3.8 GEOLOGY AND SOILS

Geologic resources include mineral resources, landforms, soils, and other earth materials. Discussions of geology and soils also cover geologic processes, such as erosion, faulting, and volcanic eruptions, and geologic hazards, such as earthquakes, landslides, and liquefaction. In the State of Hawai‘i, the fate and transport of chemical contaminants has been identified as an issue of concern; therefore, the discussion of geologic resources has been broadened to include the distribution and fate and transport of chemical contaminants in soils, sediments, and other geologic materials.

3.8.1 Introduction/Region of Influence

Because of the interrelationship between geology and hydrology, the ROI for geology incorporates the ROI for water resources. Laws or regulations that govern geologic resources at MMR and PTA include EPA Region IX PRGs, the State CZMP, and the Farmland Protection Act. Contaminant concentrations in soils are compared to EPA Region IX industrial PRGs for soils.

The purpose of comparing observed chemical concentrations in soils to the PRGs is to determine whether further assessment of health risks associated with on-site concentrations is needed. As described in the water resources section, PRGs are not promulgated cleanup standards, and higher or lower standards may be reasonably applied to sites based on site-specific exposure levels rather than the default exposure assumptions used to develop the PRGs.

In addition, it is usually not appropriate to rely on individual sample results for comparison to the PRGs; a better approach is to use a set of sample results collected over an area of exposure, or over a period of time, to evaluate the average concentrations to which people may be exposed. This increases the degree of confidence in the results and tends to better represent the actual exposures. The EPA recommends using a statistical sample and comparing the calculated 95 percent upper confidence limit (UCL) of the sample set to the PRGs. The UCL is a conservative estimate of the average concentration in a set of samples. Therefore, this comparison usually yields a conservatively protective estimate of the health risk associated with the chemical. This method was used to evaluate surface soil results for metals and selected contaminants where multiple detections were observed.

Some risks from individual contaminants are additive with the risks from other contaminants. An accurate determination of cumulative risks can be complex because, for example, not all chemicals affect the same organs,

and some chemicals when combined may have a greater effect than they would have individually. A screening level analysis is used to determine whether further assessment of risk is needed. If the risk from exposure to the principal chemicals of concern, based on comparison to PRGs, is within the acceptable risk range, and if the types of exposures that would occur at the site are similar to those assumed in the PRGs, then generally no further action is needed to address the chemicals at the site.

Geological issues identified in comments received during the public scoping process for the Mākua EIS included:

- Sediment transport;
- Soil contamination and its effects on groundwater and crops;
- Frequency of soil sampling;
- Soil erosion and land maintenance; and
- Landslides.

Mākua Military Reservation

The MMR ROI for geology and soils includes the Mākua Valley, the adjacent attached valleys in which live-fire training and associated activities will occur, the adjacent beach, and the nearshore area.

Pōhakuloa Training Area

The PTA ROI for geology and soils is all areas in which project-related activities may occur, including the footprint of each training range and the corridors of the military vehicle roads. It also includes adjacent areas that may be affected by geologic processes in the project area. An example would be downslope areas adjacent to a roadcut or embankment that might be affected by slope failure.

3.8.2 Geologic Setting

Mākