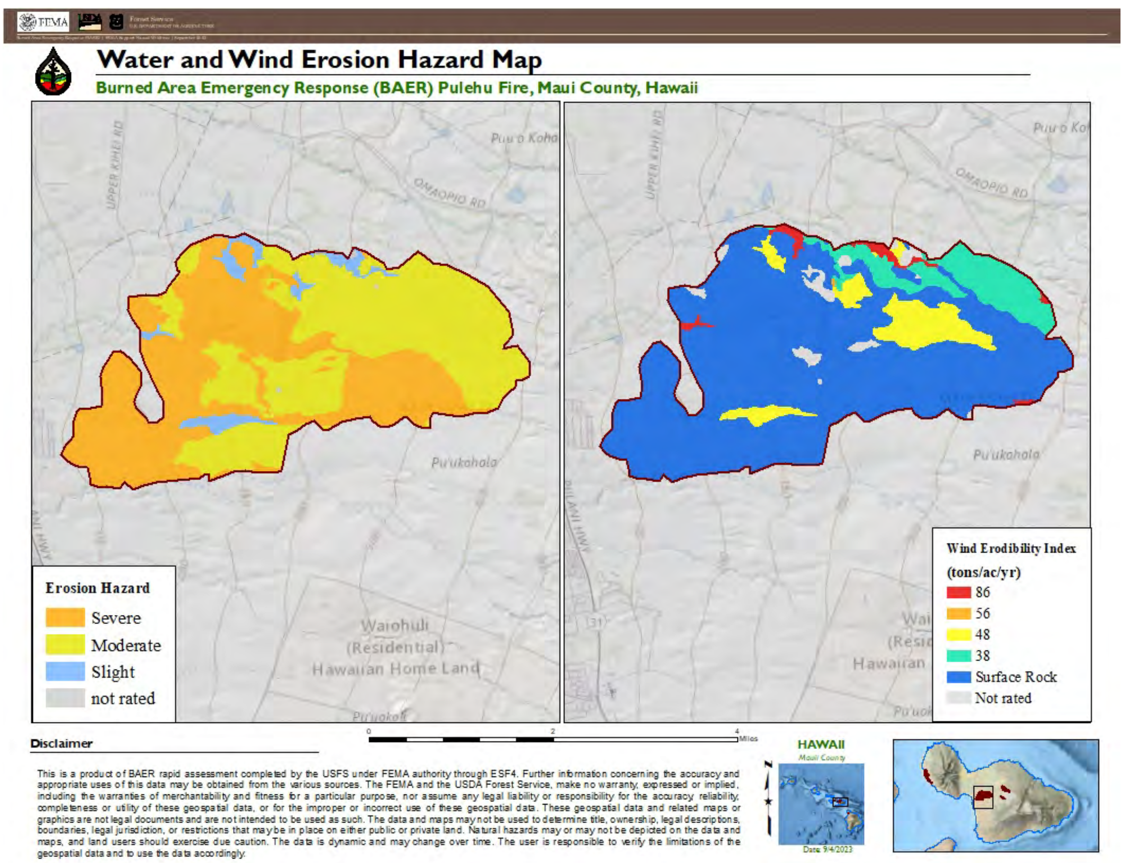

Figure 3. Water and Wind Erosion Hazard Map for the Pulehu Fire.

low wind erosion hazard ratings. Areas where surface rock has been removed to facilitate agricultural production would have an increased erosion hazard over mapping products and thus increased erosion rates over natural conditions (Figure 3).

The Forest Service *Erosion Risk Management Tool* (ERMiT) was used to model erosion and sediment potential within all fire perimeters (Robichaud et al. 2007). ERMiT is a storm-based erosion-potential model and 2-year (50% probability), 5-year (20% probability), and 10-year recurrence interval (10% probability) runoff events were modeled. Results suggest that post-fire erosion rates will increase in parts of all the burned areas due to the relative loss of ground cover and soil structural stability. The predicted erosion rates are a coarse approximation of how the various burned areas will respond in different storm and runoff events. This information is best used as a relative comparison to determine where highest risk of soil loss or other effects of erosion and sedimentation are present. Factors such as vegetation recovery or land use alterations can change how much soil eroded from hillslopes is transported to stream channels or is deposited elsewhere on the landscape. Soils within the burned areas have been assigned a tolerable annual soil loss rate between one to five tons/acre/year, which corresponds to a maintenance of agricultural soil productivity using this system. While the tolerable soil loss rate provides a context for interpretation of the modeled post-fire erosion potentials, it should not be used as an absolute number to determine risk for episodic erosion events that occur post-fire.

Pre-fire erosion rates in all fires for the 50% probability event are all equal to or lower than five tons/acre/year. For the 50% probability event, the only burned areas with hillslopes that exceed the tolerable soil loss rate are the Olinda and Kula fires, which have steep areas along the gulches with predicted rates up to 10 tons/acre/year. The steep side slopes and ashy soils adjacent to gulches in the Olinda and Kula fires are very erodible, even in small storm events. Stored sediment and ash along stream channels and gulch edges will be easily transported and mobilized downstream. Gulch banks are likely to develop rills and gullies in loosely consolidated sediments and are susceptible to localized slope instability. The *pre-fire* predicted erosion response for a 10% probability event exceeds the response of the *post-fire* 50% probability event in all burned areas. This result suggests that erosion on these landscapes is more a function of rainfall intensity than whether areas were burned. Erosion rates estimated by the model exceed 20 tons/acre in 10% probability events only for the fires on Maui. The total area predicted to have high erosion rates is not large, but the proximity of these areas to mainstem stream channels suggest that they are likely to produce sediment that will become entrained in streamflow versus being deposited elsewhere on the landscape. The modeled erosion rates represent the conditions immediately following the fires. Erosion potential will decline as groundcover becomes re-established. Grass recovery was already evident in several areas on each fire.

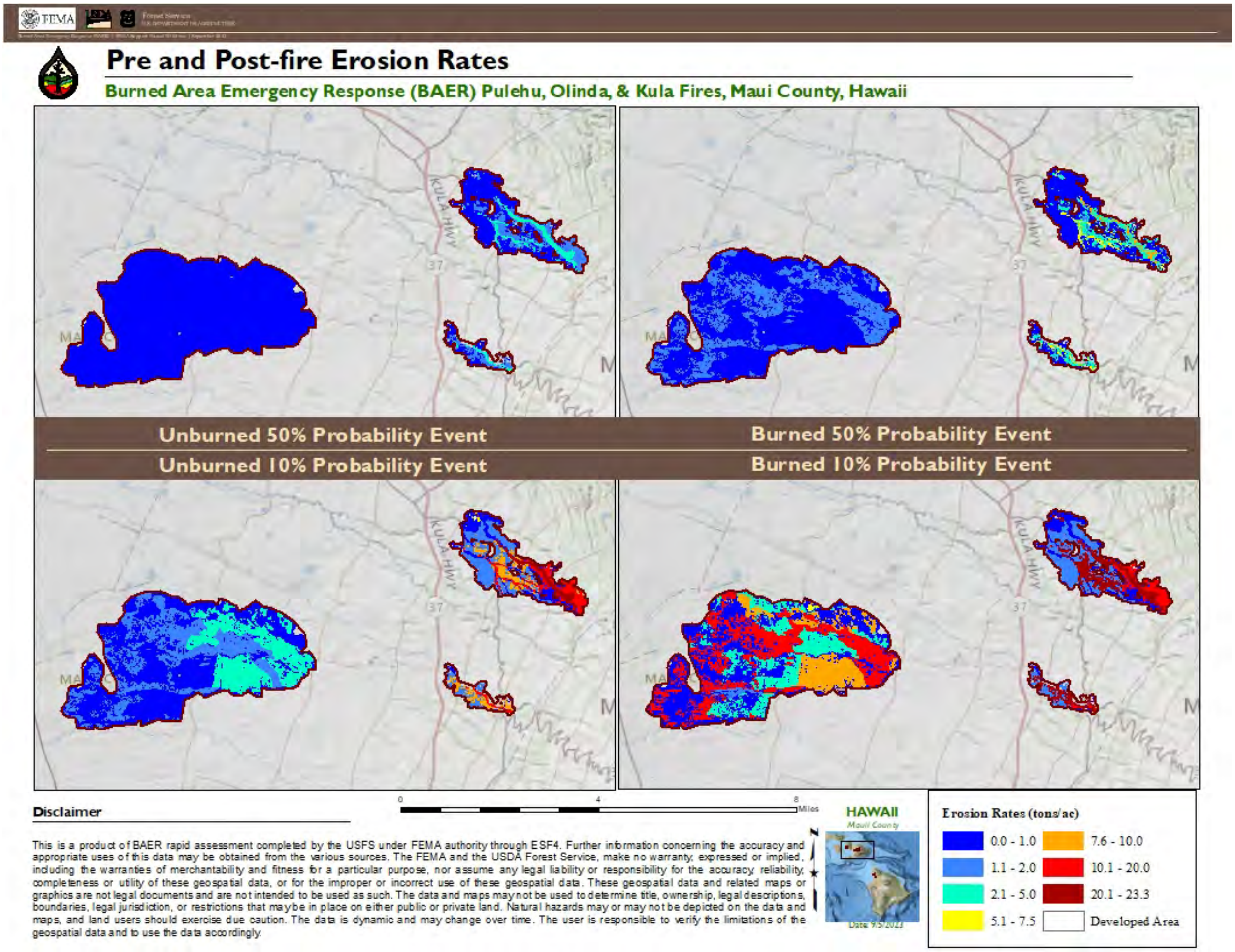

Figure 4. Pre and post-fire erosion rates for the Pulehu, Olinda, and Kula Fires.

These rates and ranges are highly variable across each fire footprint due to differences in slope, soil type, and precipitation across the islands (Figure 4, Appendix A-F. Map Products). Landscape alteration also challenges the ability to predict whether increased erosion will result in additional sediment delivery to stream channels. Constructed berms, sediment basins, and other flow path alterations may result in the deposition of eroded soil on the landscape instead of entering streams and being carried to the ocean, especially from more modest rainstorms.

Hydrology and Runoff

Hydrologic response following wildfire typically includes reduced interception and infiltration of precipitation, increased runoff and erosion, higher stream flow volumes for a given precipitation input, and a more rapid rise of stream and river levels compared with those of unburned conditions. However, the relatively small size of the Maui and Hawaii burned areas as well as generally low soil burn severity should lead to relatively minor increases in runoff in the first year following the fires, especially at the scale of the larger streams that drain the burned areas.

Water quality in streams that drain the burned area will be impaired during runoff events, particularly following higher-intensity rainstorms. An initial flush of ash and fine sediment is likely in response to the first intense rain events following the fires. Suspended sediment loading and turbidity levels in streams within and below the burned area will likely be elevated during and after rainstorms until groundcover becomes re-established, likely within one to three years. Large woody debris will likely accompany the initial flush of fine sediments and ash, with continued downstream delivery of large debris during peak flow events. Additionally, levels of some nutrients will likely be elevated in concert with higher turbidity and suspended load.

Picture 9. BAER team member assessing culvert condition in the Lahaina Fire (USDA FS)

Typical USDA FS BAER hydrology analytical methods include a field assessment to identify critical values vulnerable to flood and related damage, an estimation of post-fire hydrologic response to rain events, and evaluation of potential mitigation measures to reduce risk of damage to critical values. Prior to the field assessment, the burned area is reviewed using maps and aerial imagery (frequently in Google Earth), ideally including the initial BARC data. Buildings, transportation infrastructure (e.g. roads, culverts, bridges), water developments, natural resources, and recreation areas adjacent to streams within and below the burned area are identified and prioritized for field assessment. In the field, these critical values are examined to determine their vulnerability to damage from post-fire flooding. The field survey typically includes qualitative assessments, as well as quantitative data collection where modeling is warranted.

Following the field assessment, the approximate change between pre-fire and post-fire runoff for one or more probability events (precipitation or runoff) is typically estimated for areas of concern. A range of models and techniques are used to estimate post-fire runoff and erosion. Each approach has its advantages and shortcomings. Given the short timeframe in which BAER assessments occur, and the challenge of modeling ungauged basins in a post-fire environment, any estimation of post-fire watershed response is imprecise at best. BAER assessment teams thus generally avoid reporting stream runoff estimates as specific flow values, but instead report the estimated magnitude of change in runoff response between pre- and post-fire conditions. These estimates assist in determining where measures should be considered to reduce the risk of damage to critical values from elevated runoff response.

Watersheds on the islands of Maui and Hawaii pose additional challenges to common rapid post-fire runoff prediction methods. Narrow, linear watershed form, high relief, and substantial range of annual and storm-scale precipitation from headwaters to outlet are among the factors that complicate this task. In addition, landscape alteration from past and ongoing management activities complicates efforts to predict post-fire watershed response using common wildland analytical approaches.

Figure 5. Central Lahaina burn area. Multiple berms are visible in the vegetated uplands surrounding Lahaina. A sediment basin/wetland and berm system hydrologically disconnect the uplands from the built environment.

Given these complexities, USGS runoff regression equations developed for Hawaii were used to estimate pre-fire flood flows in the major watersheds draining the six burned areas. A method commonly used in the mainland western states was employed to approximate post-fire runoff using the pre-fire regression values and soil burn severity data (Foltz et al., 2009). This method entails increasing the proportion of runoff from burned areas using an adjustment factor and assumes that each unit of area within a drainage contributes the same amount of runoff to the aggregated flow at the outlet. For this assessment, area burned at low SBS was assumed to contribute 150% of pre-fire runoff, area at moderate SBS contributed 190%, and area in high SBS contributed 200% of pre-fire runoff for the runoff event evaluated. The regression-derived 50%-annual-probability (two-year recurrence interval) flood was selected for analysis. This flood has an 88% chance of occurring in the next three years, the approximate time it will take for groundcover vegetation to recover to pre-fire conditions.

A small catchment above Lahaina was outside of the acceptable range to obtain reliable results using the regression equations. This catchment was evaluated with the runoff curve number approach (USDA Soil Conservation Service, 1973) as used in the Wildcat5 spreadsheet interface (Hawkins & Barreto-Munoz, 2016). This approach requires assigning a runoff response *curve number* for different land uses and burn severities. Curve number selection was informed by published values for Hawaii (Lau & Mink, 2006) and field observations (Table 3). Whereas the USGS runoff regression equations estimate flood events of varying occurrence probabilities, the curve number method takes precipitation from a single rainstorm of a given duration and depth, and routes it through a watershed to the outlet. The probability of the selected rainstorm may not equate to the same probability of the resulting flow event. Consequently, runoff predictions using regression equations and the curve number method are not directly comparable. However, pre-fire flow estimates using both methods on this drainage were similar.

Table 3. Runoff curve numbers selected for evaluation of the Lahaina 3 catchment.

Land use class	Curve number
Unburned	75
Low SBS	80
Moderate SBS	90

One or two catchments draining each fire were evaluated (Appendix A-F. Map Products). Catchments were generally selected with outlets at critical values (typically a major road/stream crossing or the ocean). Selected catchments were generally those of the largest streams draining the burned areas. In many cases, the area burned in these catchments was relatively small. The estimates suggest a minor increase in runoff due to burned conditions, except for the small drainage on the north end of the Lahaina Fire (Table 4). Elevated runoff response at the hillslope and small-catchment scale within burned areas is likely to be greater than at the scale of the evaluated watersheds, as results in the 113-acre *Lahaina 3* catchment indicate. However, these smaller-scale effects will generally be diminished in the flow volumes of the larger streams. Critical values immediately downstream of smaller, more extensively burned catchments (such as *Lahaina 3*) are likely at higher risk of damage from elevated post-fire runoff during intense rainstorms. Extensive drainage modification in the *Lahaina 3* catchment

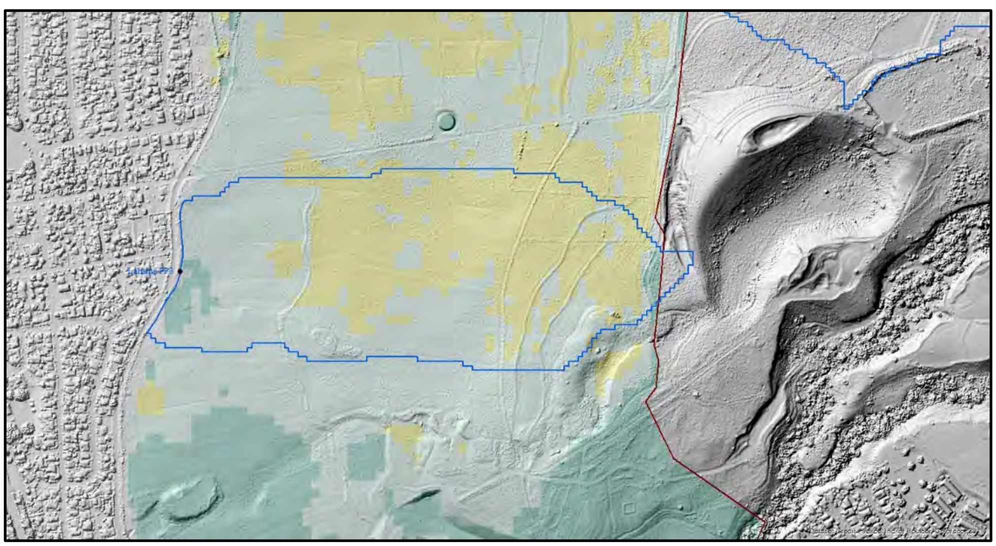

Figure 6. Lidar imagery of the Lahaina 3 catchment illustrating the landscape alterations

may reduce the impact of any elevated runoff event coming from this small basin. The elevation data used to delineate this drainage (10-meter digital elevation model) may not capture the drainage patterns as they actually exist, due to the heavily modified terrain. An increase of runoff in this area is likely to be diffuse across the landscape given the complex microtopography of the area.

Table 4. Estimated percent increase in two-year (50% annual probability) flood for selected watersheds.

Fire	PP#	Catchment name	Area (ac)	Area burned (%)	Area mod+high SBS (%)	Increase in post-fire Q2 (%)
Lahaina*	L3	Unnamed 3	113	84%	43%	180%*
Lahaina	L2	Unnamed 2	560	10%	2%	2%
Pulehu	P1	Keahuaiwi Gulch	5,020	15%	<1%	8%
Pulehu	P2	Waiakoa Gulch	6,080	9%	<1%	5%
Kula	K1	Pulehu Gulch	3,390	2%	1%	2%
Olinda	O1	Kailua Gulch	1,700	16%	8%	11%
Olinda	O2	Kalialinui Gulch	990	9%	<1%	5%
Mauna Kea	MK1	Waiulaula Gulch	1,940	<1%	<1%	0%
Kohala	Ko1	Pohakuloa Gulch	1,660	<1%	<1%	0%
Kohala	Ko2	Kamilo Gulch	340	7%	<1%	0%

* pre and post-fire flows calculated using RCN method with two-year (50% probability), one-hour rainfall event.

The estimated change in runoff due to burned-area conditions described in this report represents an increase in clear water flow. In a post-fire setting, flow volumes are further increased by additional sediment loading, as well as other debris. This flow “bulking” is not anticipated to substantially change flood flow volumes below the 2023 fires, especially in the larger streams draining the burned areas. Although elevated runoff due to post-fire conditions is expected to be muted at larger scales, the additional woody debris and sediment made available by the fires will likely pose a threat to critical downstream values during typical rainy season peak-flow events.

Groundwater recharge is not likely to be affected by any of the burned areas. Aquifers on both islands are recharged across an area much larger than the combined footprint of the fires and are well-connected (State of Hawaii Commission on Water Resources, 2019). Any temporary reduction in soil infiltration capacity in these relatively small areas is unlikely to have a measurable impact on groundwater levels.

2015 Kawaihae Fire and Response

In 2015 the Kawaihae Fire burned roughly 4,500 acres on the island of Hawaii. Within a few days of the fire, a large rain event caused extensive erosion in an extensively burned drainage, resulting in a sediment plume that clouded the ocean and negatively impacted marine life. This event was highlighted to the assessment team as a potential analog to post-fire runoff from the 2023 burned areas.

The 2015 rainstorm had intensities with an approximate return interval of 25-200 years (USDI-NPS 2015, Perica et al. 2011). A rainstorm of this magnitude would likely have caused substantial erosion and sediment delivery from this watershed even in unburned conditions. In addition to the high storm intensity, factors that contributed to the high erosion response in 2015 include a relatively high proportion of burned area (30%) in the large Pelekane Bay watershed (11,350 acres), with several smaller sub-watersheds 90-100% burned. The runoff from the burned area was concentrated into Makeahua Gulch, which is near the bay and had lost riparian vegetation and thus sediment filtering capacity due to the fire. The watersheds draining the 2023 fires have a lower proportion of area burned and soil burn severity is generally low. Nonetheless, if a similar rainstorm were to occur on watersheds burned in the 2023 fires, extensive erosion and sediment delivery are likely, although the burned areas would not be the only or even the largest contributors of sediment.

Geologic Hazards

Debris Flow Potential

Debris flows (also called mudslides) are fast-moving flows of water, fine sediment and rock and are among the most numerous and dangerous types of landslides in the world. They are particularly dangerous to life and property because they move quickly, destroy objects in their paths, and often occur with little advanced warning. Wildfire typically alters the hydrologic response of a watershed such that even modest rainfall amounts can produce debris flows. Debris flows are commonly initiated in steep headwater slopes or from roads.

In most BAER assessments, the probability of debris flows originating in a burned area is estimated by the USGS Landslide Hazards Program, using soil burn severity data provided by the BAER team as well as other parameters. The USGS model divides a burned area into smaller watersheds, up to around 1,500 acres in area. The model predicts debris flow probability for a range of 15-minute rainfall intensities (I_{15}), the upper limit of which is a 40 mm/hr I_{15}.

The USGS provided debris flow probability estimates for all six fires (Appendix A-F. Map Products). The model estimated a low-to-moderate probability for debris flows across most of the burned areas using the 40 mm/hr I_{15}. This is a rainfall intensity with roughly a 50% probability of annual occurrence on the Big Island fires, annual (100%) probability on the Lahaina and Pulehu burned areas, and sub-annually on the Olinda and Kula fires. The probability of debris flows can generally be expected to increase as storm intensity increases. However, in the 2023 fires, the relative narrowness of the watersheds results in relatively few, short tributary channels, limiting the concentration of flow outside of the main channel. Additionally, sediment storage in the main channels is likely insufficient to generate debris flows, especially given the relatively small proportion and low severity of burned area in most watersheds. These characteristics, relatively modest hillslope gradients, and the small percentage of acreage burned all reduce the risk of debris flow initiation on these burned areas. At higher storm intensities, localized slope failures and slumping become more likely, and the suspended sediment load in the main channel flow will increase. In these situations, burned areas are more likely to produce sediment-laden stream flows, as opposed to debris flows. No obvious geomorphic evidence of debris flows was identified in any of the burned areas, suggesting that this process is relatively uncommon in these settings.

Slope Instability and Rockfall

Although the burned areas are not likely to generate a large debris flow, other slope instability such as shallow landslides, slumps, and rockfall are expected to increase in the Kula and Olinda burned areas. Interbedded lava flow layers exposed in the gulch walls have varying levels of erosion resistance with low levels resulting in loose soils, debris cones, and unconsolidated slopes. Local increases in runoff can exacerbate the likelihood of small slope failures. High-velocity streamflow can erode the base of destabilized slopes, creating a negative feedback loop of instability. Woody debris along the gulch that is not entrained in flows may alter flow paths locally, or creating log jams that could direct flow toward banks, causing scour. Streambank erosion and slope instability in the gulches could compromise footings and foundations of homes constructed nearby.

Picture 10. Slope instability observed in the Kula Fire (USDA FS)

Rockfall is a type of rapid landslide where rocks or particles of rocks fall down steep to vertical slopes. Generally, rockfall is composed of one to a few rocks. Rockfall typically originates from hard, erosion-resistant rock that becomes unstable for a variety of reasons. Rockfall events can cause property loss, personal injury, or even loss of life. Rockfalls can also create unexpected hazards on roads, causing damage to vehicles. Angular boulders in the channel below fractured outcrops were observed in the gulches. Boulders on loose soils may slide or fall into the gulch. Other areas potentially at risk from falling rock and debris are homes and roads directly downslope of burned slopes.

Summary of Post-fire Watershed Response

- Soil burn severity is low to moderate throughout the majority of burned areas.
- Erosion will be elevated slightly in most of the burned areas, and substantially elevated on and near areas of moderate and high soil burn severity in gulches.
- Ash and fine sediment will likely be transported to stream channels and washed downstream during the first substantial rainstorms, potentially impacting the nearshore ocean environment.
- Mobile woody debris in many of the stream channels throughout the burned areas will likely be entrained in flood flows, threatening downstream in-channel structures such as culverts, bridges, and diversions.
- Water quality in streams and the nearshore environment will be impaired by ash, fine sediment, nutrients, and dissolved organic carbon during and following rainfall on the burned areas.
- Fire-related increases to flood flows are predicted to be minimal at the watershed scale due to the relatively small area burned within each watershed and the generally low severity of the burn.

- The probability of debris flows was predicted by USGS models to be relatively low for most of the burned areas with a 15-minute rainfall intensity of 40 mm/hour (about 0.4 inches in 15 minutes).
- Rockfall and hillslope instability are risks on steeper slopes, especially in Kula fire area.

Post-fire Vegetation Mapping and Recovery

The USDA FS's *Rapid Assessment of Vegetation Condition After Wildfire* (RAVG) program creates vegetation burn severity products that represent the wildfire effects to forested vegetation. These products are percent basal area loss, percent canopy loss, and composite burn index. Regression equations, based on field data (tree mortality data by species and size class), are used to derive the burn severity metrics. These product help wildlife biologists, botanists, silviculturists, and other specialists understand what to expect from the changed landscape for wildlife habitat, invasive weeds, timber production, among other parameters. RAVG maps are typically created several months after the fire in order to capture delayed post-fire tree mortality. While a formal RAVG product was not created for this assessment, a preliminary vegetation mortality map with seven classes was produced using similar methodology to the RAVG product. The maps produced for the fires are calibrated using field data from the mainland United States based on forested ecosystems and, therefore, are not an accurate reflection of vegetation burn severity for these fires. Many areas are showing low vegetation mortality in this product because the model does not accurately represent vegetation mortality of grassland and agricultural areas. It is presented here for comparison to the soil burn severity map and to provide a preliminary estimation of vegetation mortality on the burned areas (Figure 7, Appendix A-F. Map Products).

Post-fire recovery varies greatly based on climate, vegetation types and soil burn severity. In typical mainland western US fires, re-establishment of groundcover in areas with low to moderate soil burn severity occurs within 3-5 years. In the 2023 Hawaii burned areas, with mostly low and moderate soil burn severity and fire-adapted non-native grasses, vegetation recovery will likely be rapid, with ground cover approaching pre-fire levels during the first year following the fire. However, drought conditions following wildfires can delay recovery.

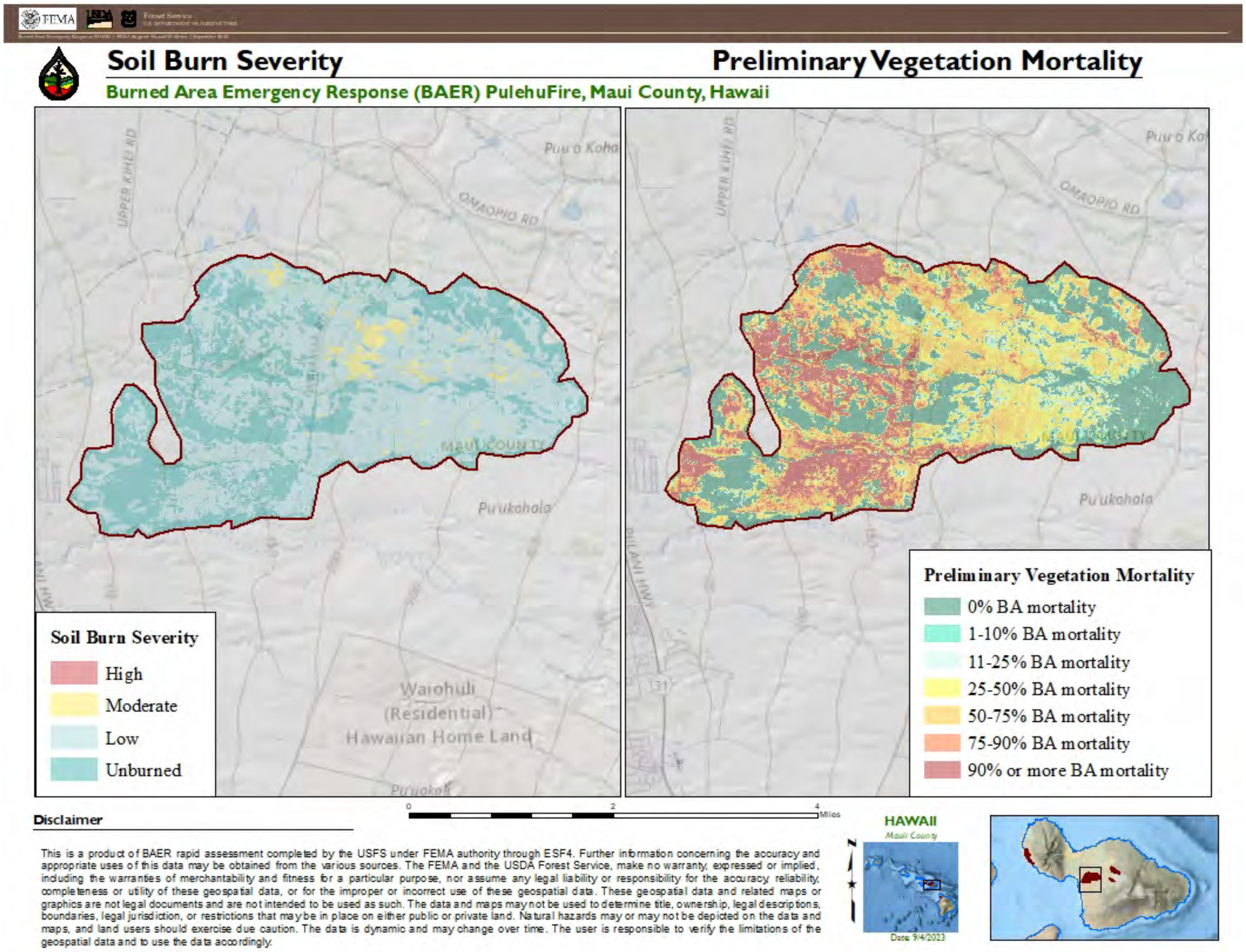

Figure 7. Comparison of Soil Burn Severity to Preliminary Vegetation Mortality for the Pulehu Fire

Summary of Results by Burned Area

Lahaina

The area surrounding Lahaina is relatively flat and surface drainage has been heavily modified with numerous berms, ditches, and impoundments, particularly on the south side of the fire. The upland areas burned at predominantly low and moderate soil burn severity. Soils are susceptible to wind and water erosion, especially in the northern part of the fire. Erosion rates are anticipated to increase in higher intensity, lower probability rainfall events. Across most of the undeveloped burned area on this fire, runoff potential was already higher than what would be expected under natural conditions due to past land use practices. Fire impacts will likely lead to an increased runoff response above the pre-fire conditions. The largest watershed draining to Lahaina has very little burned area and is effectively routed through town in an engineered channel. Burned-area influence on runoff in this watershed will be minimal. A smaller (113-acre) watershed upslope of the north side of town (*Lahaina 3*) burned across 84% of its area. Post-fire runoff from this catchment for a 50%-probability rainstorm was estimated to be more than double the pre-fire rate, potentially posing an elevated risk to downstream safety and infrastructure. Extensive drainage modification in this catchment may mitigate this risk to some degree, though some of these features may need to be cleaned out or repaired in order to be functional. On the south side of town, burned areas are hydraulically disconnected from natural channels by berms, ditches, and other work. Eroded sediment from smaller storms may be impounded by these features and remain on site. Burned woody debris in the channels and along banks can be mobilized during high flows, impacting undersized in-channel infrastructure downstream.

Picture 11. Sediment basin in the northern part of the Lahaina Fire (USDA FS)

Pulehu

Slopes within the Pulehu fire are relatively gentle apart from gulch walls. However, surface roughness has been altered by past agricultural practices through removal of surface rock and construction of berms and furrows. Grass roots hold the soil in place where they have not been consumed by the fire. Soil burn severity was observed to be predominantly very low to low with isolated areas of moderate SBS. These soils are susceptible to an increased risk of wind and water erosion due to the removal of surface rock. Changes in runoff due to the fire were predicted to be modest at the scale of the mainstem streams, reflecting the generally low severity of the burn and relatively small proportion of the drainages impacted by the fire. Areas prone to flooding downstream are at a slightly elevated risk of flooding due to burned conditions and the addition of woody debris into post-fire flows. For example,

Picture 12. Riparian area in the Pulehu Fire (USDA FS)

due to inherent flood risk, the capacity of the small road bridge near the shore in Kihei was frequently exceeded during even small floods in pre-fire conditions. While post-fire floods are unlikely to be outside the normal range of variability in this stream, the undersized bridge is at a greater risk of plugging due to the potential for higher levels of large woody debris floating downstream from the burned area. Buffel grass (*Cenchrus ciliaris*), the primary vegetation in the fire area, is likely to recover by the end of the next wet season based on observations from similar burned areas. However, non-native axis deer may threaten regrowth and prolong recovery to pre-fire conditions.

Kula

The Kula fire is located at higher elevations, receives higher rainfall at the storm and annual scales, and has steeper slopes relative to most of the other fires apart from Olinda. The larger stream channels are deeply entrenched with unstable gulch walls that exhibited slumping, sliding, and rockfall in pre-fire conditions. Soil burn severity was predominantly low with areas along the gulches found to have moderate and high (15%) SBS. Soils show severe to very severe water and wind erosion hazards. Gulches in the burned area are anticipated to have increases in erosion rates even in smaller, more common runoff events. Elevated post-fire watershed response from the Kula burned area was predicted to be minor at the watershed scale, given the small footprint of the fire. However, higher stream flows in the main channel will entrain ash and fine sediment. The gulch will also contribute woody debris to flood flows, threatening downstream infrastructure.

Picture 13. Moderate and high soil burn severity in a gulch in the Kula Fire.

Olinda

The Olinda fire is located at higher elevations, receives higher rainfall at the storm and annual scales, and has steeper slopes relative to most of the other fires aside from Kula. The channels are deeply entrenched with unstable gulch walls that exhibited slumping, sliding, and rockfall in pre-fire conditions. Soil burn severity was predominantly low with areas along the gulches found to have moderate and high SBS. Soils show severe to very severe water and wind erosion hazards. Similar to the Kula Fire, gulches in the burned area are anticipated to have increases in erosion rates even in frequent events. Grassy slopes in the Olinda fire are already recovering and are not expected to contribute substantial additional post-fire runoff. A rapid recovery of groundcover in this area is expected as grasses had intact roots and were observed already resprouting during the field assessment. Burned pine and eucalyptus stands will have a higher post-fire watershed response due to the moderate to high soil burn severity prevalent in these areas. Riparian areas lined with eucalyptus trees exhibited water repellency both in unburned and burned conditions, with depth and thickness of the water-repellent layer increasing in the burned soils. Deep ash and loose sediment along gulch edges can be transported to the channel during rainstorms. Although leaf litter is present, it will likely provide minimal protection or stabilization due to the steepness of the gulch slopes. Leaf litter and woody material contribute surface roughness which will slow runoff and sediment transport on gentler slopes.

Picture 14. Mosaic patterned burn in the Olinda Fire (USDA FS)

Mauna Kea Beach Resort and Kohala

Mauna Kea Beach Resort and Kohala burned areas are on the Kona Coast of Hawaii with relatively low rainfall and relatively low-gradient slopes. Surface-soil rock content is mostly intact in these burned areas. Soil burn severity was predominantly very low and low. The water erosion hazard is moderate for these areas, but the wind erosion hazard is lower-risk due to the high surface-rock content. Like other fires, woody debris, sediment and ash within or near channels can be entrained and transported by stream flow, potentially impacting infrastructure downstream. Channels are entrenched, steep, generally straight and relatively uniform in gradient, so delivery of entrained sediment to the ocean is likely. Localized increases in sediment delivery and runoff are expected, though increases will be minor at the watershed scale due to the relatively small burned areas and low soil burn severity. Some homes below burned hillslopes on the Mauna Kea Fire may be at risk of sediment deposition during heavy rains. In the Kohala fire, some drainages upslope of the highway are unburned or only slightly burned with intact riparian vegetation, whereas riparian areas closer to the ocean saw greater mortality. Grasses are the primary vegetation type across these burned areas, which is expected to recover after the first rainy season.

Picture 15. Low soil burn severity in the Kohala Fire below Highway 270 (USDA FS)

Critical Values, Threats, and Treatment Recommendations

The values considered in this report include life and safety, transportation infrastructure, and critical natural and cultural resources. While several values are discussed below, this report does not contain a comprehensive list of all values that could be affected by post-fire threats.

Measures taken to reduce post-fire risk to critical values generally consist of point-protection measures and larger-scale slope-stabilization measures. Even with large-scale hillslope treatments, it is difficult or impossible to eliminate the risk of elevated flooding below extensively burned areas. Consequently, point-protection measures are generally favored. Measures to reduce risk to individual structures vary widely and would need to be developed through site-specific evaluations.

Life, Safety, and Residential Infrastructure

In typical USDA FS BAER assessments, treatments for the protection of life and safety are the highest priority. Much of this work is coordinated across several Federal and State agencies that all have a role in post-fire protection and response, including land management agencies, weather and meteorological services, and local emergency management agencies, among others.

Picture 16. BAER team working with interagency partners during the assessment process (USDA FS)

During and after heavy rainstorms, people, homes and other infrastructure near stream channels are at risk from floodwaters and debris flows. The risk of flash floods made larger due to burned area conditions is relatively low across most of the fires, with a few exceptions. A small catchment immediately above the north side of Lahaina, which has a high percentage of burned area, and similar smaller watersheds above Mauna Kea Beach Resort may see an elevated response due to post-fire conditions. Users of roads within and downstream of the burned areas may also be at risk from road washouts during and after heavy rainstorms, especially at stream crossings. The National Oceanic and Atmospheric Administration's National Weather Service (NOAA-NWS) can establish an early warning alert plan for areas that are potentially at risk from these events. Additional mitigation measures related to drainage obstructions are described below.

As discussed in previous sections, a potential threat of erosion and sedimentation impacts to houses and other structures exists in all the burned areas except the Pulehu Fire, along with post-fire slope instability observed adjacent to residential areas on the edge of Pulehu Gulch within the Kula Fire.

Recommendations

- State, County, and USDA Natural Resources Conservation Service (NRCS) personnel should continue to evaluate private residences in and around fires areas for post-fire erosion and flooding impacts.
- State, County, NRCS, and other federal personnel should continue to evaluate post-fire slope stability for houses along Pulehu Gulch in Kula fire.
- Ensure drainage ditches and impoundment structures on the eastern edge of Lahaina particularly adjacent to the *Lahaina PP3* catchment and areas directly downhill of burned ground are cleared of debris and are continuous and in good repair to maximize temporary storage of storm runoff and minimize localized flooding in town.
- Compromised trees adjacent to trails, roads, and residential areas should be evaluated for risks to life and safety and mitigated. Priority areas include:
    - Roads and residential areas with fire-damaged trees
    - Waihou Spring Trail in the Olinda fire
    - Mauna Kea Beach Trail in the Mauna Kea Beach Resort Fire
- Coordinate with NOAA-NWS on an early warning alert plan for areas that are potentially at risk.

Transportation Infrastructure

Roads in and downstream of burned areas are at risk of damage due to post-fire conditions. The most likely threat due to the fires is clogging of culverts, bridges, and other in-channel infrastructure from the higher levels of floatable debris (especially burned trees) in burned watersheds. Once blocked by debris, road drainage structures no longer function and the stream flows over the road, often causing considerable damage and limiting access. Debris flows are less likely than debris-laden flood flows, but they pose a greater threat to roads when they do occur and are difficult to mitigate.

Picture 17. Road crossings in the Olinda Fire that would be at risk post-fire (USDA FS)

Post-fire threats to the road and bridge infrastructure will persist for the next couple of years as the watershed recovers. Infrastructure adjacent to and passing through areas of moderate and high soil burn severity are susceptible to increased sediment- and debris-laden flows causing the ditches to fill, infrastructure to plug, and damaging road sections or compromising bridge integrity.

Various measures can reduce this risk, including protecting culvert inlets with debris racks, removing large floatable debris from channels upstream of structures before floods, and making heavy equipment available for rapid mobilization during storm events to keep structures clear of debris. The purpose of road storm-proofing and storm patrol is to move water and debris more efficiently across a road to prevent or mitigate post-fire damage or significant road damage. Storm-proofing treatments include maintaining and clearing debris from existing drainage structures such as rolling dips, culverts, culvert inlets, culvert outlets, ditches, catch basins, and similar features. Sites that likely warrant treatment considerations include:

- Roads located below or passing through areas of high to moderate soil burn severity that are determined to have elevated erosion risk due to increased runoff.
- Roads that intersect sustained steep slopes greater than 10 percent and are located on the lower two-thirds of the slope within areas with high to moderate soil burn severity.
- Road segments around or below areas of high soil burn severity that lead to areas of concern such as homes, recreation sites, and water collection sites.
- Road segments and road/stream crossings with the potential to deliver sediment to streams due to flood-caused failure.

Recommendations

Storm-proofing and storm patrol are recommended along roads to keep road drainage functioning and travel routes free of debris. Specific roads that were identified during the field assessment are listed below. Work should be coordinated with state, county, and local road managers for efficiencies in response.

- State highways 37 and 377 - Olinda and Kula burned areas
    - Road-stream crossings, flooding and debris, rockfall, bridge integrity
- State highways 3000 and 30 - Lahaina burned area
    - Flooding, debris and sediment
- County roads - Makawao and Makani Roads - Olinda burned area
    - Road-stream crossings, flooding and debris
- Lower Kula Road - Kula burned area
    - Flooding and debris, bridge and guardrail integrity
- Lower Kihei Road - Pulehu burned area
    - Flooding and debris, bridge integrity
- Roads within the Kohala and Mauna Kea Beach Resort burned areas
    - Flooding and debris, nuisance sediment and rockfall

Water Quality: Nearshore Ocean Habitat

Coral reef and other nearshore habitat is threatened by elevated sediment, ash, and other contaminants from the burned areas. These contaminants include nutrients from burned agricultural and woodlands as well as hazardous materials primarily from developed areas. The primary mechanism of transport to the nearshore environment is in streams draining the burned areas, but wind transport of these materials will also occur. Sediment is derived from soil erosion in the uplands, including the burned areas and unrepaired dozer lines, as well as typical pre-fire sources. However, the amount of additional sediment above background levels that the burned areas will contribute is difficult to predict.

Picture 18. Windblown ash and sediment in a drainage ditch on the Lahaina Fire (USDA FS)

Urban and other developed areas with high potential for erosion of hazardous materials into watercourses include Lahaina as well as developed areas burned in the Kula and Mauna Kea Beach fires. It was beyond the scope of this assessment to evaluate large areas of hazardous materials for post-fire risk and mitigation. At the time this report was written, the US Environmental Protection Agency (EPA) and the US Coast Guard are working with FEMA to mitigate the risk of hazardous materials.

As described above, erosion from the burned areas may occur at rates above those under pre-fire conditions, at least for the first year following the fire. As with erosion from unburned areas, rates will scale with the intensity and duration of rainfall. A considerable potential source of fire-related sediment to streams and the ocean is the network of dozer lines left unmitigated on the landscape. Whereas fire often leaves behind roots, rock, and other materials that help to stabilize the land and aid in its recovery, dozer lines typically remove these materials, leaving a highly erodible surface. This is made worse when the line is on a slope or is connected to a waterway.

It is nearly impossible to prevent sediment and ash from entering and being transported by streams in mountainous wildland fire environments. Although there are various erosion control practices as well as sediment impounding measures that are occasionally used in post-fire settings, they are typically expensive when employed at a meaningful scale and tend to be only partially effective, and only during relatively modest rainfall and flood events.

Erosion and Sediment Control

Post-wildfire storm events in the moderate and high soil burn severity class in and along gulch walls in the Kula and Olinda fires are likely to result in accelerated erosion and sediment delivery. Hillslope treatments such as scattering of wood from mastication or chipping may be effective at a site-specific scale and for low-rainfall-intensity storms. While these efforts are generally overwhelmed by heavier rains and are difficult to implement at a large enough scale across large watersheds to result in a measurable reduction of peak runoff or sediment loading, they can be effective at preventing localized erosion concerns for lighter rains.

When evaluating wood mulching, the size and composition of the mulch is integral to the effectiveness. Wood products come in a variety of size compositions, measured in the predominant length of pieces as well as the percentage of fine material (pieces less than 2” in length). Research has shown that small, rounded wood pieces (typical wood chips) are not effective at reducing erosion because they are easily displaced by overland flow (Foltz and Wagenbrenner 2010, Robichaud et al. 2013). Wood shreds composed of longer material are heavier and can interlock with each other, making the shreds less susceptible to movement by wind or overland flow. While the chipping treatments may not be as effective at erosion control as larger wood shred material, they do provide ground cover and organic matter to the soil to help with mitigate soil productivity loss, especially in low-gradient areas.

Additional treatment options for site-specific erosion control could include placement of wattles or silt fencing around important resources to capture or divert eroded sediment and overland flow.

Recommendations

Consider seeding, mastication, and/or placement of fire-damaged woody material on areas that burned at moderate and high soil burn severity in gulches to mitigate post-fire erosion.

Channel Treatments

Sediment or settling basins are sometimes constructed within or adjacent to ephemeral channels to impound sediment-laden flood waters or debris torrents during a runoff event. The goal of the dams and basins is to reduce the amount of sediment carried downstream, thus reducing impact of high flow volume and sedimentation to the downstream critical value. To have a meaningful positive impact, these structures must have enough volume to store a high percentage of the fine sediment that would otherwise flow downstream. Settling basins are also more difficult to construct and more prone to fail in steep, dissected terrain. They require considerable effort and expense to install properly and have large disturbance footprints. Additionally, to remain effective, basins must be dredged of deposited materials after each basin-filling event, and the sediment removed from the site, which is an ongoing expense. While sediment basins can be cost-effective at a small scale or where extensive suitable terrain exists, they may not be a practical solution for reducing sediment loading and transport in larger streams draining the burned areas.

Recommendations

Some sediment basins and drainage ditches already exist within the Lahaina fire footprint. Maintain and, if needed, clean out debris that is deposited in these structures and ensure culvert outlets are kept clear of debris to ensure the free flow of water. Ensure channels and flow paths leading to sediment basins are functioning as intended, and water flow is not diverted out of the designed systems. Consider larger settling basins if an engineering analysis demonstrates their cost-effectiveness, suitable sites exist, and a longer-term source of funding is identified for maintenance.

Picture 19. Drainage ditch below the Lahaina Fire that needs cleaning (USDA FS)

Fire Suppression Actions and Repair

Picture 20. Dozer line on the Kula Fire (USDA FS)

Suppression repair efforts rehabilitate impacts to the landscape, roads, and other resources that occurred during fire suppression activities. During suppression, fire containment lines were constructed near the burned areas with bulldozers. Some of these lines follow the approximate fall-line of the topography and elevated berms remain on both sides side of the lines. The BAER Team was not able to observe the total extent of the lines. Additionally, there were no water bars or other erosion control measures evident on the observed lines. These dozer lines are likely to become sources and vectors for eroded sediment because bare soil is exposed, there is considerable slope along some of the lines, and the blade berms will tend to concentrate flows. Without intervention, erosion and sediment delivery to nearby or connected stream channels is likely.

Recommendations

When using bulldozers in suppression, follow best management practices. Heavy equipment use best management practices can be found from USDA FS, the National Wildfire Coordinating Group (NWCG), and other sources, a few of which are listed below.

- *USDA FS Dozer Boss S-232 training prework* (USDA FS, undated)
- *NWCG S-236 Heavy Equipment Boss, Student Workbook* (NWCG, 2013)
- *Mechanized Equipment for Fire and Fuels Operations* (Jaffe and O'brien, 2009)

After suppression activities are complete:

- Rehabilitate suppression line created by dozers or other heavy equipment.
    - Where not needed as a future road or fuelbreak, fully rehabilitate the line using an excavator with bucket and thumb to de-compact the soil and interrupt drainage pathways downslope, leaving a lumpy, discontinuous surface. Drag woody material or chipped material into the rehabilitated line and maximize ground contact by pressing material into ground with the excavator. Consider seeding with native plants appropriate to the site.
    - Where needed as a future road, install drainage features (e.g. water bars) to avoid erosion and gully formation. Avoid keeping steep dozer line on the landscape as these are difficult and expensive to maintain. Consider seeding with native grasses.

- Where dozer line crosses a stream, ensure that the line is properly rehabilitated or drained upslope from the stream to avoid sediment delivery from the line. Repair banks as needed and scatter woody debris and mulch in the areas adjacent to the channel.

Vegetation Recovery

Vegetation recovery is key to reducing erosion and preserving the cultural landscape. Native vegetation recovery is complicated in this vastly transformed landscape dominated by non-native tropical grasses and invasive species, the result of several hundred years of land-use practices that have shifted the systems away from indigenous flora. Fire is just the latest disturbance that threatens the remnants of the native landscape. Without intervention, the burned areas provide the conditions for incremental expansion and further entrenchment of fire–adapted invasive species. The dominate species anticipated on the post-fire landscape is Buffel grass (*Cenchrus ciliaris*), native to Africa and tropical Asia. While difficult, the fire provides an opportunity for intervention and restoration of native species. The reestablishment of native species onto the landscape could also lessen the future fire risk over time.

Picture 21. Resprouting grasses observed on the Mauna Kea Beach Resort Fire (USDA FS)

In addition to the non-native vegetation, non-native ungulates have been introduced to the island systems. For example, axis deer from Asia were introduced to the island of Maui in the 1950s to provide hunting opportunities and without a natural predator, populations have expanded. In the post-fire setting, herbivory of resprouting vegetation depletes stored carbon and leads to mortality of plants that would normally recover from fire. This intensive herbivory from introduced ungulates, such as axis deer, is especially a concern for vegetation recovery in the Olinda and Pulehu fire areas. Fencing prevents grazing by non-native axis deer that could inhibit recovery and may differentially impact native species more than island species that evolved in the absence of large herbivore grazing.

Recommendations

- Seeding and/or hydroseeding have been proposed at locations within the burned areas by partner agencies to help control erosion, sedimentation, and restore forage for livestock. In these areas, consider using native seeds in a re-seeding mix where reseeding proposed.
- Consider placing ungulate exclusion fencing in areas where herbivory pressure could hinder vegetative recovery, especially in the Olinda and Pulehu fires.

Other Identified Threats

Additional items identified by the team include the following:

Olinda Fire – The team observed high levels of fuel loading from a combination of standing dead vegetation, eucalyptus and gorse, and concentrated tree piles along dozer lines. Fuels reduction work is recommended to reduce the risk of future wildfire.

Kohala Fire – A pig exclusion fence was noted in a stream channel that could be washed out or compromised in post-fire events by capturing debris. Storm patrol of the fence is recommended to maintain the functionality and prevent additional damage.

Capacity and Collaboration

We encourage the State of Hawaii to continue and expand upon the ongoing collaborations with FEMA, USDA agencies (FS, NRCS, Farm Service Agency, Rural Development, and others), United States Department of Interior agencies (USGS, Fish and Wildlife Service, and others), NOAA-NWS, EPA, U.S. Coast Guard, Army Corps of Engineers, and Hawaii Wildfire Management Organization, among others. These partners can assist in establishing a post-fire assessment and response process. This process includes identifying a rapid post-fire assessment team of key resource specialists and developing post-fire guidance and training materials using existing protocols as well as local knowledge and experience. In addition, we encourage the further development of relationships with local municipalities in fire-prone areas to streamline cooperation and availability for post-fire response on municipal and private land.

The USDA FS Post-fire Programs welcome further collaboration through professional exchange and training opportunities.

Picture 22. Interagency field day on the Kohala Fire (USDA FS)

Monitoring

Monitoring burned area conditions and recovery, as well as treatment effectiveness, can assist in improving post-fire response. We recommend working closely with University of Hawaii, USDA FS Pacific Southwest and Rocky Mountain Research station staff in the development and implementation of monitoring mitigation efforts. We recommend further evaluation of implemented land and channel treatments over time, and especially after heavy rainstorms to assess function, refine methods and best practices, and determine whether repairs or clearing are needed to maintain or improve function in future storms. Monitoring should include tracking of rainfall amounts and storm intensities using precipitation gauges located in representative areas of the burned areas. In addition to rainfall amounts, measurements or estimates of peak stream discharge where significant floods occur can help in understanding what rainstorm magnitude triggers a flood response in various locations and will assist in forecasting hazards from future storms, and on future fires.

In addition to official data collection, the use of "citizen scientists" can provide additional information where there are data gaps. Consider facilitating a network such as the North America-based Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS) where citizens can report, and view data collected on precipitation and flood events.

Conclusions

The overall impression from the USDA FS BAER assessment of the 2023 Hawaii fires is that while the soil burn severity caused by the fires in the reviewed burned areas was predominately low to moderate, post-fire risks remain for the communities, infrastructure, and values within and below the burned areas. Many burned-area watersheds were already hydrologically responsive to rainfall and prone to erosion and sediment transport prior to the fire and will likely be even more responsive due to post-fire conditions. However, vegetation recovery is anticipated to be rapid with ground cover approaching pre-fire conditions within 1-3 years, which will attenuate any post-fire effects on watershed processes.

We encourage the State of Hawaii to continue and expand upon the ongoing collaborations with local, state, and federal agencies and partners for long-term recovery.

Picture 23. Interagency field day on the Kula Fire (USDA FS)

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Appendix A. Lahaina Fire Map Products

Soil Burn Severity Map - Lahaina Fire

Burned Area Emergency Response (BAER) Lahaina Fire, Maui County, Hawaii

Soil Burn Severity

Soil Burn Severity is a measure of the fire's effects on the ground surface and soil condition. This map identifies the fire-induced changes in soil and ground surface properties that may affect infiltration, runoff, and erosion potential. The BAER Team uses this map to identify areas of unacceptable risk to a critical value and where mitigating treatments may be most effective. This product is appropriate for wildland landscapes and does not represent fire effects in developed areas.

<u>Severity Indicators</u>

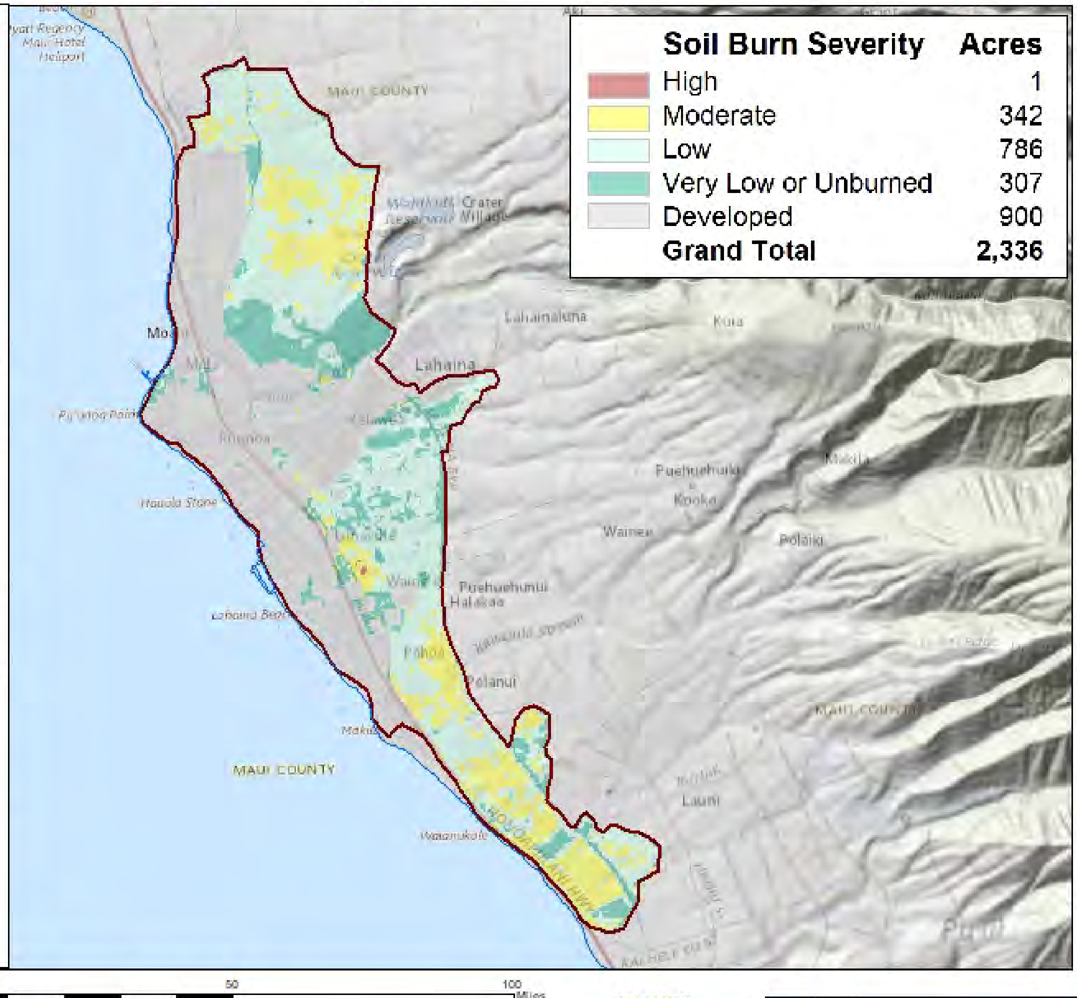
High soil burn severity: Most or all of the pre-fire ground cover and surface organic matter (litter, duff, and fine roots) is generally consumed, and charring may be visible on larger roots. Soil is often gray, orange, or reddish at the ground surface where large or dense fuels were concentrated and consumed. Soil structure is often altered and less stable at the surface.

Moderate soil burn severity: Up to 80 percent of the pre-fire ground cover may be consumed but generally not all of it. There may be potential for recruitment of effective ground cover from scorched needles or leaves remaining in the canopy that will soon fall to the ground. Soil structure is generally unchanged.

Low soil burn severity: The ground surface, including any exposed mineral soil, may appear brown or black (lightly charred), and surface organic layers are not completely consumed. The canopy and understory vegetation will likely appear "green."

Very Low soil burn severity or Unburned: Little to no burn expected within these areas except in small patches, or where fuels were sparce. Canopy and ground litter almost completely intact. Little to no vegetation mortality expected.

For additional information including photo examples of soil burn severity see the Field Guide for Mapping Post-Fire Soil Burn Severity at: https://www.fs.usda.gov/rm/pubs/rmrs_gtr243.pdf



Soil Burn Severity	Acres
High	1
Moderate	342
Low	786
Very Low or Unburned	307
Developed	900
Grand Total	**2,336**

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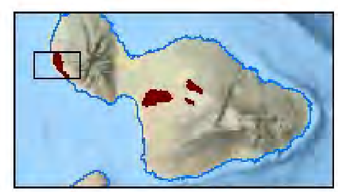
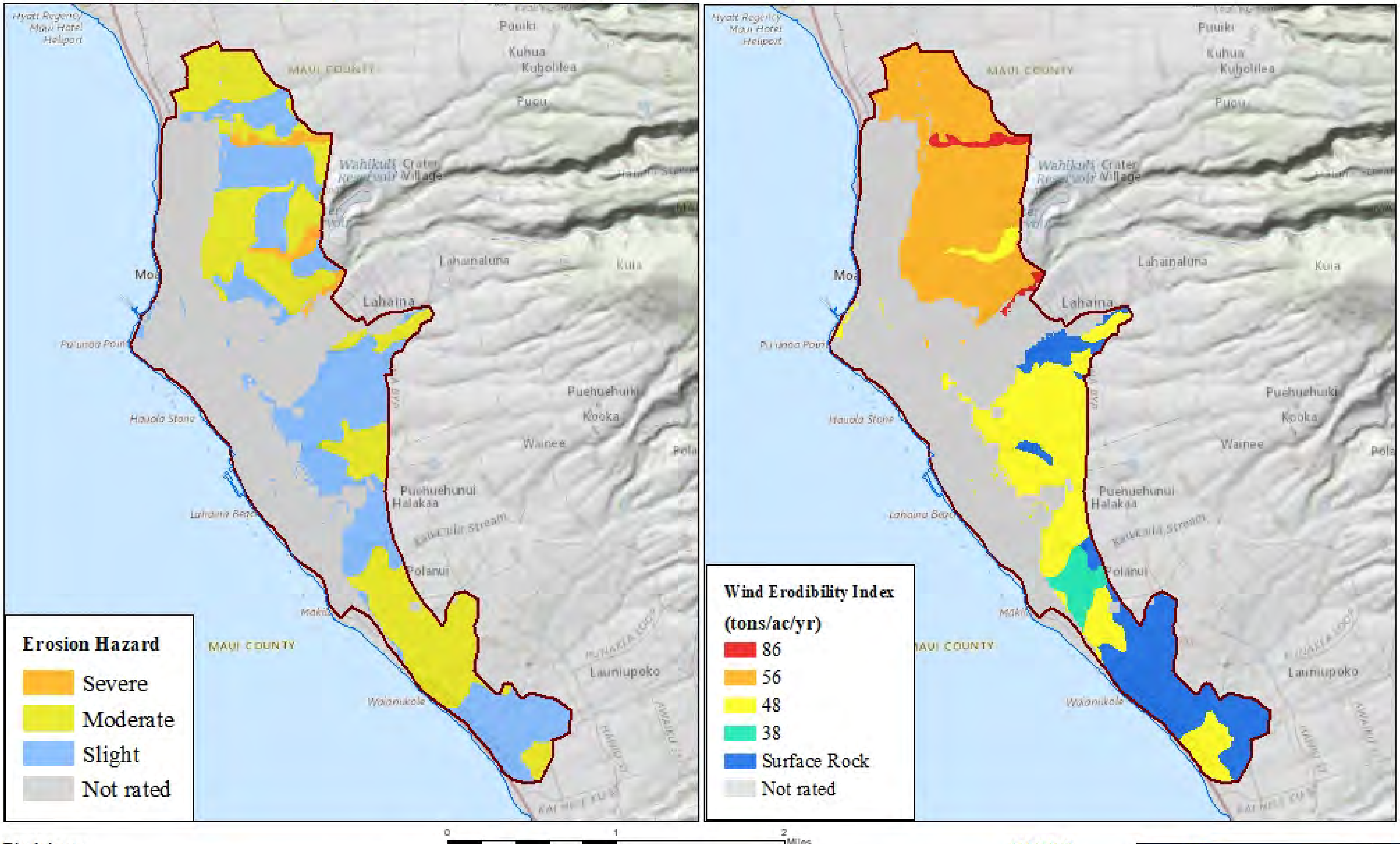


Water and Wind Erosion Hazard Map

Burned Area Emergency Response (BAER) Lahaina Fire, Maui County, Hawaii



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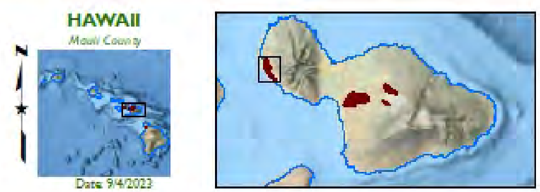
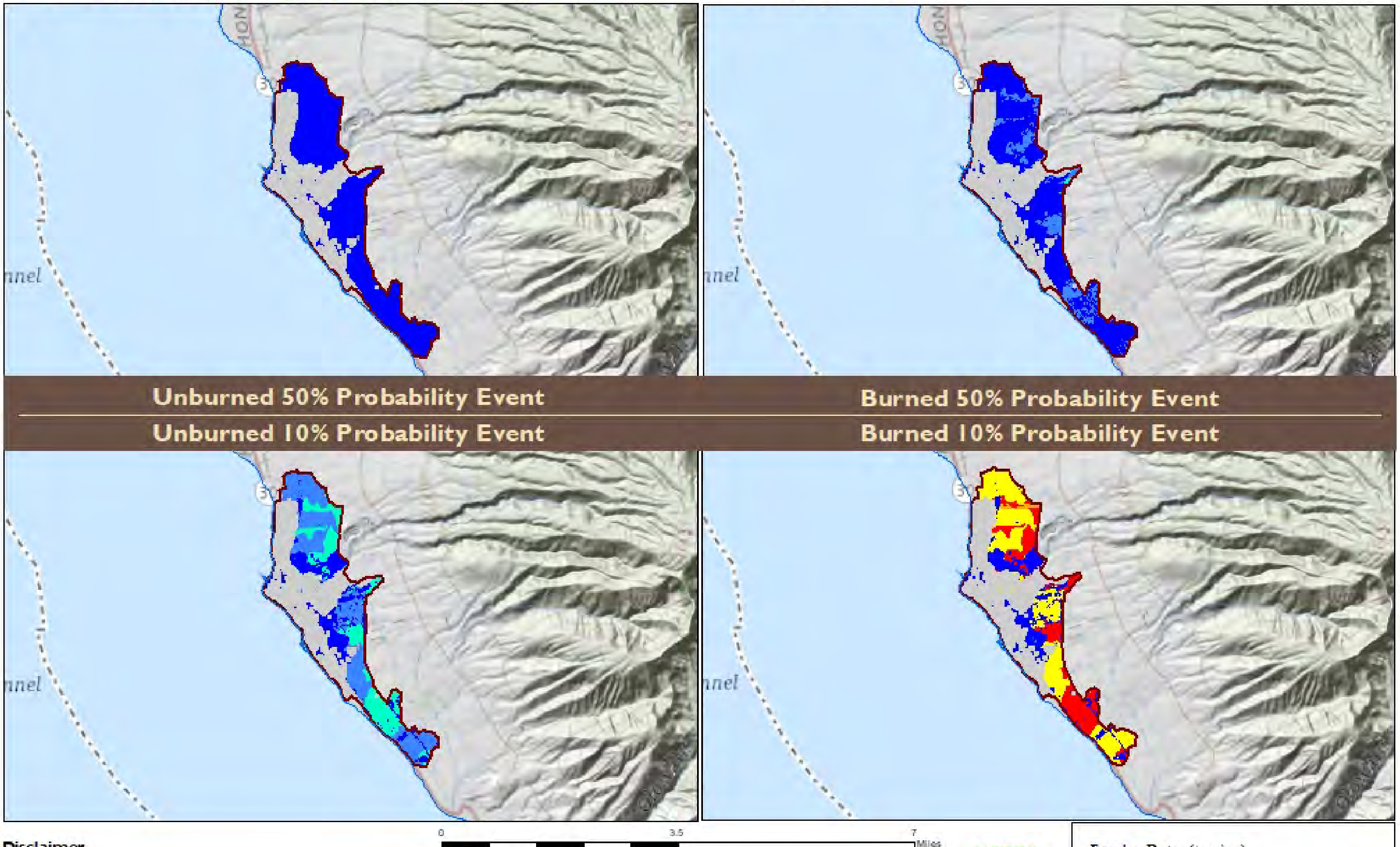


Pre and Post-fire Erosion Rates

Burned Area Emergency Response (BAER) Lahaina Fire, Maui County, Hawaii



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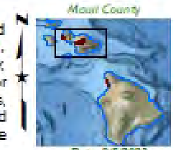
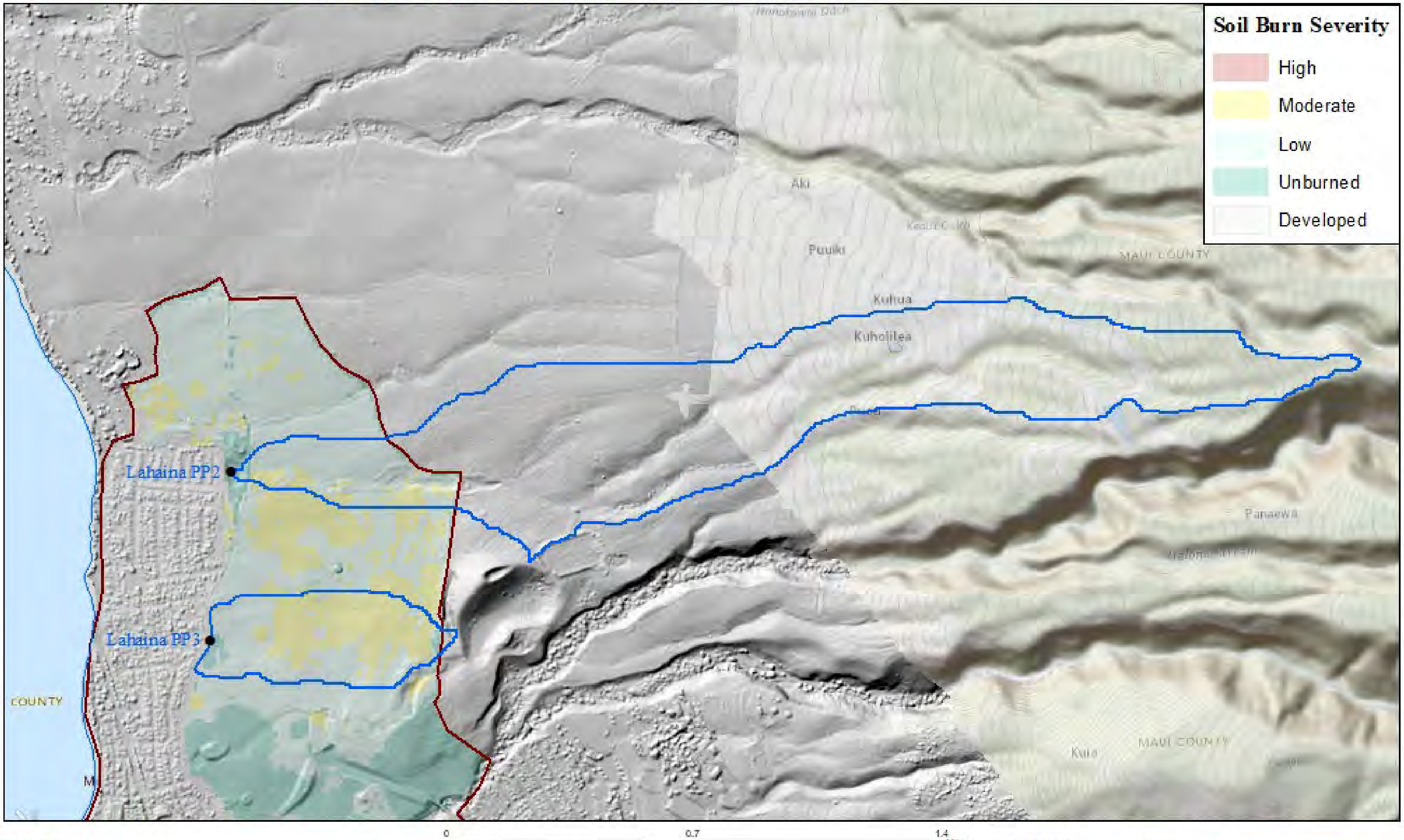


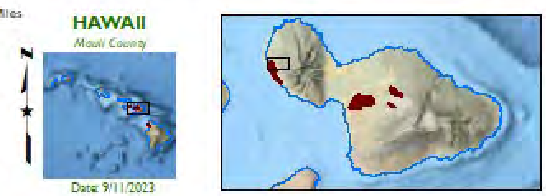
Erosion Rates (tons\ac)

- 0.0 - 1.0
- 1.1 - 2.0
- 2.1 - 5.0
- 5.1 - 7.5
- 7.6 - 10.0
- 10.1 - 20.0
- > 20.0
- Developed Area

Analysis Drainages in Lahaina Fire

Burned Area Emergency Response (BAER) Lahaina Fire, Maui County, Hawaii





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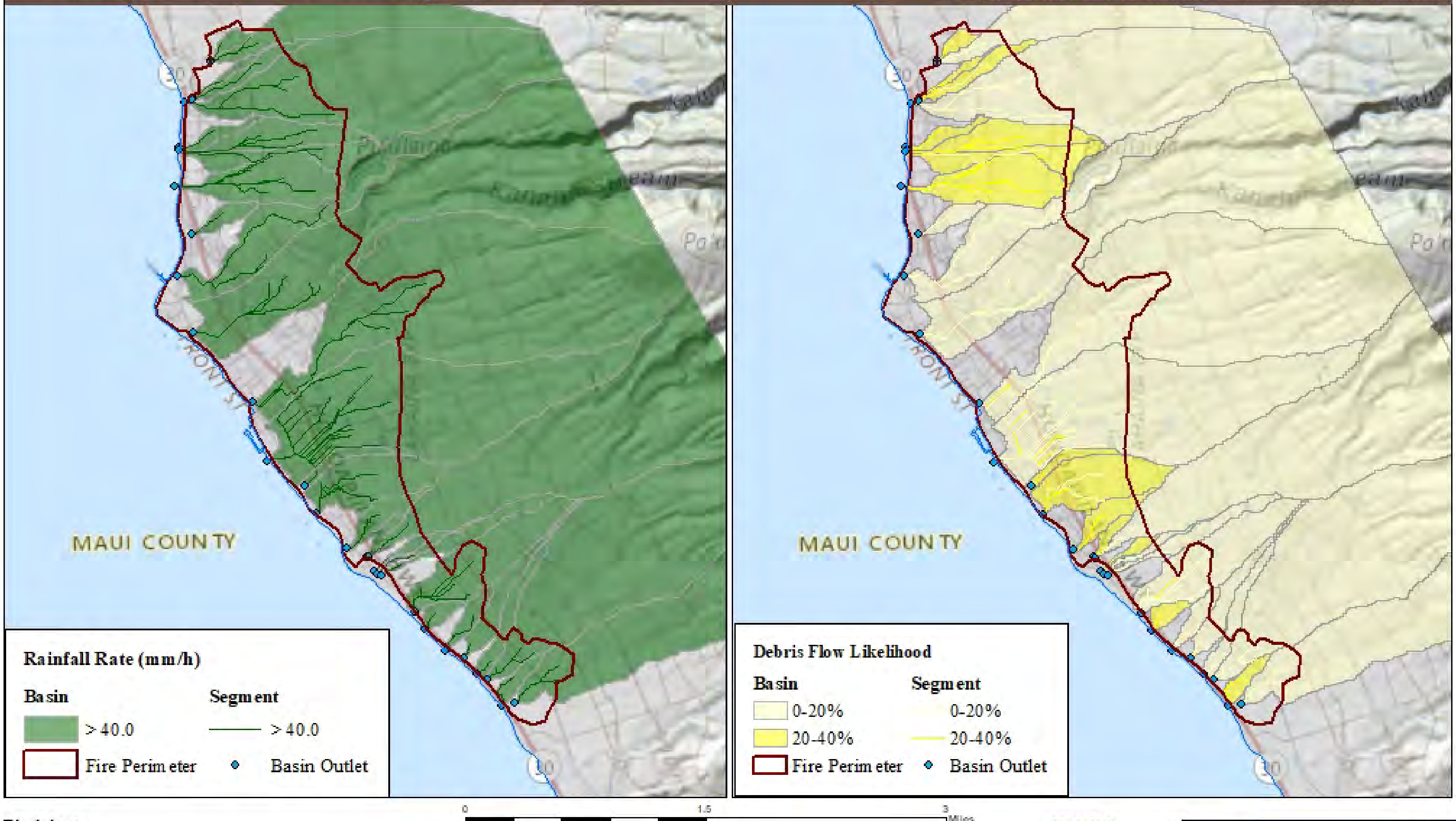
USGS Debris Flow Hazard Assessment

Burned Area Emergency Response (BAER) Lahaina Fire, Maui County, Hawaii

Year 1 Rainfall Thresholds
Rainfall rates that have a 50% likelihood of triggering debris flows

Debris-flow Likelihood
Design storm: Peak 15-minute rainfall intensity 40 mm/h



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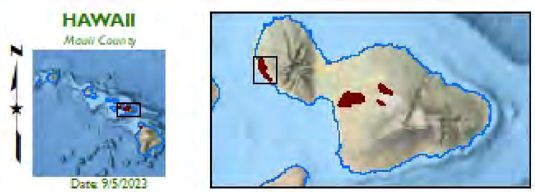


Preliminary Vegetation Mortality - Lahaina Fire

Burned Area Emergency Response (BAER) Lahaina Fire, Maui County, Hawaii

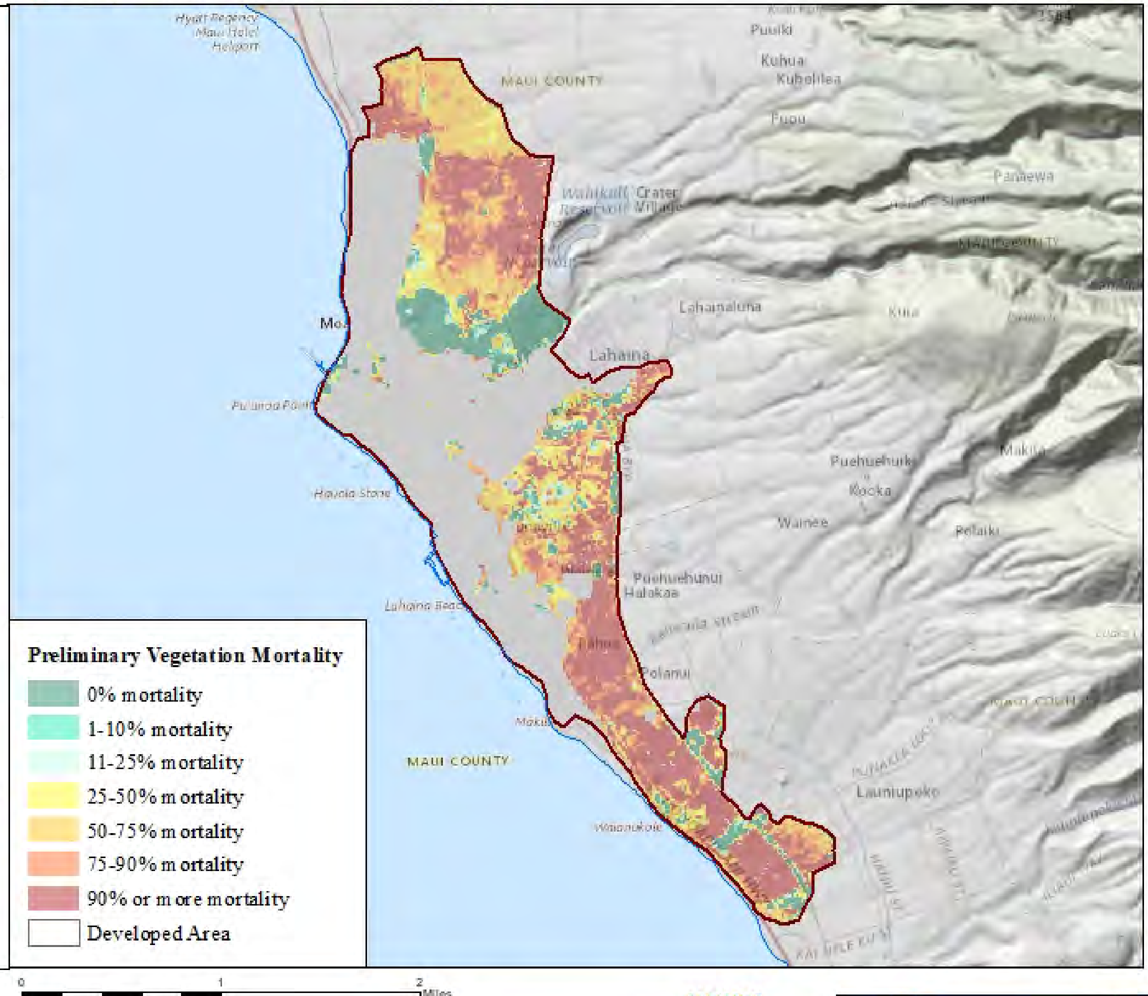
Preliminary Vegetation Mortality

This is a post-fire preliminary vegetation mortality product that focuses on the current wildfire effects to the forest vegetation and is reported in percent of live vegetation loss. This product was derived from satellite image classification, using Google Earth Engine (GEE) to provide image collections and derive cloud-free pre and post fire images over the fire area. This product helps BAER team scientists understand the scope and scale of vegetation mortality in assessing emergency response strategies.

The BAER Team uses this Vegetation Mortality product to compare with Soil Burn Severity to illustrate the difference between the effect of the fire on vegetation vs the effect of the fire on the soil. This vegetation mortality has not been field verified. The classification method used to generate the Vegetation Mortality product was developed for a forested environment and may not be accurate outside that environment. Many other factors can affect the accuracy of an image classification, including regrowth of grasses post-fire and wind erosion removing sediment and ash deposits. This product has not been field verified.

Within the Forest Service this post-fire product is shared with the local forest staff and agency partners for use in assessing fire-related reforestation needs. These data help forest staff on local units prioritize areas for further assessment and facilitate post-fire vegetation management decision-making.

Within the USDA Forest Service Geospatial Technology and Applications Center (GTAC) Rapid Assessment of Vegetation Post-Fire (RAVG), the program produces a similar product using single pre and post-fire images. This product is usually generated 45 days after fire containment to get a more accurate assessment of Vegetation Mortality. For more information on the see: (https://burnseverity.cr.usgs.gov/ravg/).



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Appendix B. Pulehu Fire Map Products

Soil Burn Severity Map - Pulehu Fire

Burned Area Emergency Response (BAER) Pulehu Fire, Maui County, Hawaii

Soil Burn Severity

Soil Burn Severity is a measure of the fire's effects on the ground surface and soil condition. This map identifies the fire-induced changes in soil and ground surface properties that may affect infiltration, runoff, and erosion potential. The BAER Team uses this map to identify areas of unacceptable risk to a critical value and where mitigating treatments may be most effective. This product is appropriate for wildland landscapes and does not represent fire effects in developed areas.

Severity Indicators

High soil burn severity: Most or all of the pre-fire ground cover and surface organic matter (litter, duff, and fine roots) is generally consumed, and charring may be visible on larger roots. Soil is often gray, orange, or reddish at the ground surface where large or dense fuels were concentrated and consumed. Soil structure is often altered and less stable at the surface.

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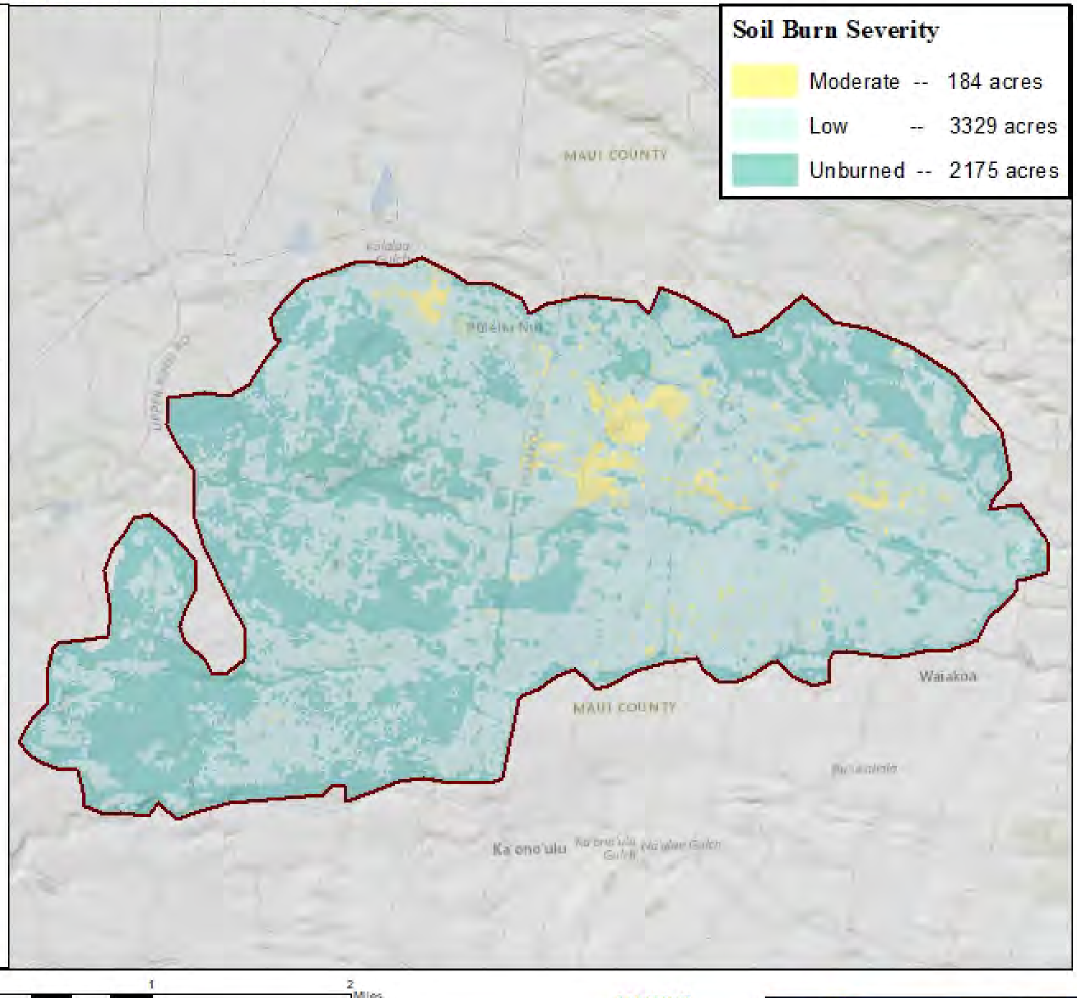
For additional information including photo examples of soil burn severity see the Field Guide for Mapping Post-Fire Soil Burn Severity at: https://www.fs.usda.gov/rm/pubs/rmrs_gtr243.pdf



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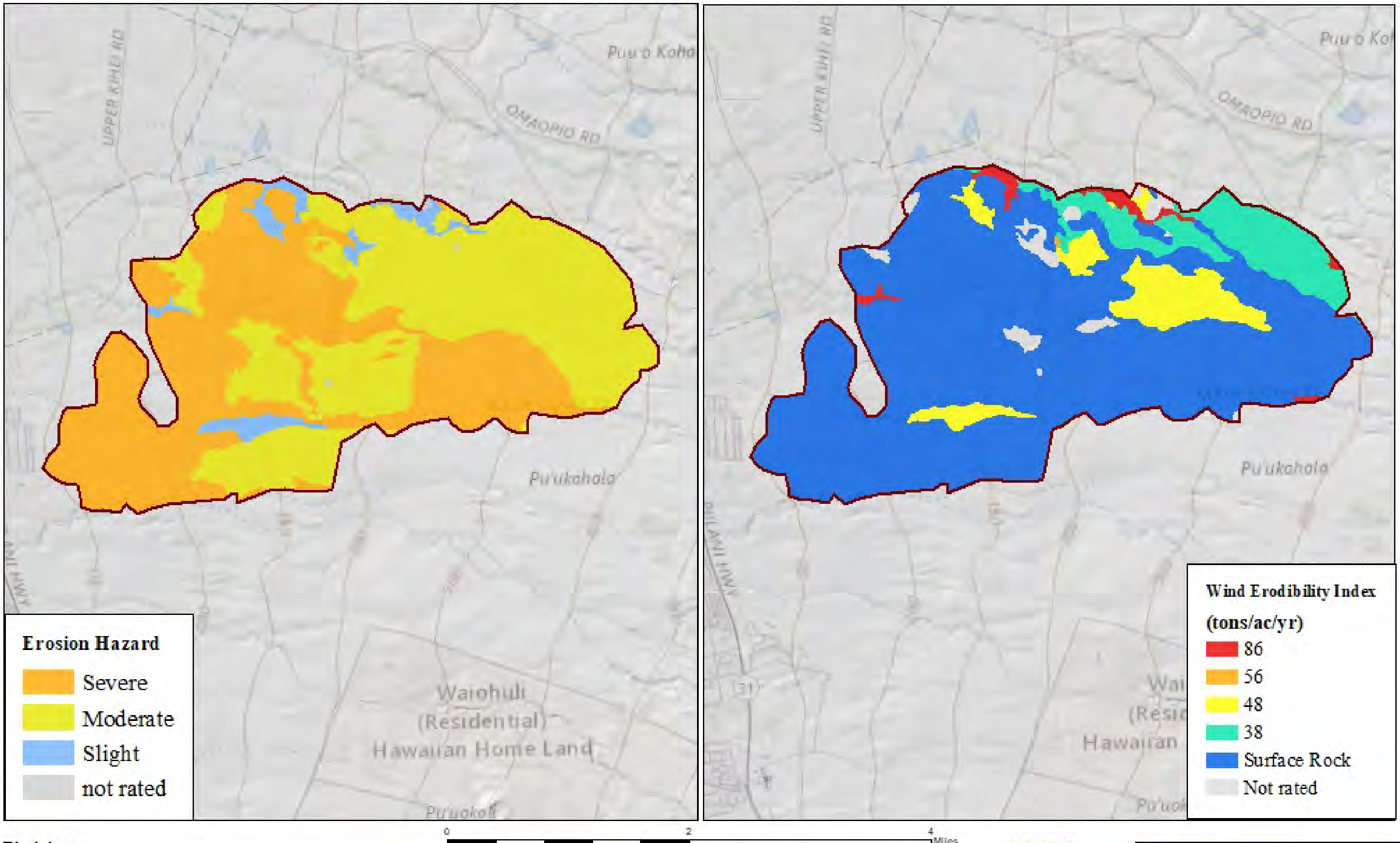
Water and Wind Erosion Hazard Map

Burned Area Emergency Response (BAER) Pulehu Fire, Maui County, Hawaii



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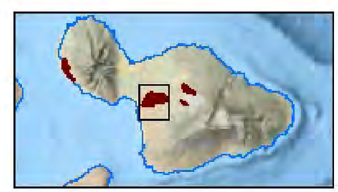
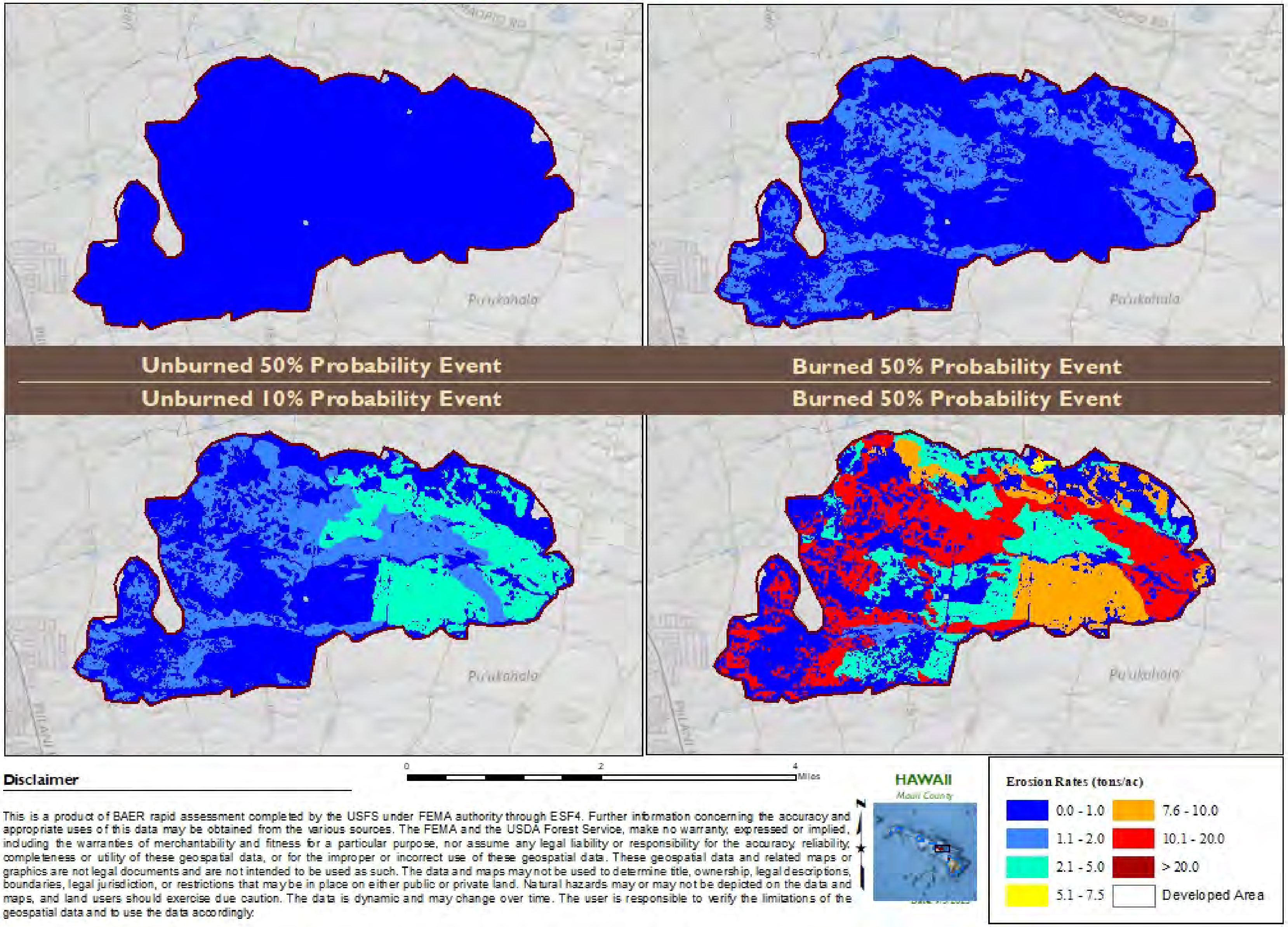


Pre and Post-fire Erosion Rates

Burned Area Emergency Response (BAER) Pulehu Fire, Maui County, Hawaii



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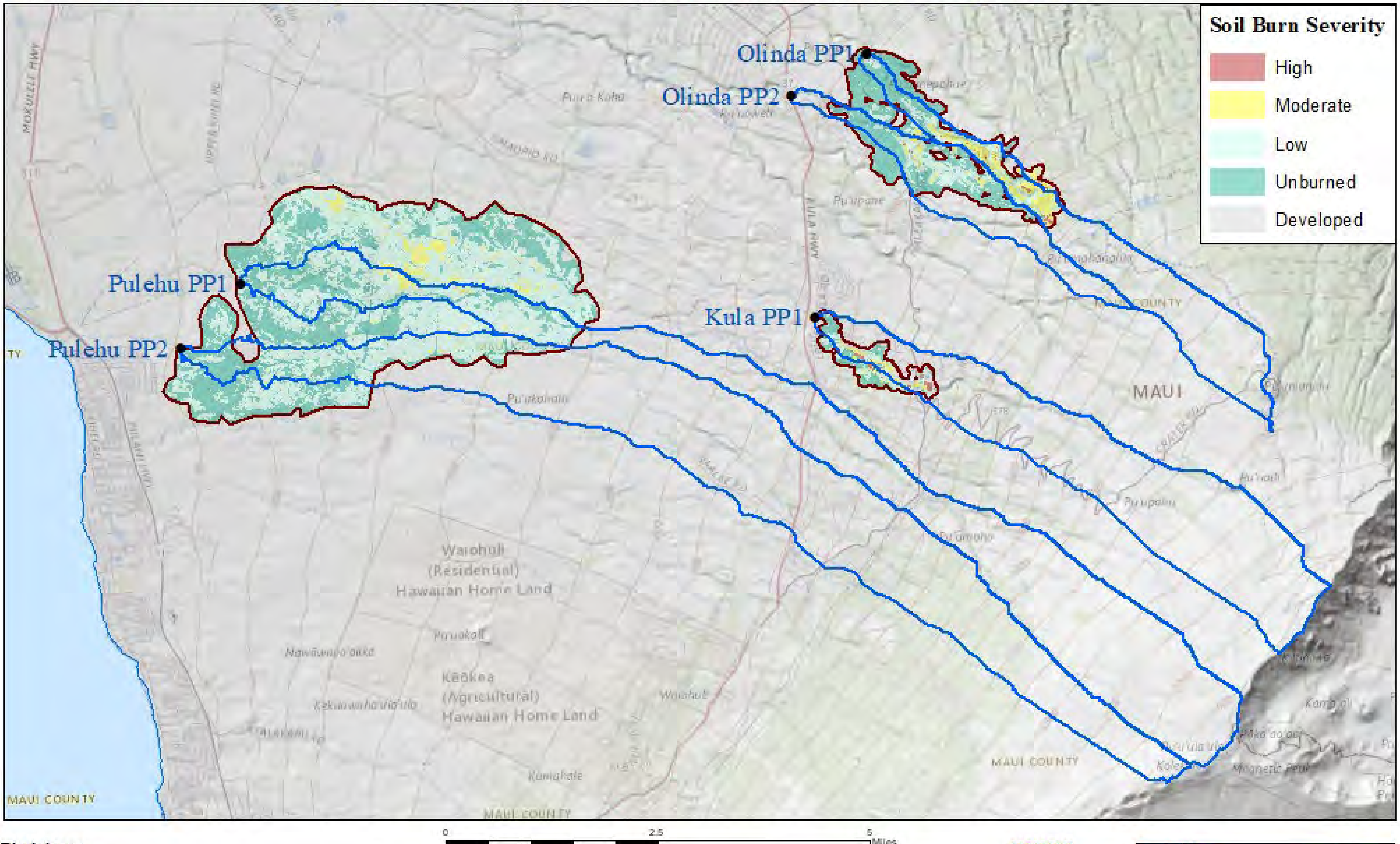
Analysis Drainages in Pulehu, Olinda & Kula Fires

Burned Area Emergency Response (BAER) Pulehu, Olinda, and Kula Fires, Maui County, Hawaii



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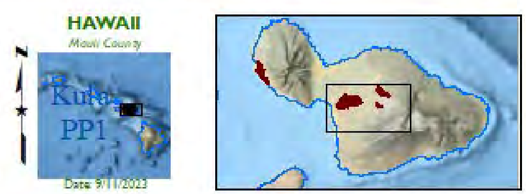
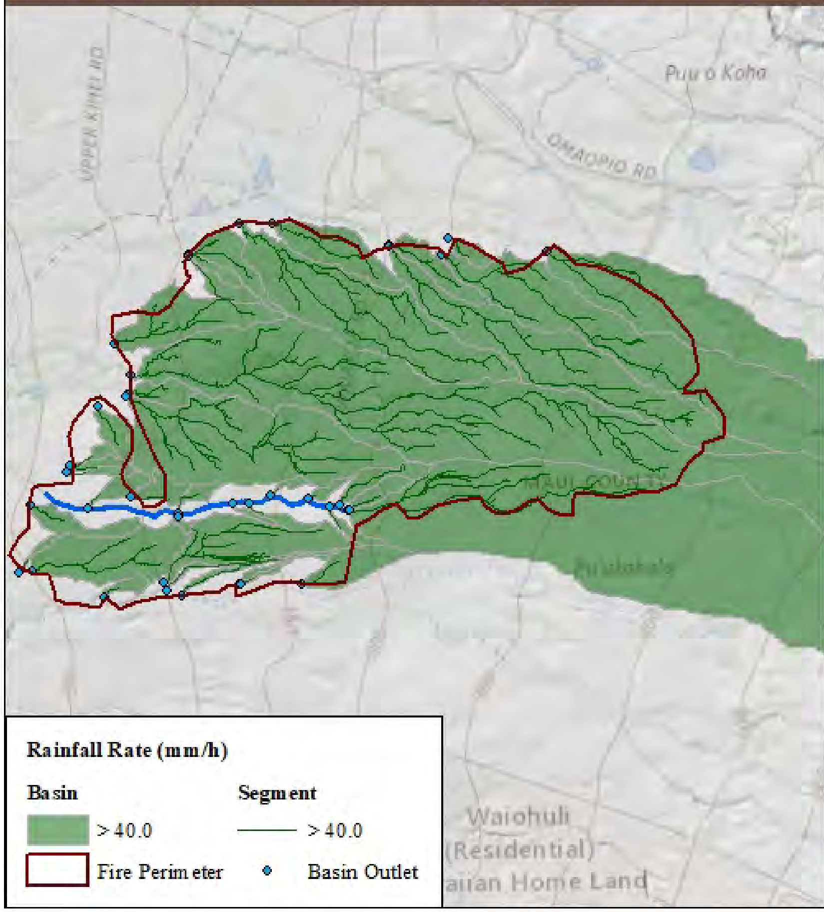


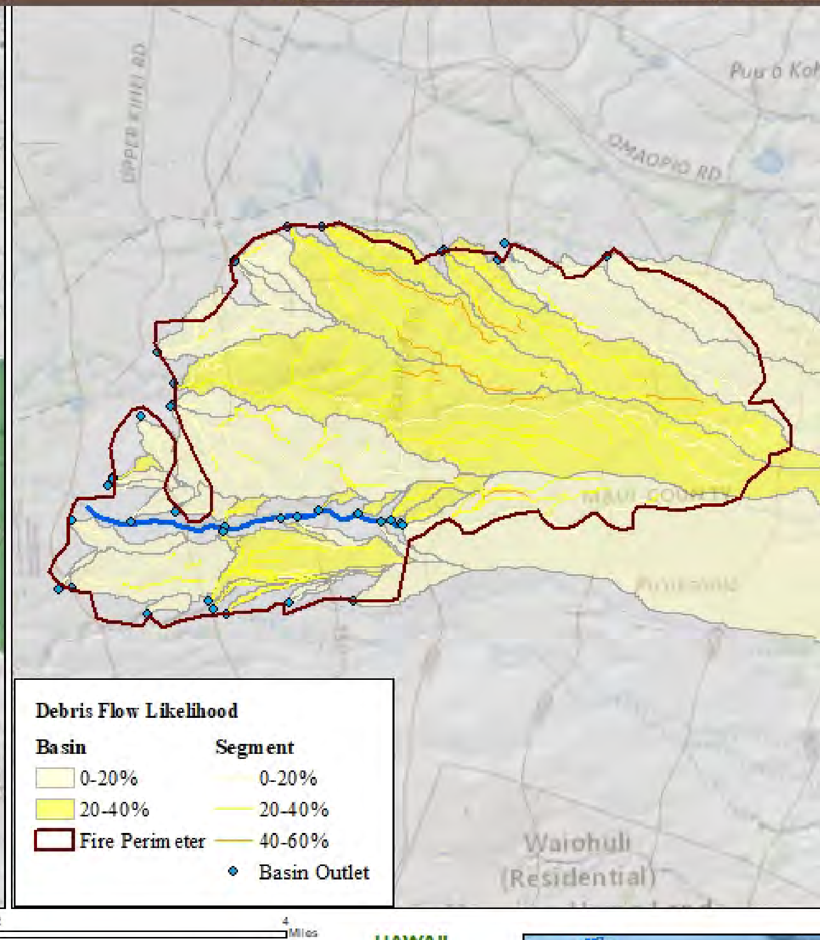
USGS Debris Flow Hazard Assessment

Burned Area Emergency Response (BAER) Pulehu Fire, Maui County, Hawaii

Year 1 Rainfall Thresholds
Rainfall rates that have a 50% likelihood of triggering debris flows



Debris-flow Likelihood
Design storm: Peak 15-minute rainfall intensity 40 mm/h



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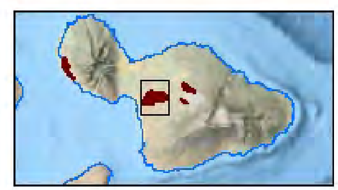
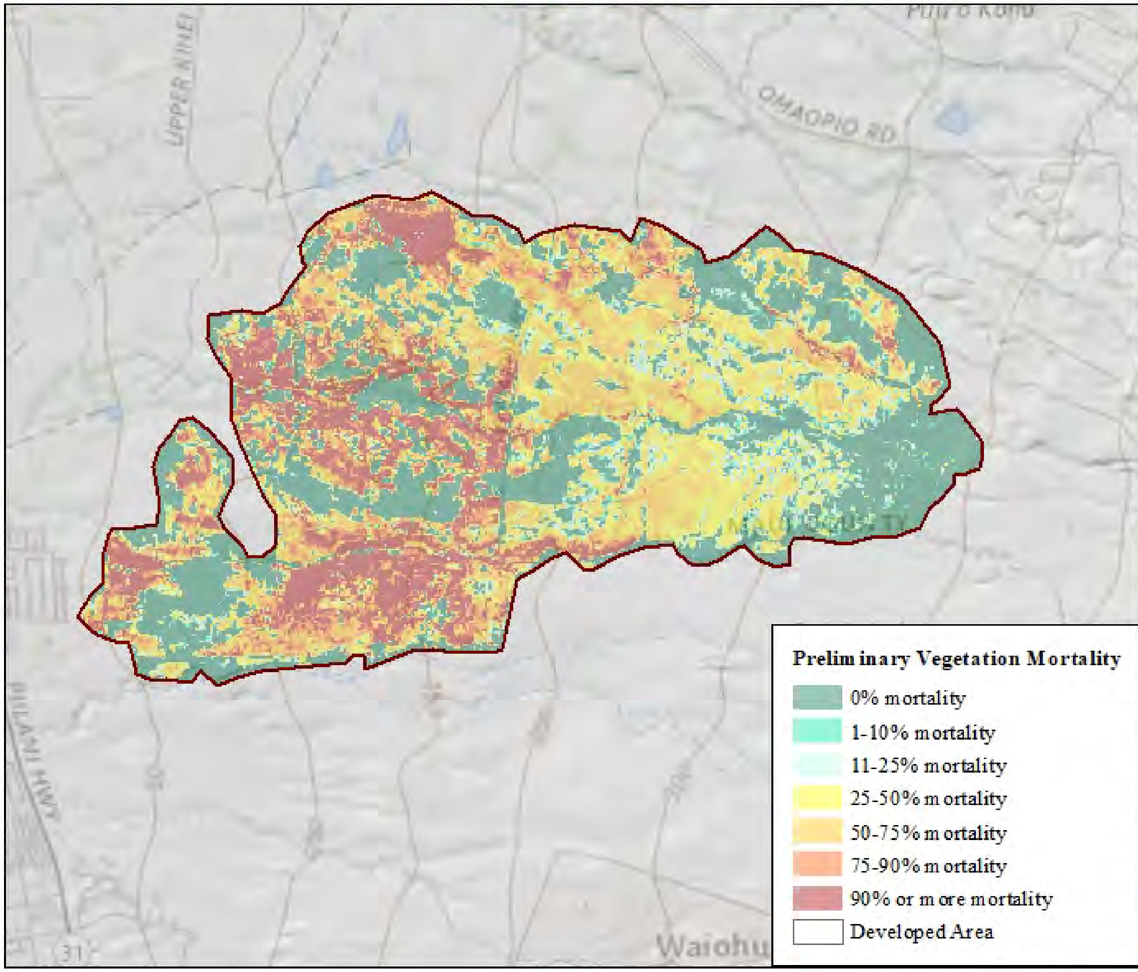


Preliminary Vegetation Mortality - Pulehu Fire

Burned Area Emergency Response (BAER) Pulehu Fire, Maui County, Hawaii



0 1.5 3 Miles

Preliminary Vegetation Mortality

This is a post-fire preliminary vegetation mortality product that focuses on the current wildfire effects to the forest vegetation and is reported in percent of live vegetation loss. This product was derived from satellite image classification, using Google Earth Engine (GEE) to provide image collections and derive cloud-free pre and post fire images over the fire area. This product helps BAER team scientists understand the scope and scale of vegetation mortality in assessing emergency response strategies.

The BAER Team uses this Vegetation Mortality product to compare with Soil Burn Severity to illustrate the difference between the effect of the fire on vegetation vs the effect of the fire on the soil. This vegetation mortality has not been field verified. The classification method used to generate the Vegetation Mortality product was developed for a forested environment and may not be accurate outside that environment. Many other factors can affect the accuracy of an image classification, including regrowth of grasses post-fire and wind erosion removing sediment and ash deposits. This product has not been field verified.

Within the Forest Service this post-fire product is shared with the local forest staff and agency partners for use in assessing fire-related reforestation needs. These data help forest staff on local units prioritize areas for further assessment and facilitate post-fire vegetation management decision-making.

Within the USDA Forest Service Geospatial Technology and Applications Center (GTAC) Rapid Assessment of Vegetation Post-Fire (RAVG), the program produces a similar product using single pre and post-fire images. This product is usually generated 45 days after fire containment to get a more accurate assessment of Vegetation Mortality. For more information on the see: (https://burnseverity.cr.usgs.gov/ravg/).

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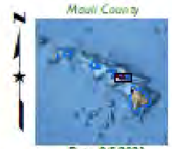
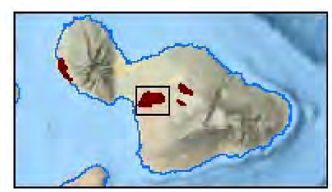
HAWAII

Maui County



Date: 9/5/2023



Appendix C. Kula Fire Map Products

Soil Burn Severity Map - Olinda & Kula Fires

Burned Area Emergency Response (BAER) Olinda & Kula Fires, Maui County, Hawaii

Soil Burn Severity

Soil Burn Severity is a measure of the fire's effects on the ground surface and soil condition. This map identifies the fire-induced changes in soil and ground surface properties that may affect infiltration, runoff, and erosion potential. The BAER Team uses this map to identify areas of unacceptable risk to a critical value and where mitigating treatments may be most effective. This product is appropriate for wildland landscapes and does not represent fire effects in developed areas.

<u>Severity Indicators</u>

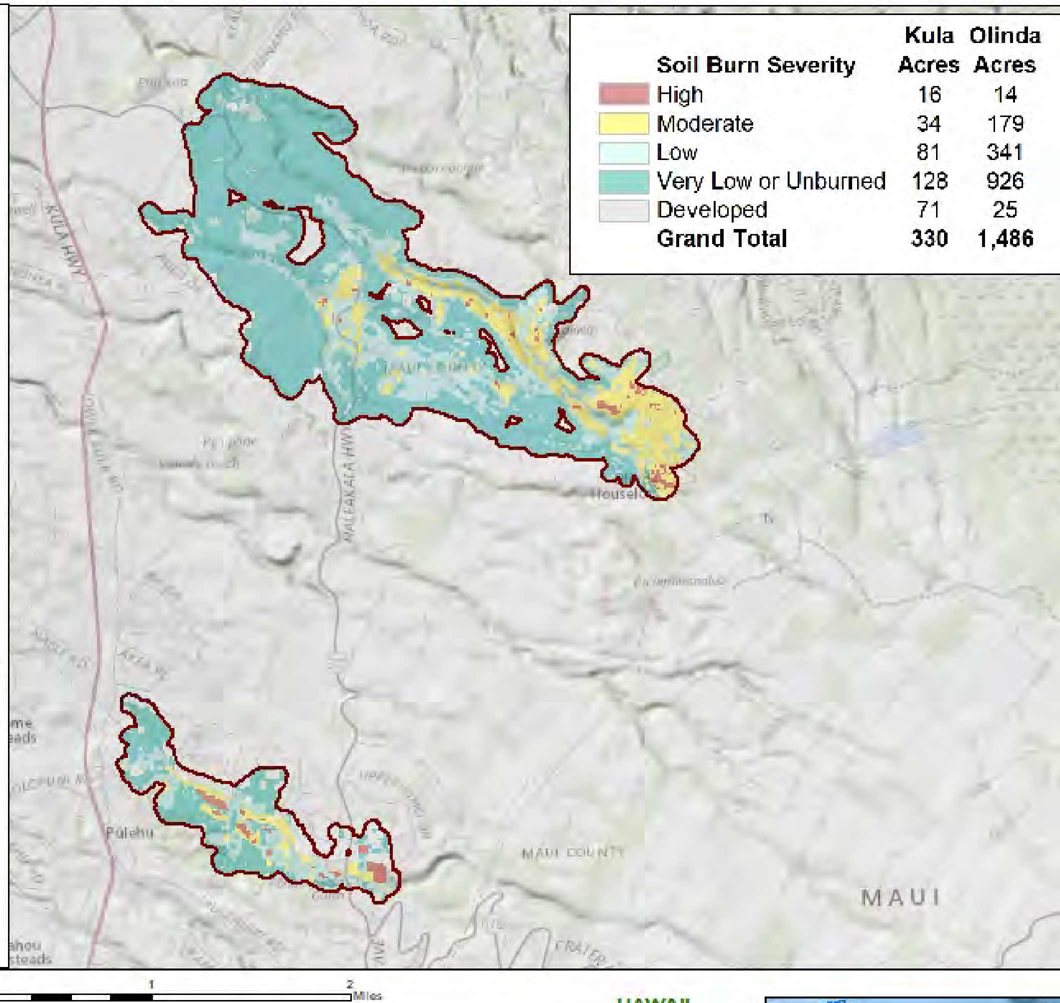
High soil burn severity: Most or all of the pre-fire ground cover and surface organic matter (litter, duff, and fine roots) is generally consumed, and charring may be visible on larger roots. Soil is often gray, orange, or reddish at the ground surface where large or dense fuels were concentrated and consumed. Soil structure is often altered and less stable at the surface.

Moderate soil burn severity: Up to 80 percent of the pre-fire ground cover may be consumed but generally not all of it. There may be potential for recruitment of effective ground cover from scorched needles or leaves remaining in the canopy that will soon fall to the ground. Soil structure is generally unchanged.

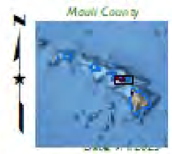
Low soil burn severity: The ground surface, including any exposed mineral soil, may appear brown or black (lightly charred), and surface organic layers are not completely consumed. The canopy and understory vegetation will likely appear "green."

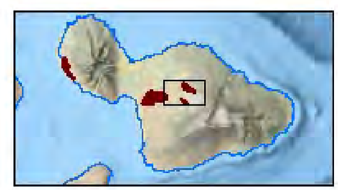
Very Low soil burn severity or Unburned: Little to no burn expected within these areas except in small patches, or where fuels were sparce. Canopy and ground litter almost completely intact. Little to no vegetation mortality expected.

For additional information including photo examples of soil burn severity see the Field Guide for Mapping Post-Fire Soil Burn Severity at: https://www.fs.usda.gov/rm/pubs/rmrs_gtr243.pdf



Soil Burn Severity	Kula Acres	Olinda Acres
High	16	14
Moderate	34	179
Low	81	341
Very Low or Unburned	128	926
Developed	71	25
Grand Total	**330**	**1,486**





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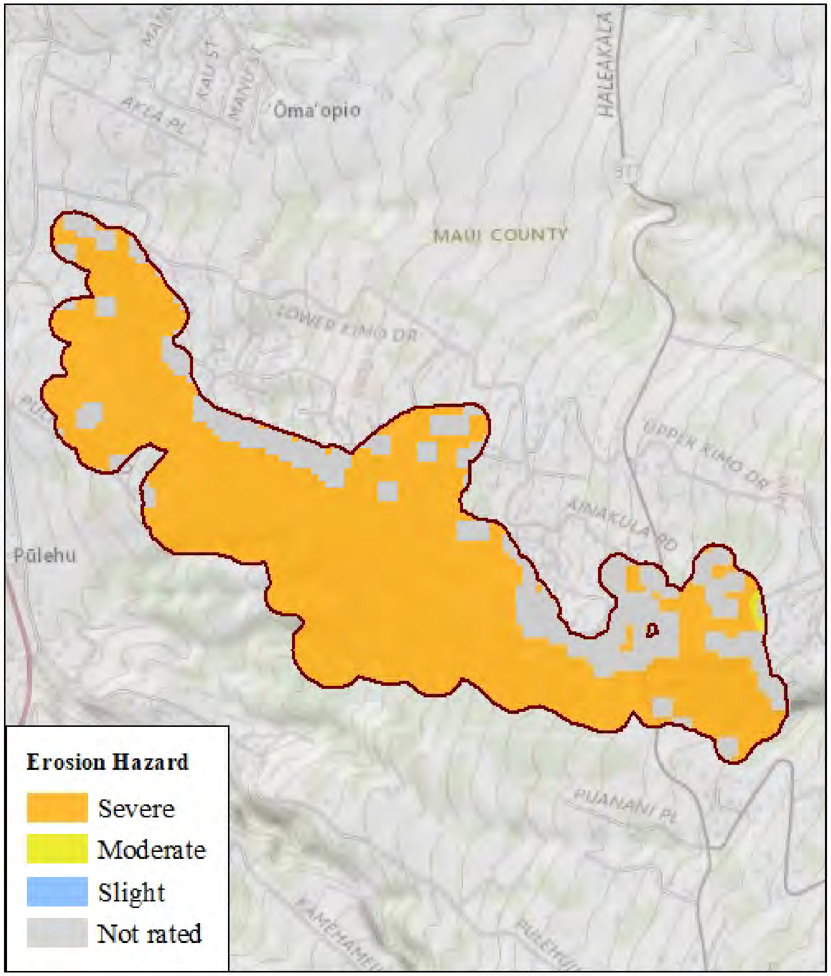
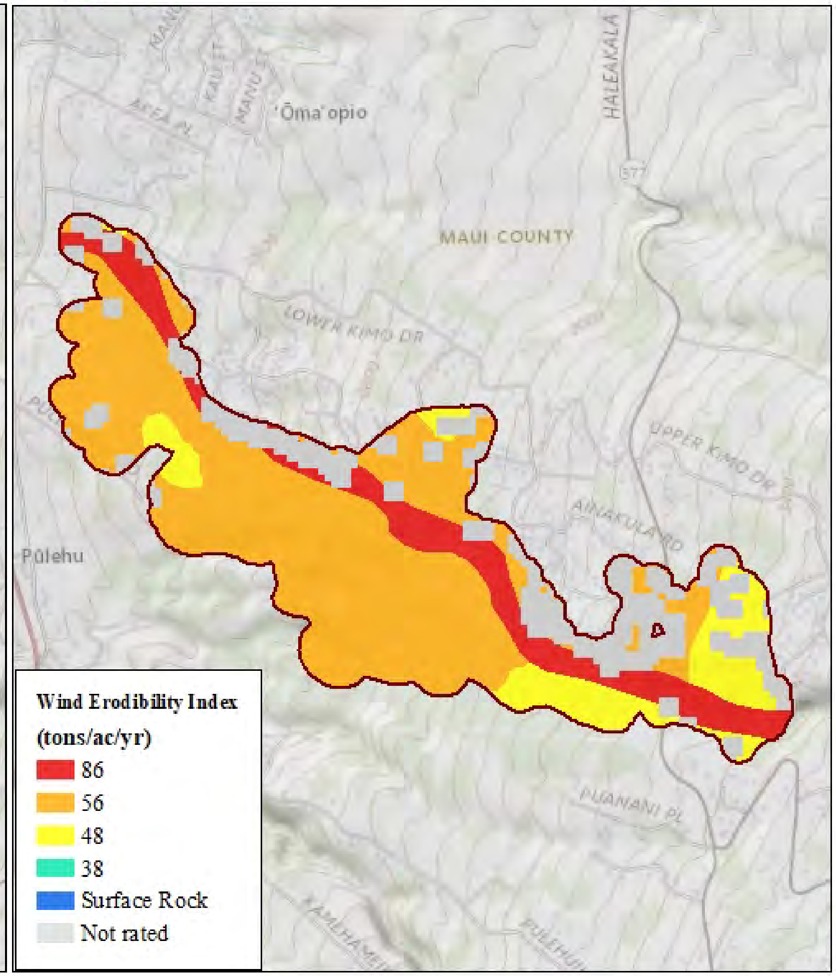
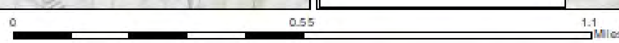
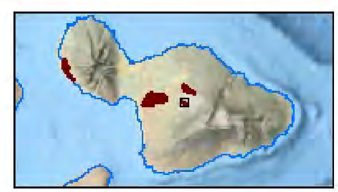
Water and Wind Erosion Hazard Map

Burned Area Emergency Response (BAER) Kula Fire, Maui County, Hawaii









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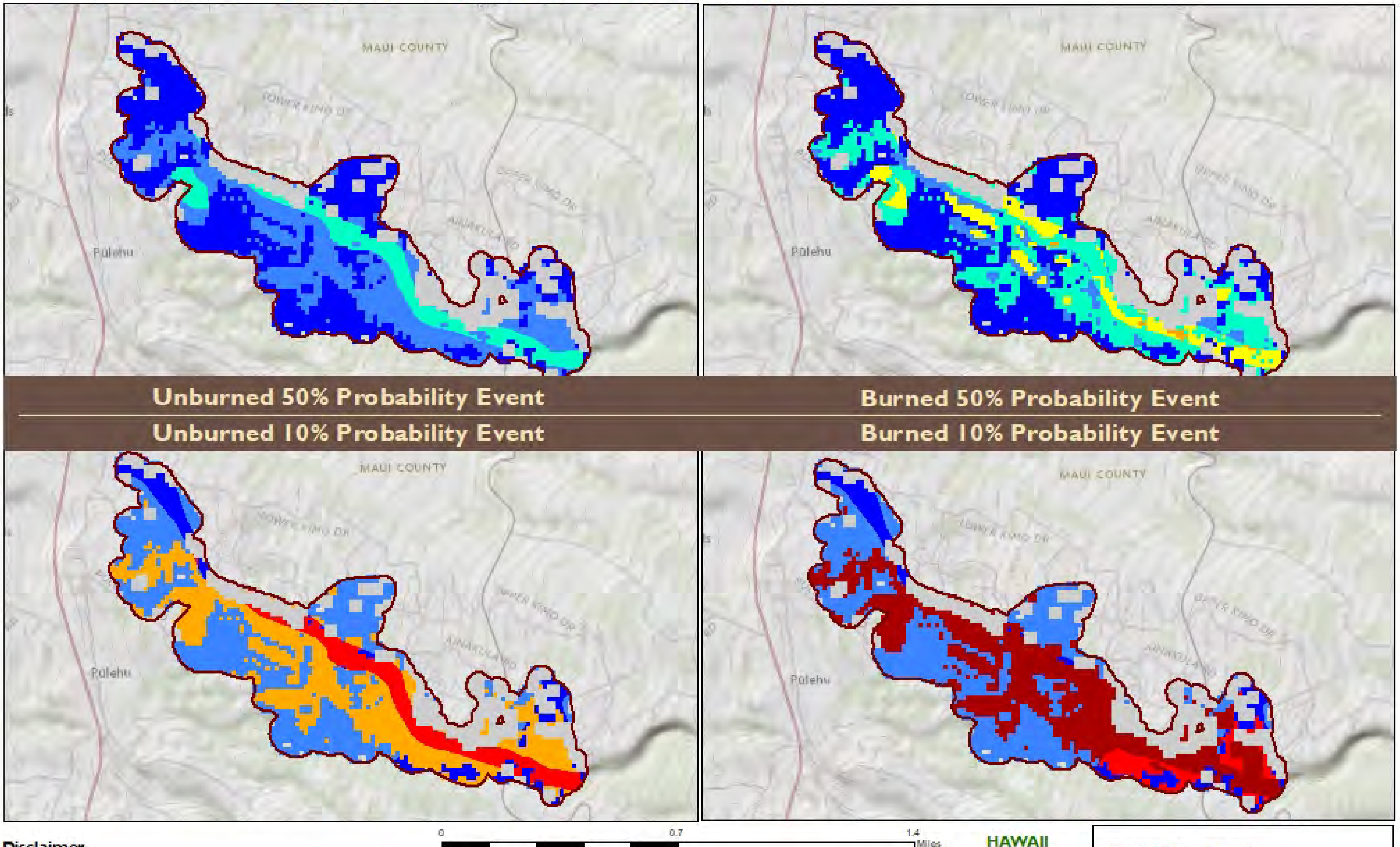
Pre and Post-fire Erosion Rates

Burned Area Emergency Response (BAER) Kula Fire, Maui County, Hawaii



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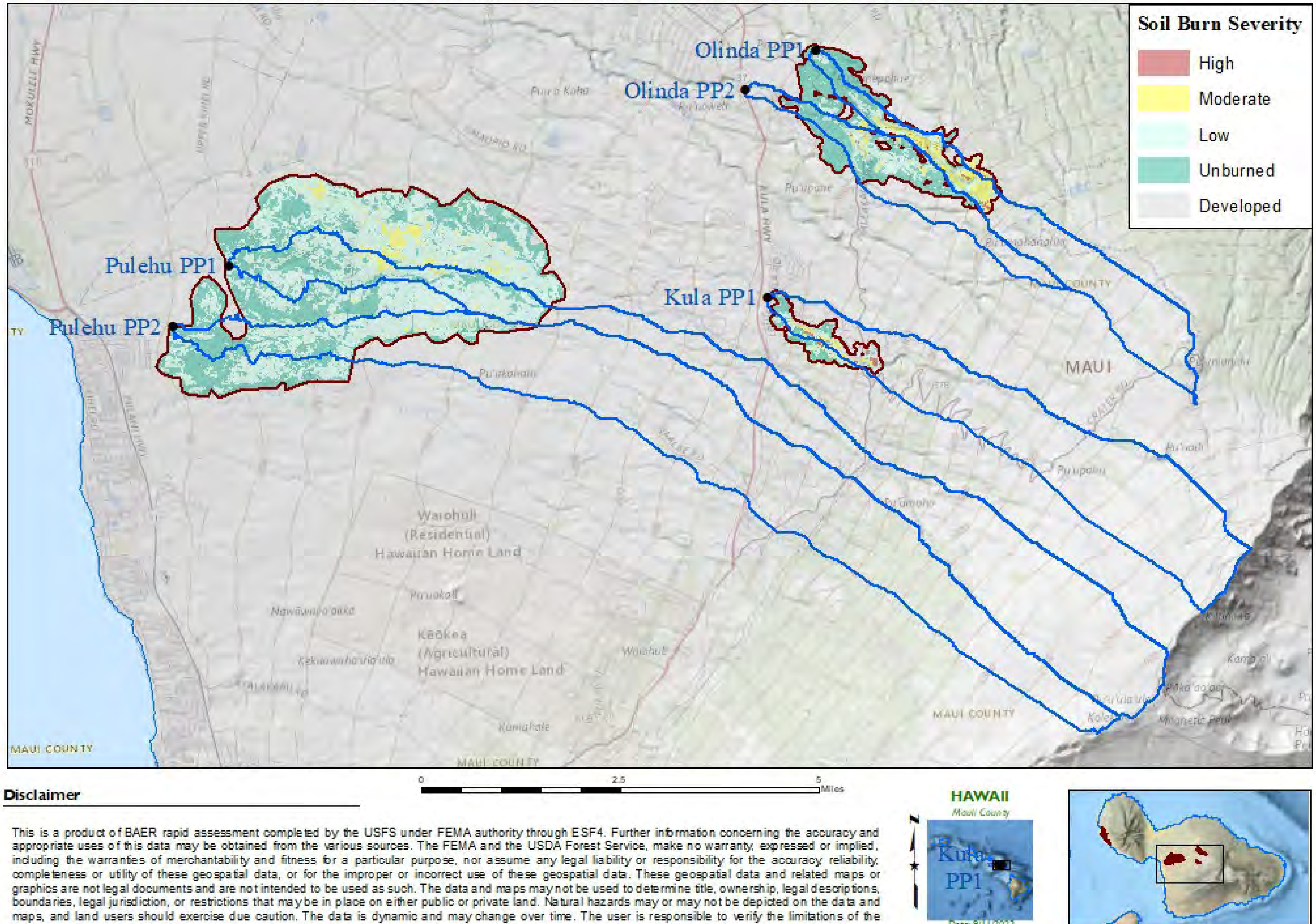
Erosion Rates (tons/ac)

- 0.0 - 1.0
- 1.1 - 2.0
- 2.1 - 5.0
- 5.1 - 7.5
- 7.6 - 10.0
- 10.1 - 20.0
- > 20.0
- Developed Area

Analysis Drainages in Pulehu, Olinda & Kula Fires

Burned Area Emergency Response (BAER) Pulehu, Olinda, and Kula Fires, Maui County, Hawaii



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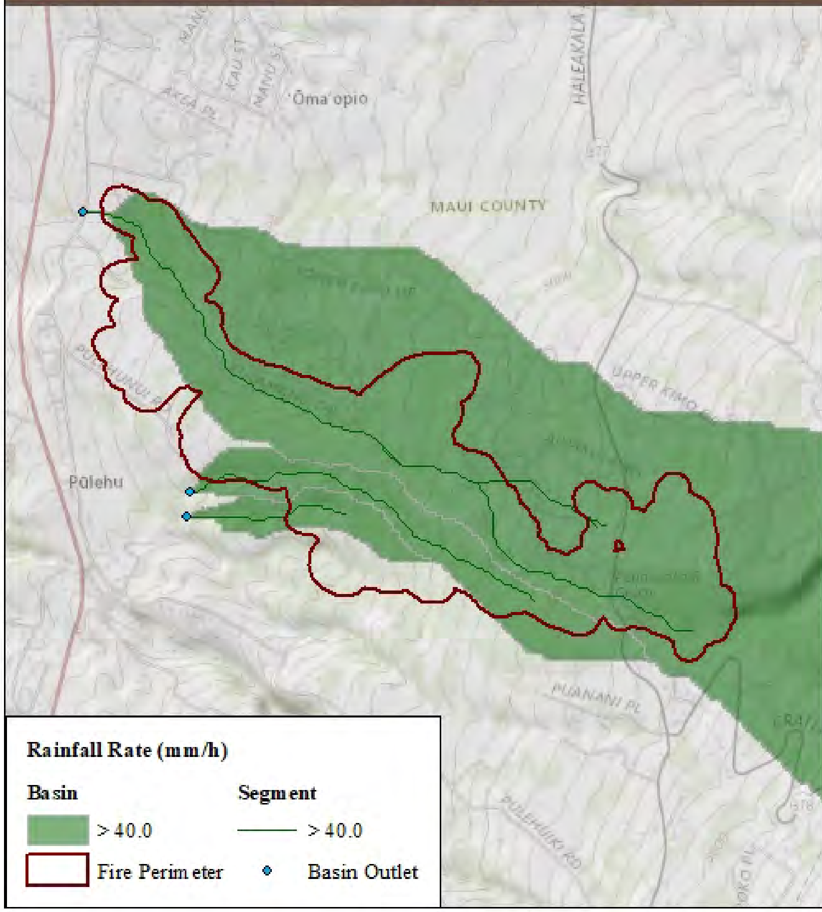
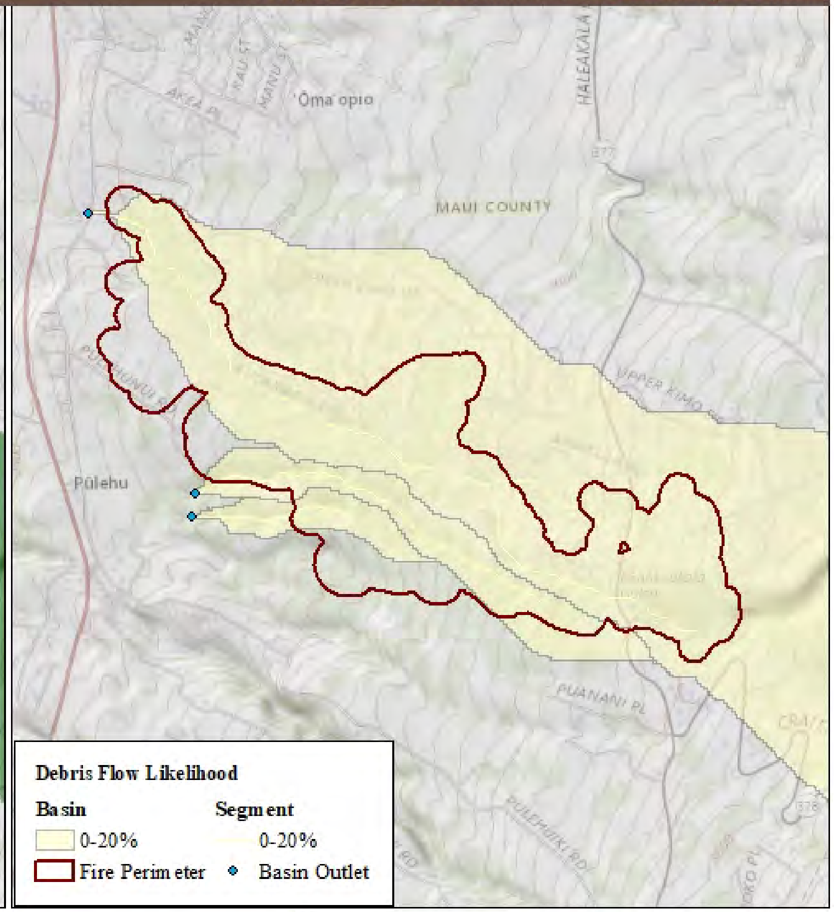
USGS Debris Flow Hazard Assessment

Burned Area Emergency Response (BAER) Kula Fire, Maui County, Hawaii

Year 1 Rainfall Thresholds
Rainfall rates that have a 50% likelihood of triggering debris flows



Debris-flow Likelihood
Design storm: Peak 15-minute rainfall intensity 40 mm/h



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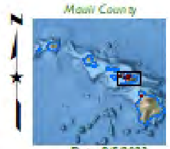
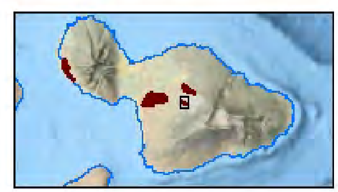
HAWAII

Maui County

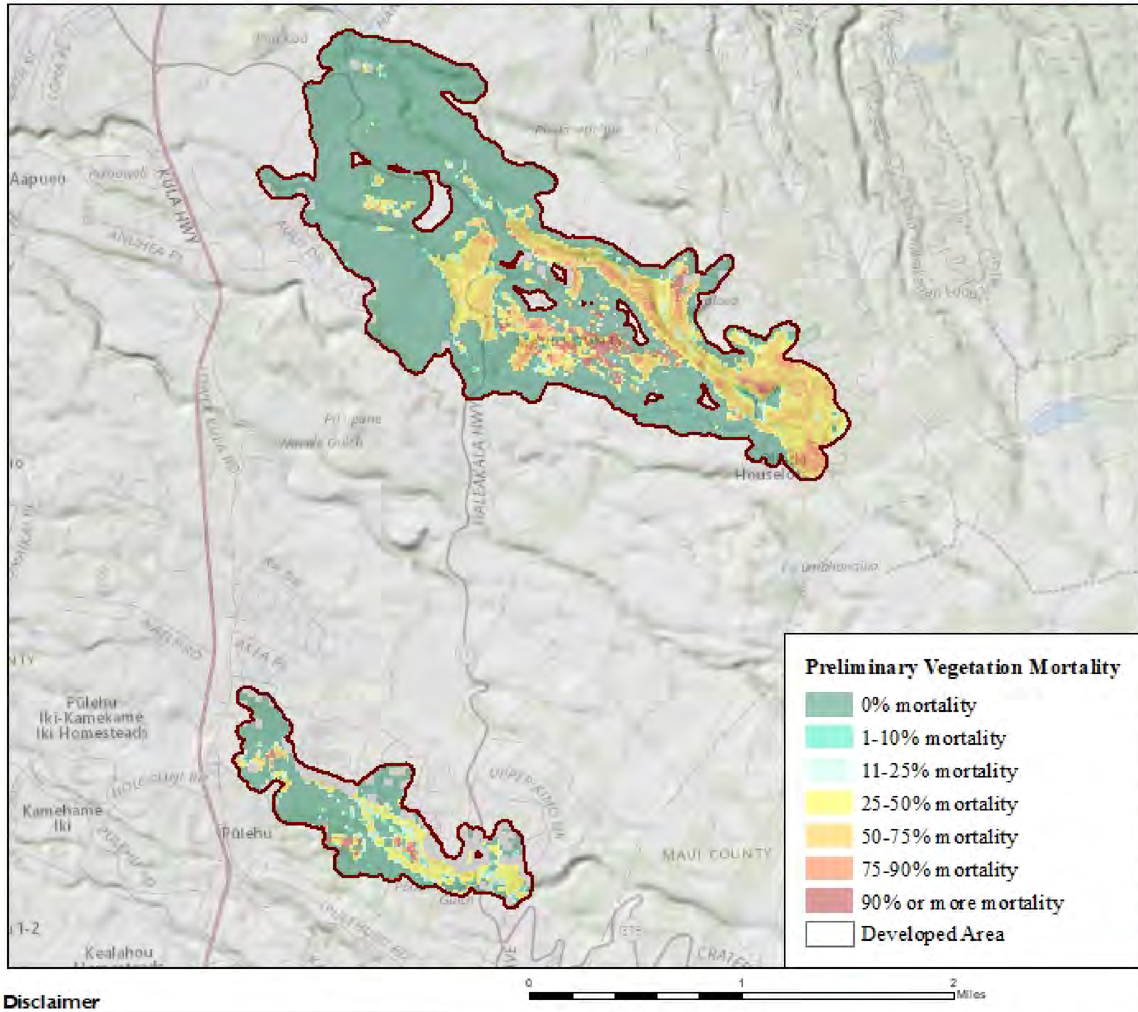


Date: 9/5/2023



Preliminary Vegetation Mortality - Olinda & Kula Fires

Burned Area Emergency Response (BAER) Olinda & Kula Fires, Maui County, Hawaii



Preliminary Vegetation Mortality

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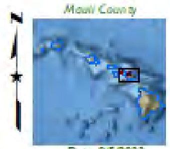
HAWAII

Maui County



Date: 9/5/2023

Appendix D. Olinda Fire Map Products

Soil Burn Severity Map - Olinda & Kula Fires

Burned Area Emergency Response (BAER) Olinda & Kula Fires, Maui County, Hawaii

Soil Burn Severity

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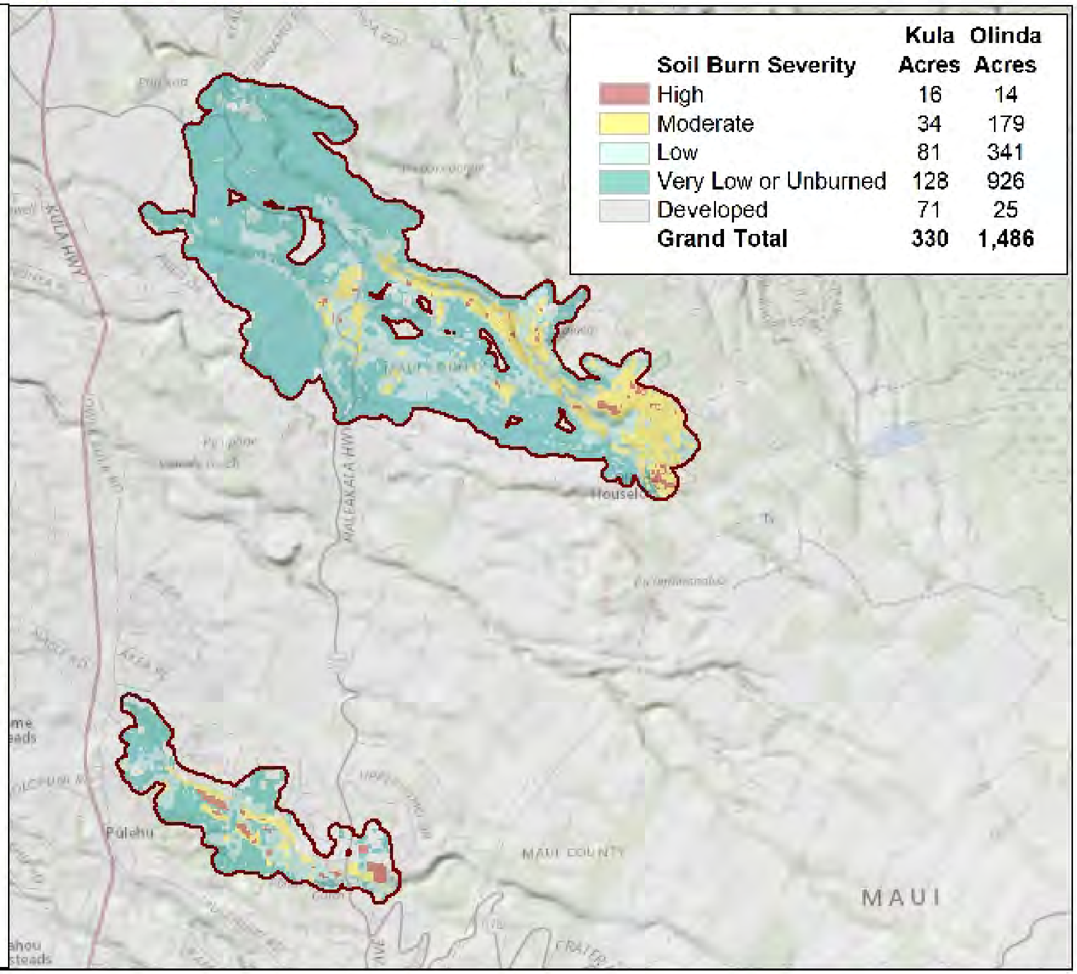

Soil Burn Severity	Kula Acres	Olinda Acres
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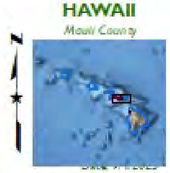
Moderate	34	179
Low	81	341
Very Low or Unburned	128	926
Developed	71	25
Grand Total	**330**	**1,486**



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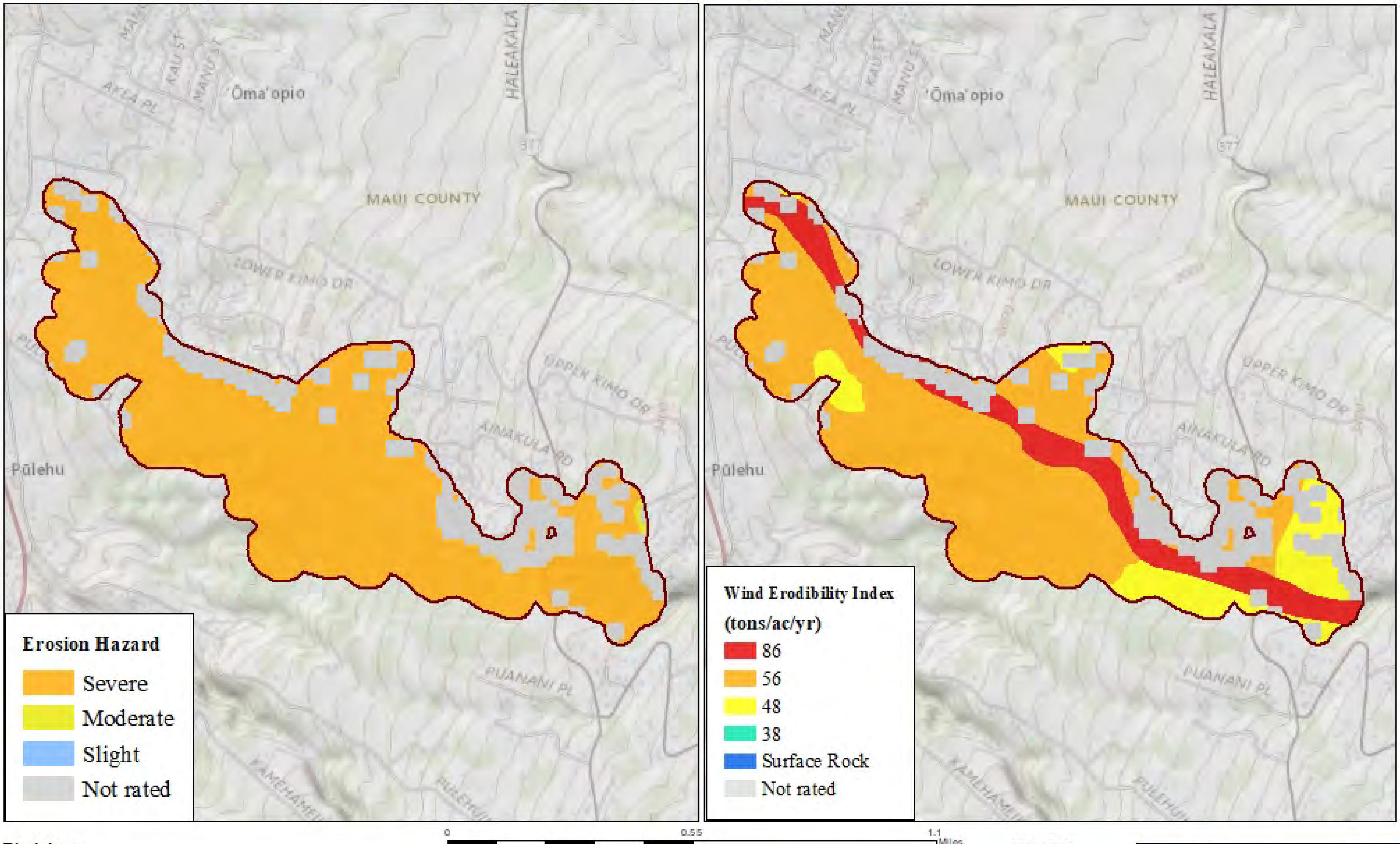
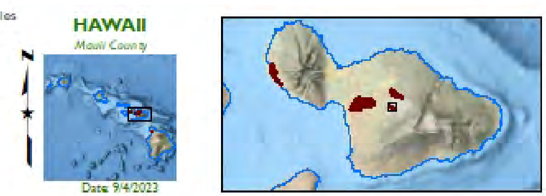
Water and Wind Erosion Hazard Map

Burned Area Emergency Response (BAER) Kula Fire, Maui County, Hawaii





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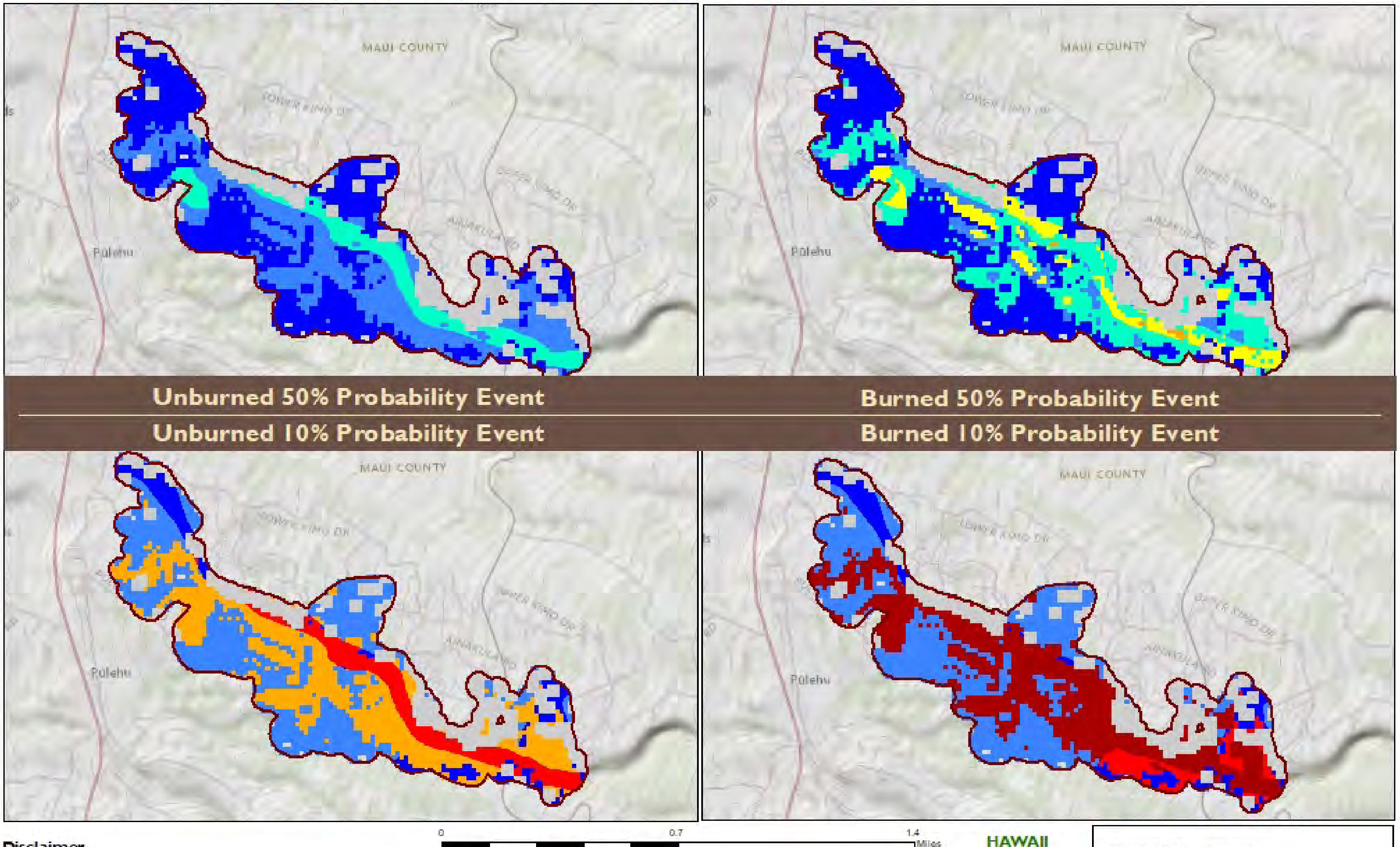
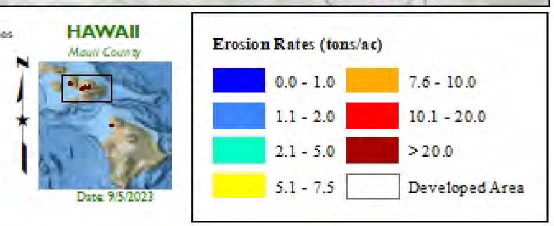
Pre and Post-fire Erosion Rates

Burned Area Emergency Response (BAER) Kula Fire, Maui County, Hawaii





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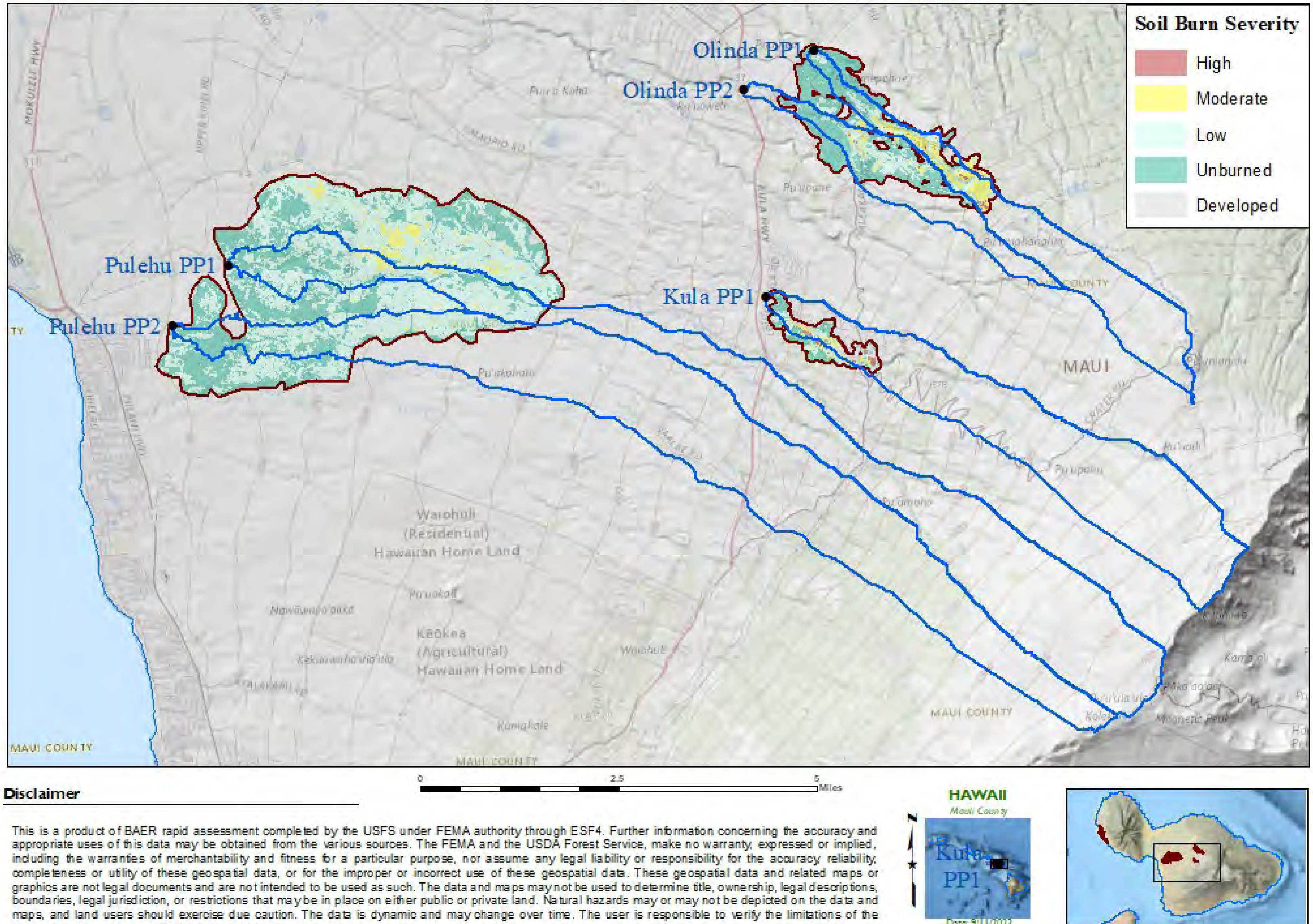
Analysis Drainages in Pulehu, Olinda & Kula Fires

Burned Area Emergency Response (BAER) Pulehu, Olinda, and Kula Fires, Maui County, Hawaii



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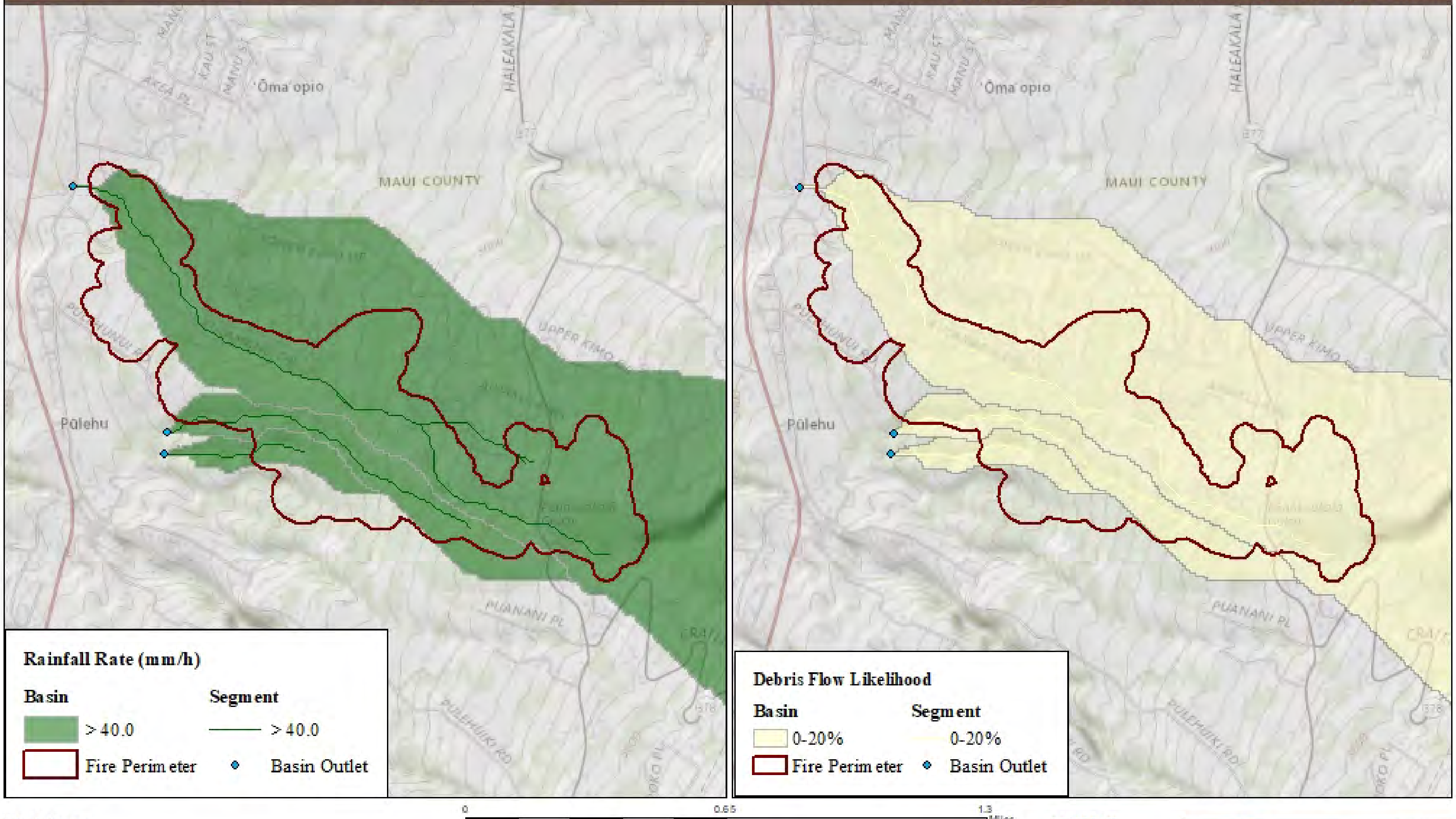
USGS Debris Flow Hazard Assessment

Burned Area Emergency Response (BAER) Kula Fire, Maui County, Hawaii

Year 1 Rainfall Thresholds
Rainfall rates that have a 50% likelihood of triggering debris flows

Debris-flow Likelihood
Design storm: Peak 15-minute rainfall intensity 40 mm/h



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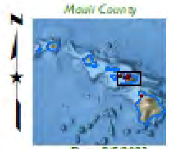
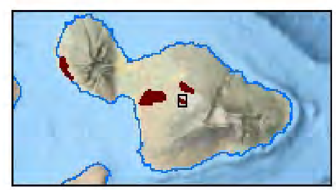
HAWAII
Maui County

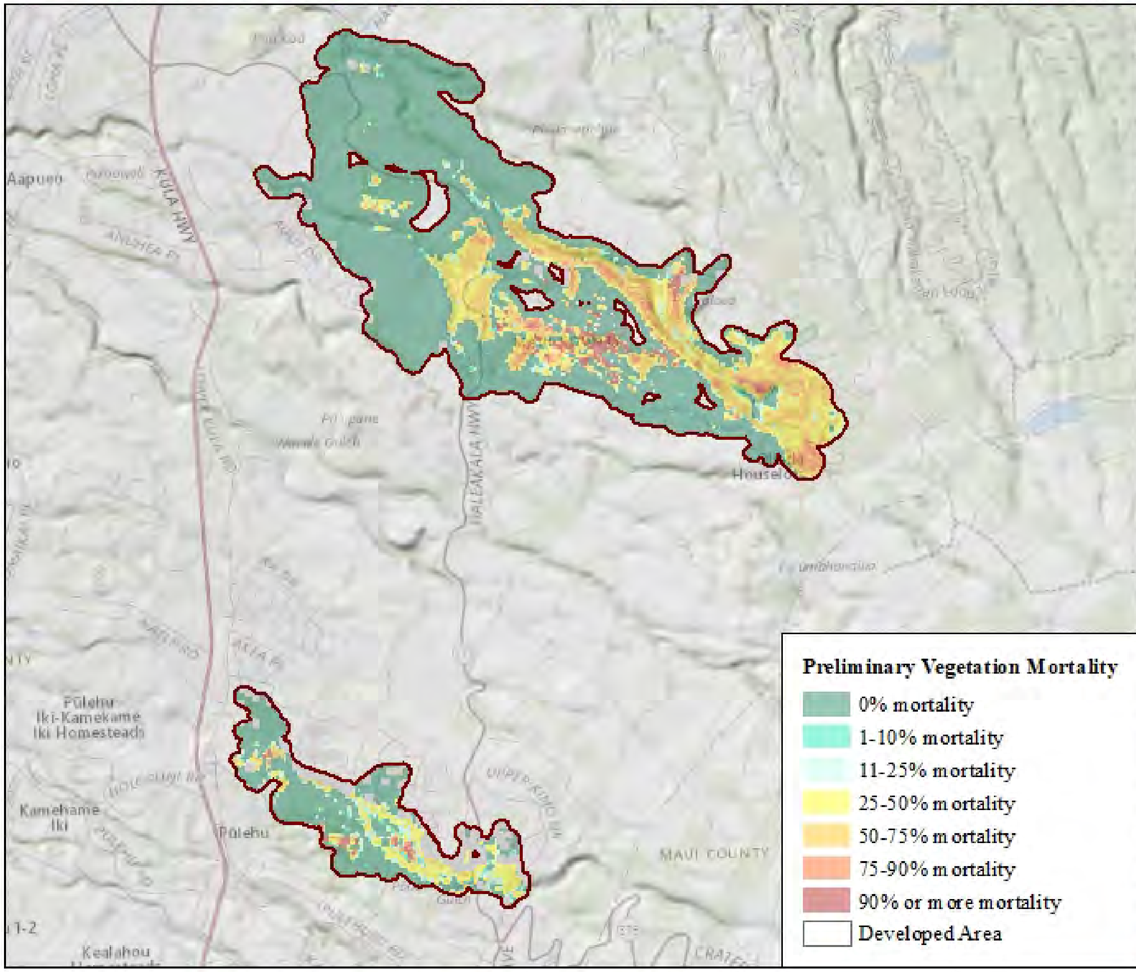


Date: 9/5/2023



Preliminary Vegetation Mortality - Olinda & Kula Fires

Burned Area Emergency Response (BAER) Olinda & Kula Fires, Maui County, Hawaii



Preliminary Vegetation Mortality

This is a post-fire preliminary vegetation mortality product that focuses on the current wildfire effects to the forest vegetation and is reported in percent of live vegetation loss. This product was derived from satellite image classification, using Google Earth Engine (GEE) to provide image collections and derive cloud-free pre and post fire images over the fire area. This product helps BAER team scientists understand the scope and scale of vegetation mortality in assessing emergency response strategies.

The BAER Team uses this Vegetation Mortality product to compare with Soil Burn Severity to illustrate the difference between the effect of the fire on vegetation vs the effect of the fire on the soil. This vegetation mortality has not been field verified. The classification method used to generate the Vegetation Mortality product was developed for a forested environment and may not be accurate outside that environment. Many other factors can affect the accuracy of an image classification, including regrowth of grasses post-fire and wind erosion removing sediment and ash deposits. This product has not been field verified.

Within the Forest Service this post-fire product is shared with the local forest staff and agency partners for use in assessing fire-related reforestation needs. These data help forest staff on local units prioritize areas for further assessment and facilitate post-fire vegetation management decision-making.

Within the USDA Forest Service Geospatial Technology and Applications Center (GTAC) Rapid Assessment of Vegetation Post-Fire (RAVG), the program produces a similar product using single pre and post-fire images. This product is usually generated 45 days after fire containment to get a more accurate assessment of Vegetation Mortality. For more information on the see: (https://burnseverity.cr.usgs.gov/ravg/).

0 1 2 Miles

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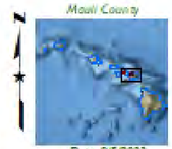
HAWAII

Maui County



Date: 9/5/2023

Appendix E. Mauna Kea Beach Resort Fire Map Products

Soil Burn Severity Map - Mauna Kea Beach Fire

Burned Area Emergency Response (BAER) Mauna Kea Beach Fire, Hawaii County, Hawaii

Soil Burn Severity

Soil Burn Severity is a measure of the fire's effects on the ground surface and soil condition. This map identifies the fire-induced changes in soil and ground surface properties that may affect infiltration, runoff, and erosion potential. The BAER Team uses this map to identify areas of unacceptable risk to a critical value and where mitigating treatments may be most effective. This product is appropriate for wildland landscapes and does not represent fire effects in developed areas.

__Severity Indicators__

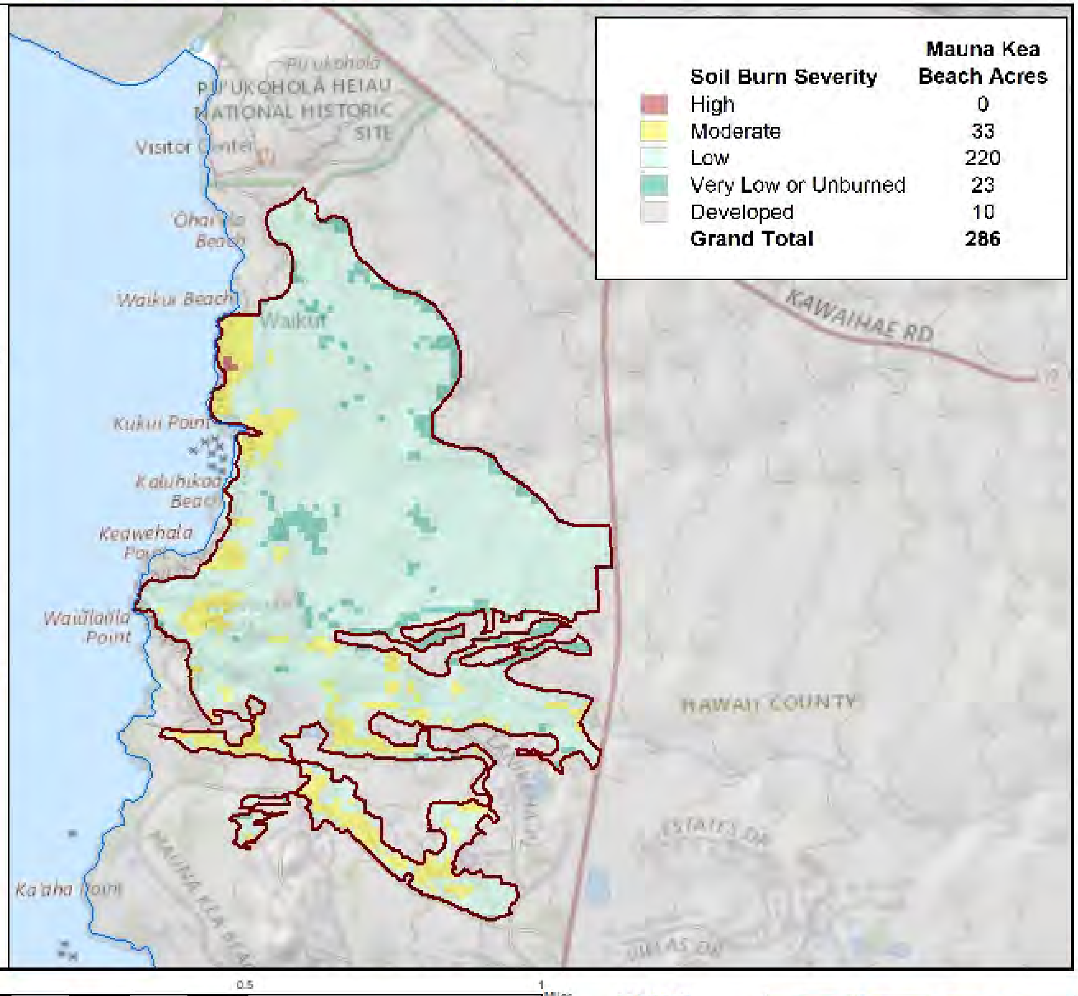
High soil burn severity: Most or all of the pre-fire ground cover and surface organic matter (litter, duff, and fine roots) is generally consumed, and charring may be visible on larger roots. Soil is often gray, orange, or reddish at the ground surface where large or dense fuels were concentrated and consumed. Soil structure is often altered and less stable at the surface.

Moderate soil burn severity: Up to 80 percent of the pre-fire ground cover may be consumed but generally not all of it. There may be potential for recruitment of effective ground cover from scorched needles or leaves remaining in the canopy that will soon fall to the ground. Soil structure is generally unchanged.

Low soil burn severity: The ground surface, including any exposed mineral soil, may appear brown or black (lightly charred), and surface organic layers are not completely consumed. The canopy and understory vegetation will likely appear "green."

Very Low soil burn severity or Unburned: Little to no burn expected within these areas except in small patches, or where fuels were sparce. Canopy and ground litter almost completely intact. Little to no vegetation mortality expected.

For additional information including photo examples of soil burn severity see the Field Guide for Mapping Post-Fire Soil Burn Severity at: https://www.fs.usda.gov/rm/pubs/rmrs_gtr243.pdf



Soil Burn Severity	Mauna Kea Beach Acres
High	0
Moderate	33
Low	220
Very Low or Unburned	23
Developed	10
Grand Total	**286**

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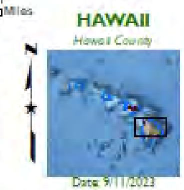
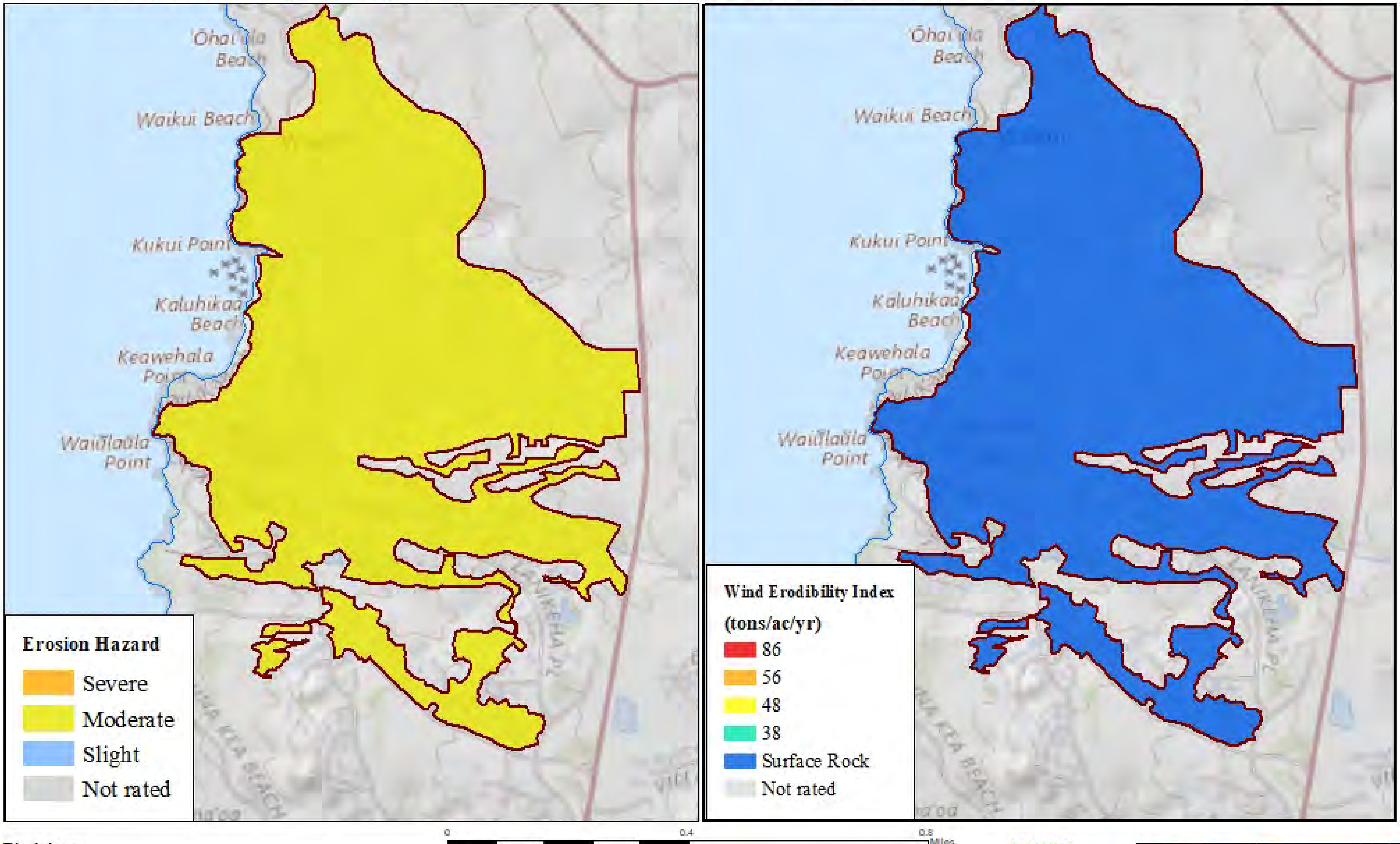


Water and Wind Erosion Hazard Map

Burned Area Emergency Response (BAER) Mauna Kea Beach Fire, Hawaii County, Hawaii



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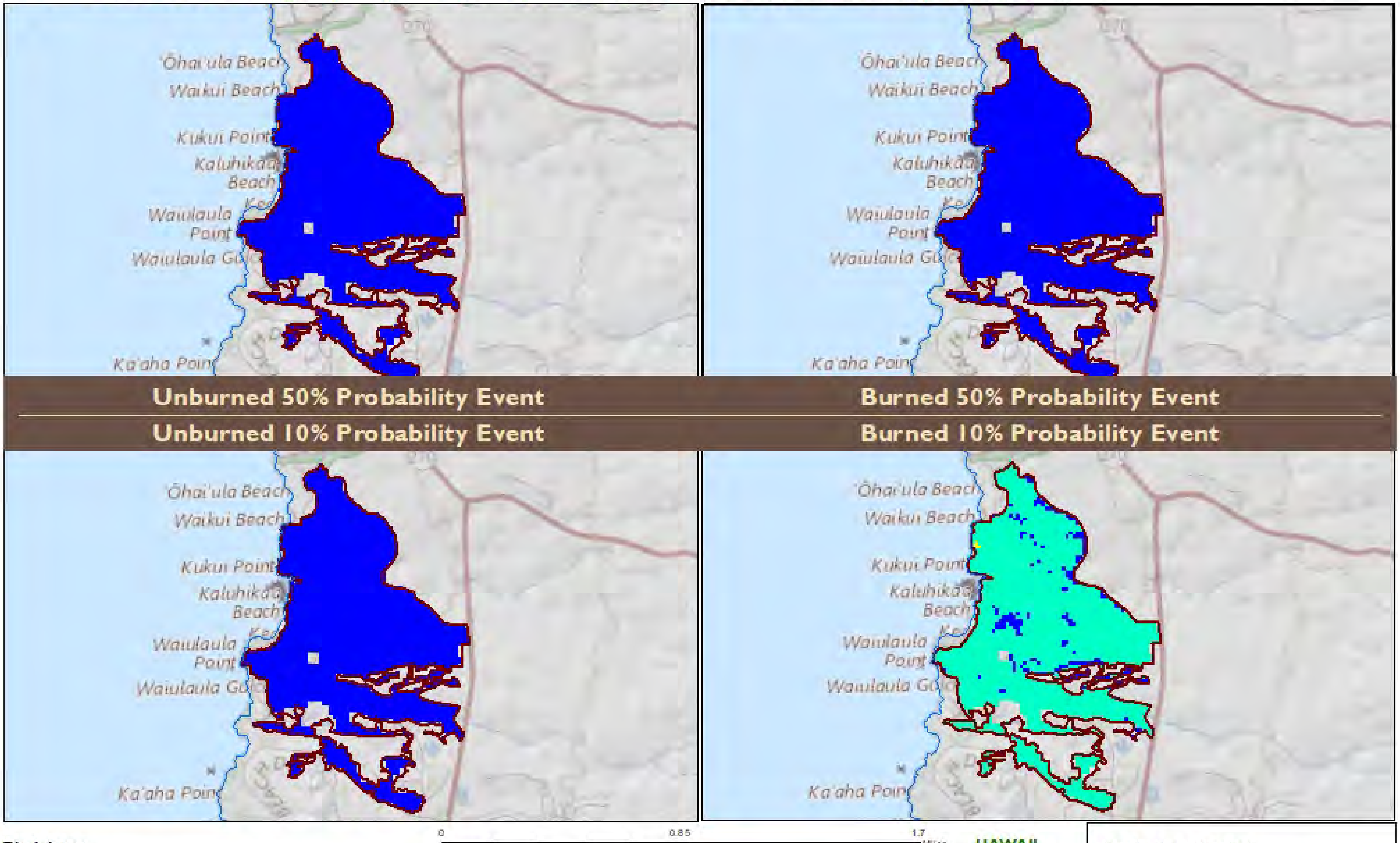
Pre and Post-fire Erosion Rates

Burned Area Emergency Response (BAER) Mauna Kea Beach Fire, Hawaii County, Hawaii



Erosion Rates (tons\ac)

0.0 - 1.0	7.6 - 10.0
1.1 - 2.0	10.1 - 20.0
2.1 - 5.0	> 20.0
5.1 - 7.5	Developed Area

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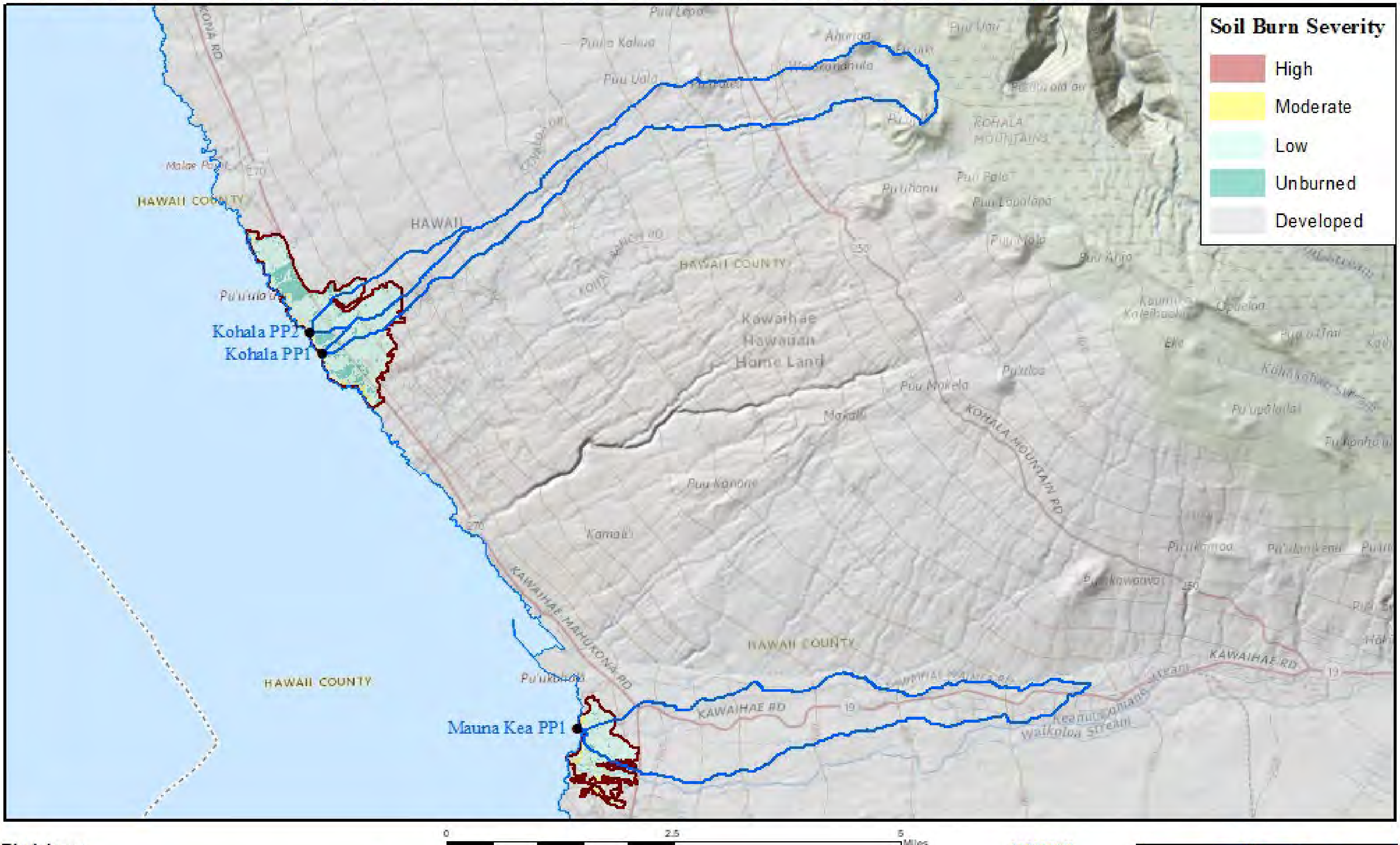
Analysis Drainages in Kohala & Mauna Kea Beach Fires

Burned Area Emergency Response (BAER) Kohala & Mauna Kea Beach Fires, Hawaii County, Hawaii



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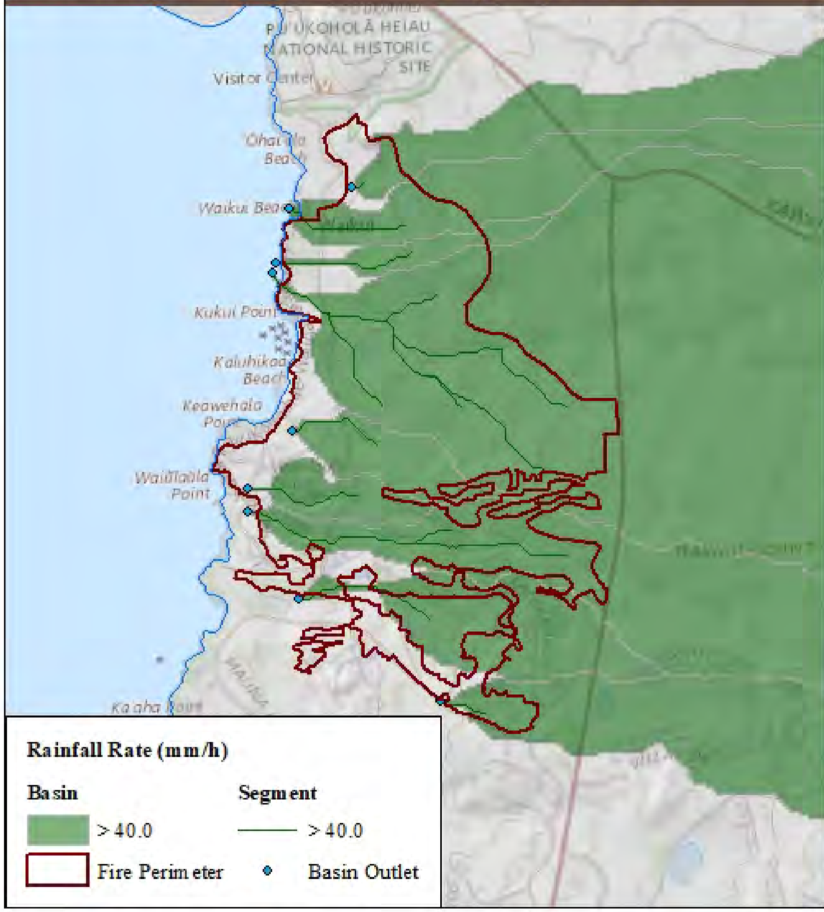
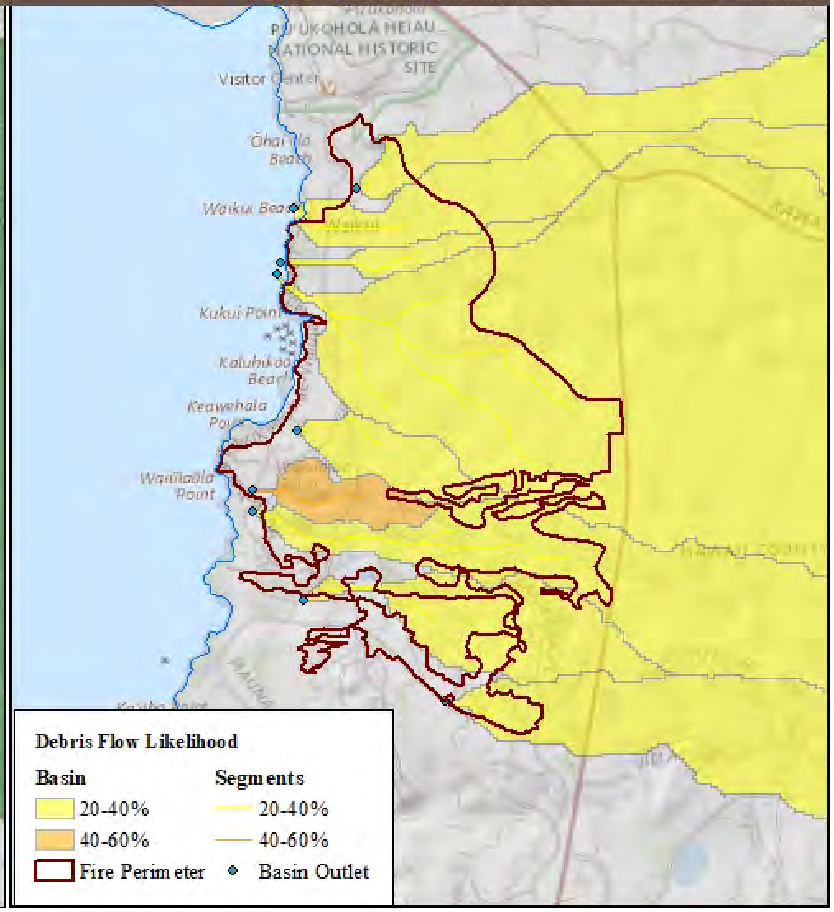
USGS Debris Flow Hazard Assessment

Burned Area Emergency Response (BAER) Mauna Kea Beach Fire, Hawaii County, Hawaii

Year 1 Rainfall Thresholds
Rainfall rates that have a 50% likelihood of triggering debris flows



Debris-flow Likelihood
Design storm: Peak 15-minute rainfall intensity 40 mm/h



0 0.55 1.1 Miles

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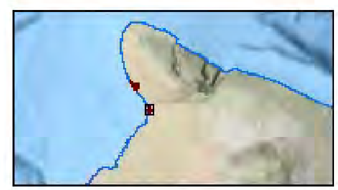

Preliminary Vegetation Mortality - Mauna Kea Beach Fire

Burned Area Emergency Response (BAER) Mauna Kea Beach Fire, Hawaii County, Hawaii

Preliminary Vegetation Mortality

This is a post-fire preliminary vegetation mortality product that focuses on the current wildfire effects to the forest vegetation and is reported in percent of live vegetation loss. This product was derived from satellite image classification, using Google Earth Engine (GEE) to provide image collections and derive cloud-free pre and post fire images over the fire area. This product helps BAER team scientists understand the scope and scale of vegetation mortality in assessing emergency response strategies.

The BAER Team uses this Vegetation Mortality product to compare with Soil Burn Severity to illustrate the difference between the effect of the fire on vegetation vs the effect of the fire on the soil. This vegetation mortality has not been field verified. The classification method used to generate the Vegetation Mortality product was developed for a forested environment and may not be accurate outside that environment. Many other factors can affect the accuracy of an image classification, including regrowth of grasses post-fire and wind erosion removing sediment and ash deposits. This product has not been field verified.

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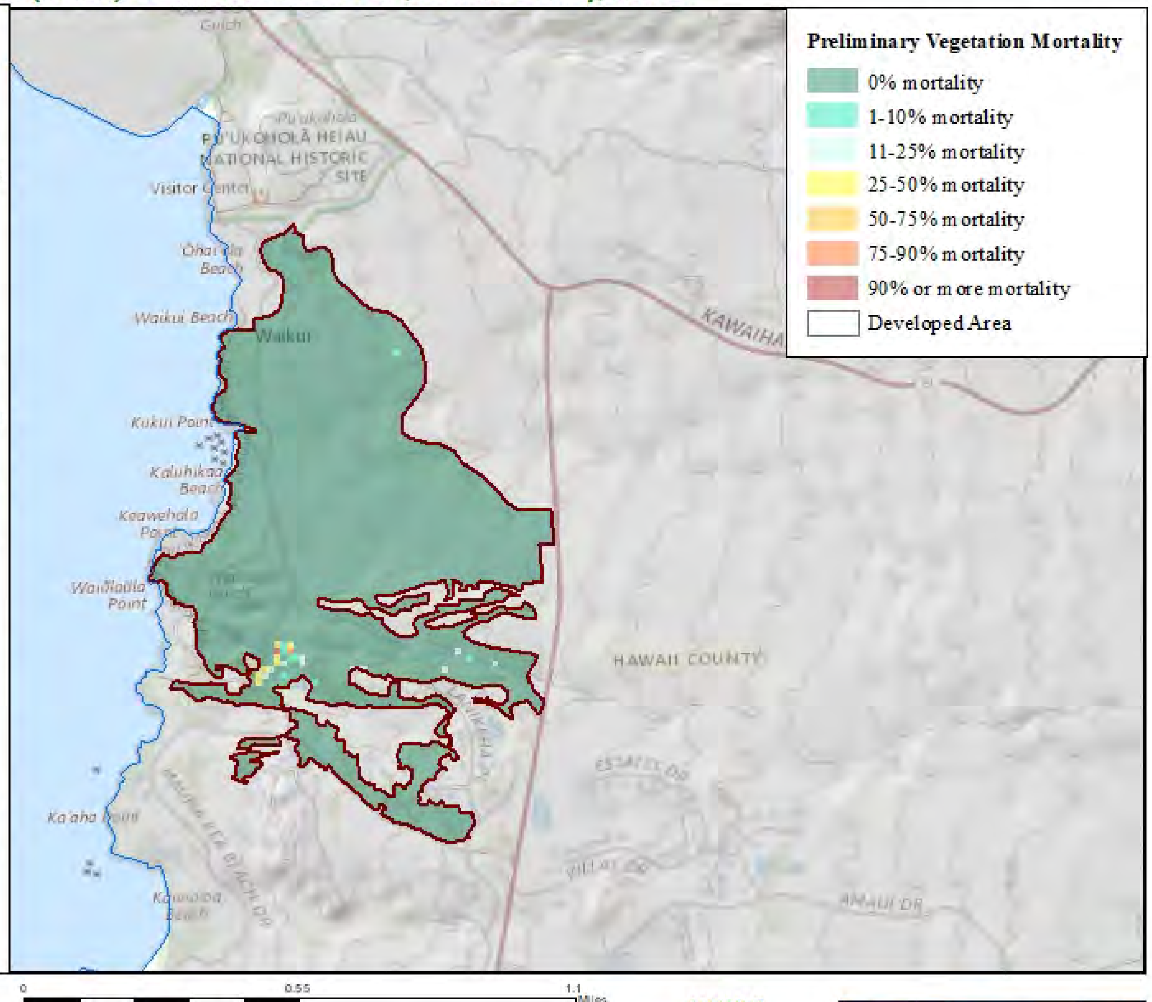
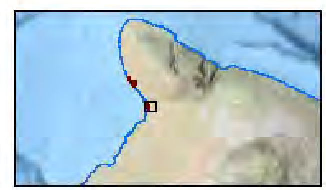
(https://burnseverity.cr.usgs.gov/ravg/).





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Appendix F. Kohala Fire Map Products

Soil Burn Severity Map - Kohala Fire

Burned Area Emergency Response (BAER) Kohala Fire, Hawaii County, Hawaii

Soil Burn Severity

Soil Burn Severity is a measure of the fire's effects on the ground surface and soil condition. This map identifies the fire-induced changes in soil and ground surface properties that may affect infiltration, runoff, and erosion potential. The BAER Team uses this map to identify areas of unacceptable risk to a critical value and where mitigating treatments may be most effective. This product is appropriate for wildland landscapes and does not represent fire effects in developed areas.

Severity Indicators

High soil burn severity: Most or all of the pre-fire ground cover and surface organic matter (litter, duff, and fine roots) is generally consumed, and charring may be visible on larger roots. Soil is often gray, orange, or reddish at the ground surface where large or dense fuels were concentrated and consumed. Soil structure is often altered and less stable at the surface.

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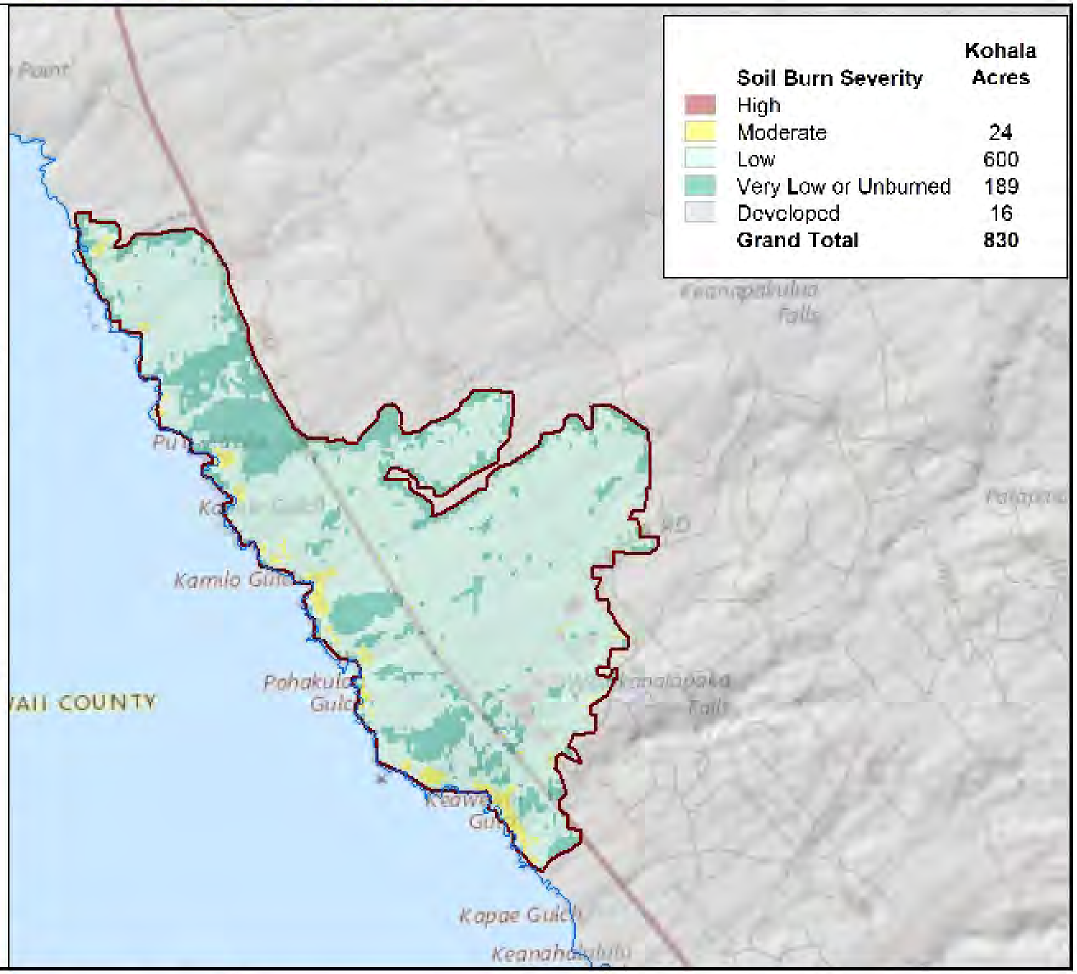
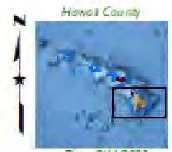


Soil Burn Severity	Kohala Acres
High	
Moderate	24
Low	600
Very Low or Unburned	189
Developed	16
Grand Total	**830**



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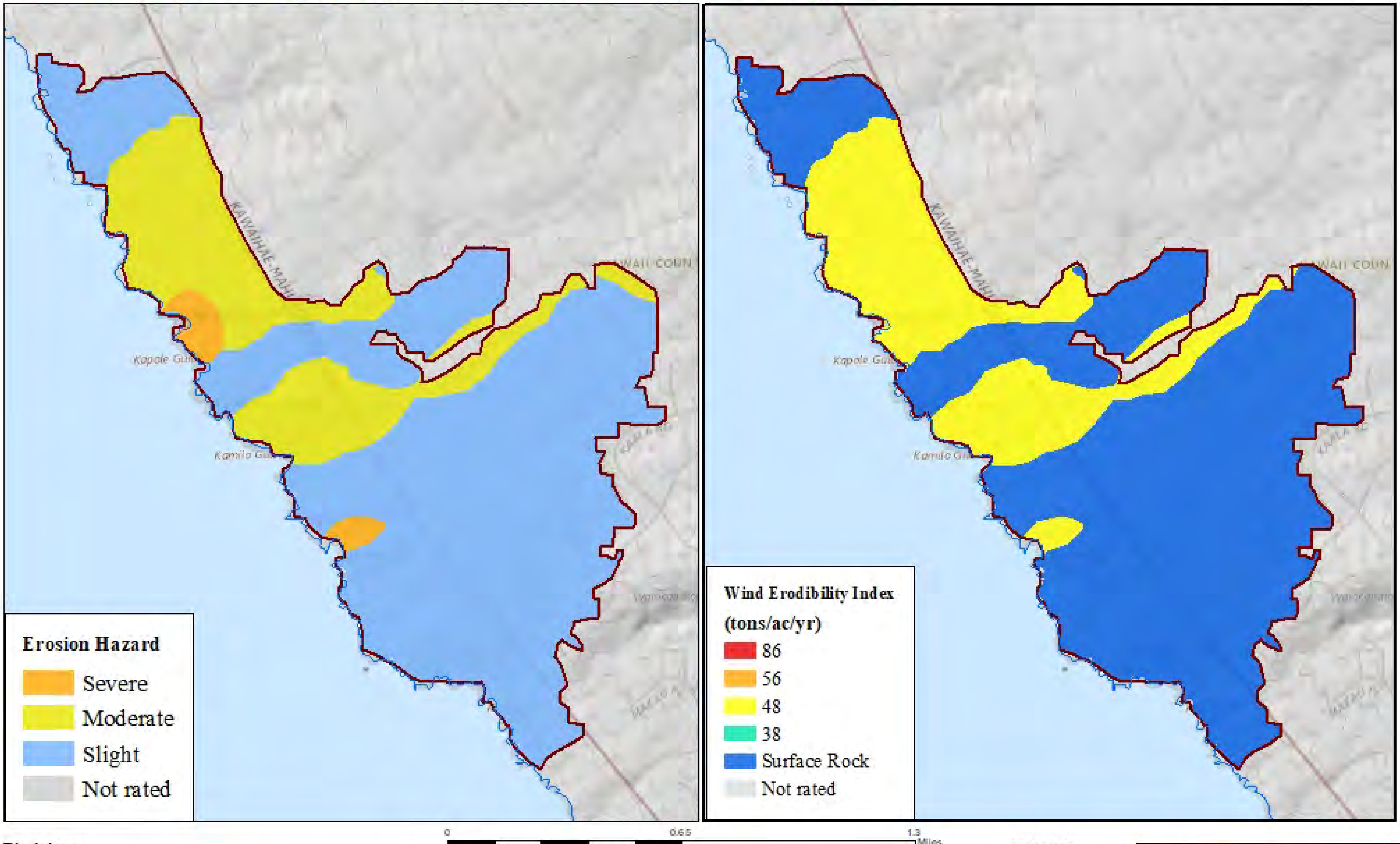
Water and Wind Erosion Hazard Map

Burned Area Emergency Response (BAER) Kohala Fire, Hawaii County, Hawaii



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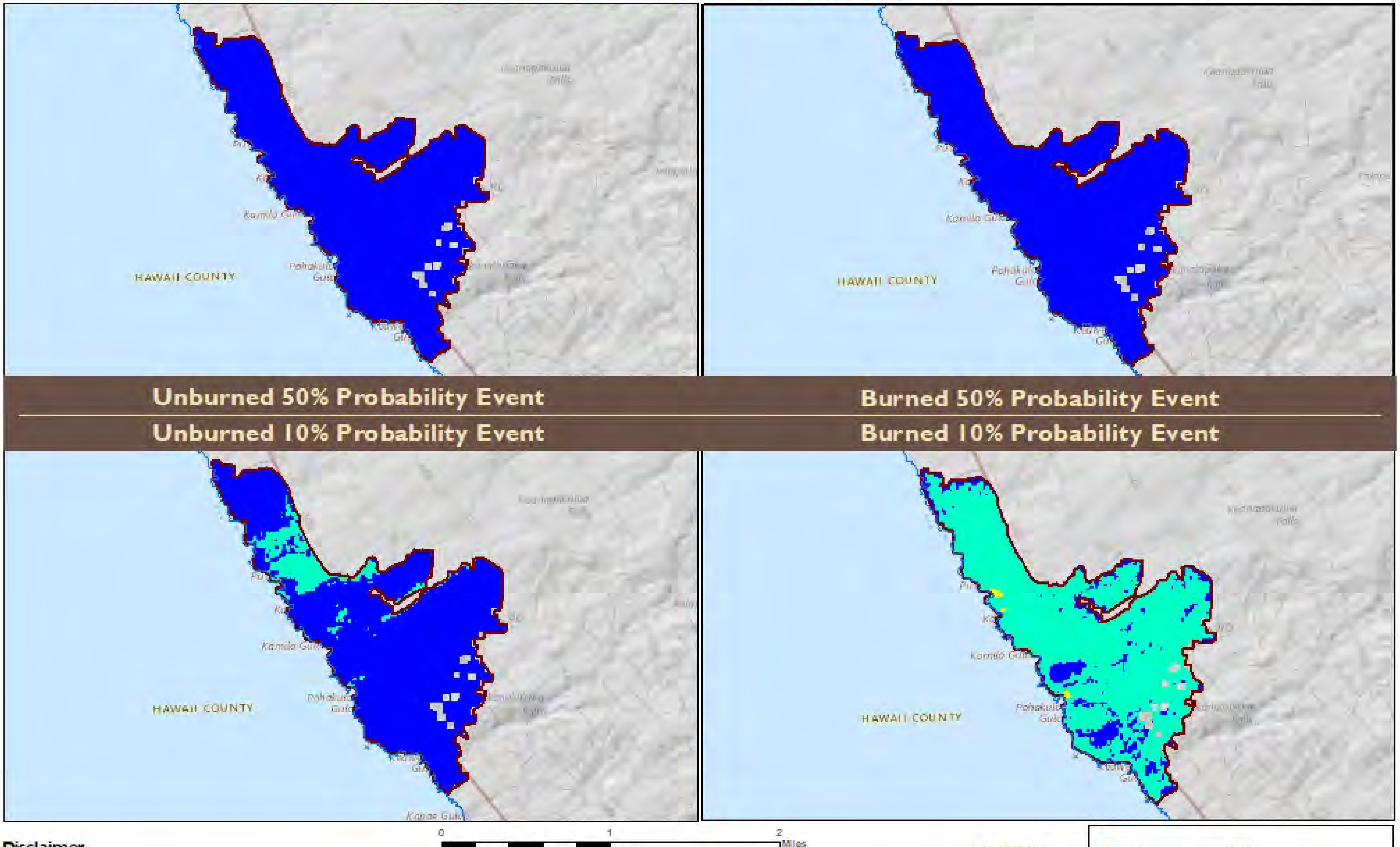
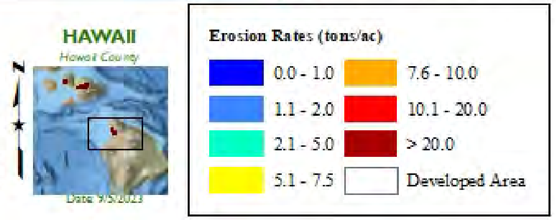
Pre and Post-fire Erosion Rates

Burned Area Emergency Response (BAER) Kohala Fire, Hawaii County, Hawaii





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Analysis Drainages in Kohala & Mauna Kea Beach Fires

Burned Area Emergency Response (BAER) Kohala & Mauna Kea Beach Fires, Hawaii County, Hawaii

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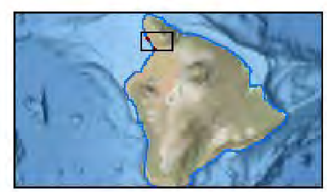
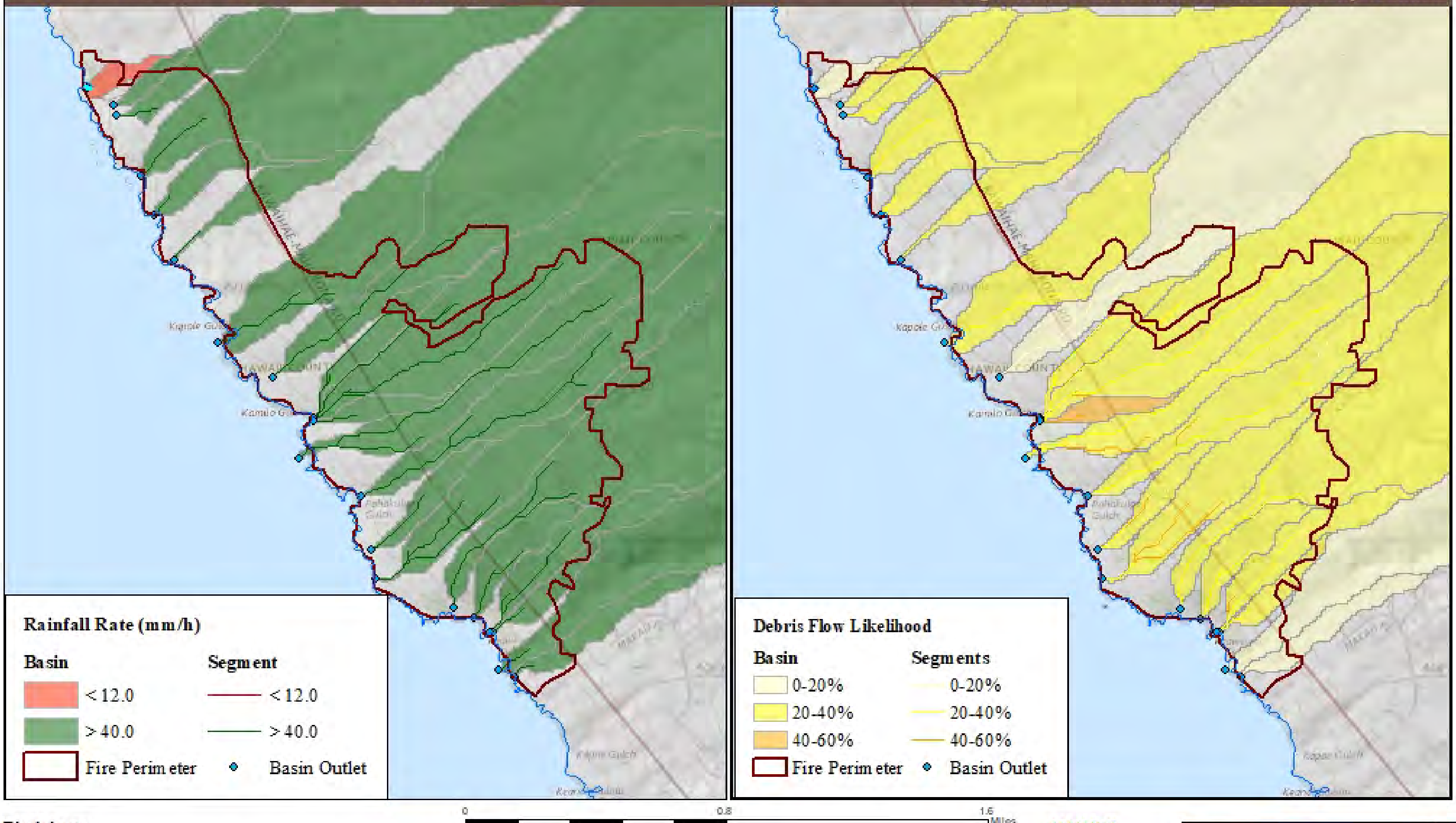


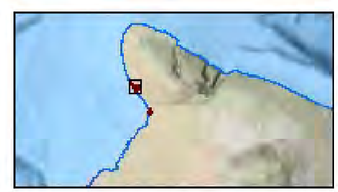
USGS Debris Flow Hazard Assessment

Burned Area Emergency Response (BAER) Kohala Fire, Hawaii County, Hawaii

Year 1 Rainfall Thresholds
Rainfall rates that have a 50% likelihood of triggering debris flows

Debris-flow Likelihood
Design storm: Peak 15-minute rainfall intensity 40 mm/h





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Preliminary Vegetation Mortality - Kohala

Burned Area Emergency Response (BAER) Kohala Fire, Hawaii County, Hawaii

Preliminary Vegetation Mortality

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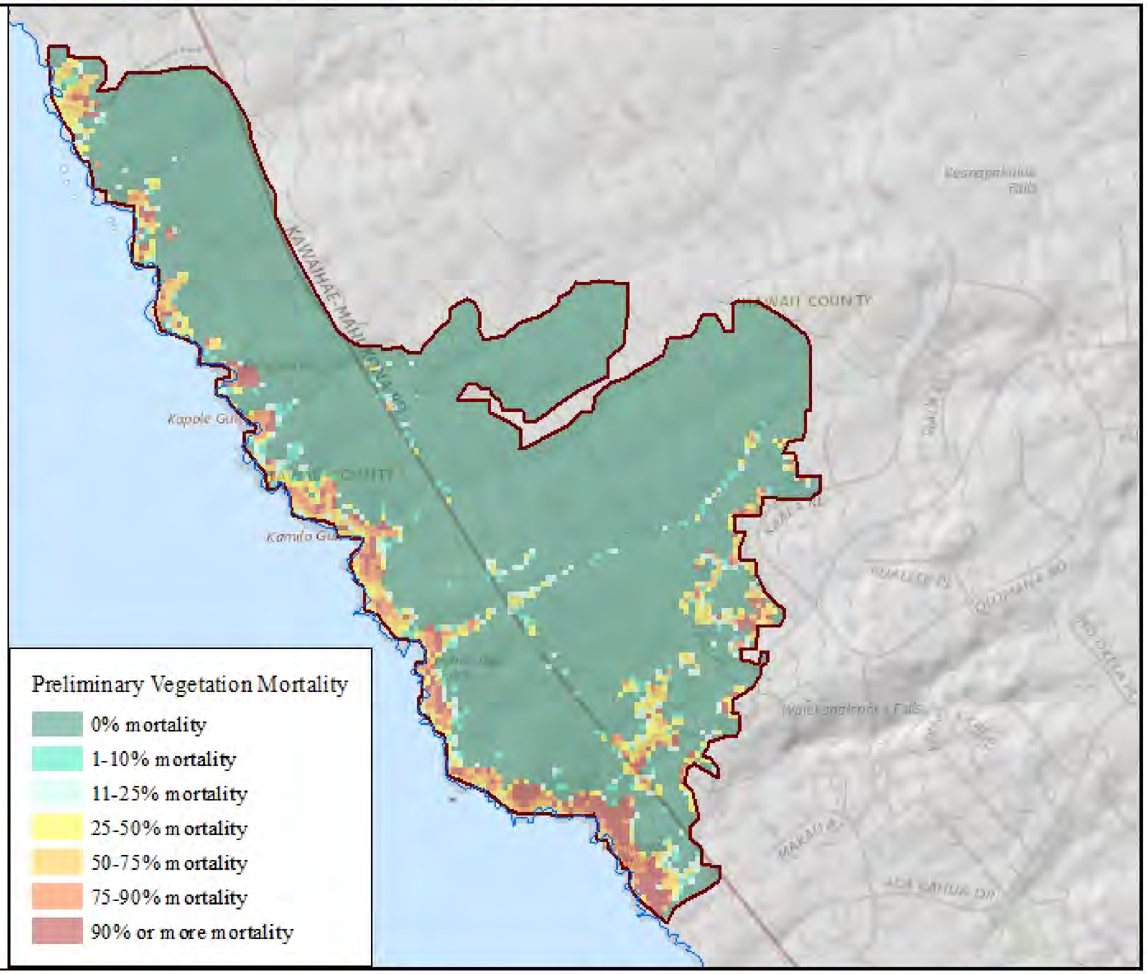
Within the Forest Service this post-fire product is shared with the local forest staff and agency partners for use in assessing fire-related reforestation needs. These data help forest staff on local units prioritize areas for further assessment and facilitate post-fire vegetation management decision-making.

Within the USDA Forest Service Geospatial Technology and Applications Center (GTAC) Rapid Assessment of Vegetation Post-Fire (RAVG), the program produces a similar product using single pre and post-fire images. This product is usually generated 45 days after fire containment to get a more accurate assessment of Vegetation Mortality. For more information on the see: (https://burnseverity.cr.usgs.gov/ravg/).



Disclaimer

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HAWAII

Hawaii County

Date 9/11/2023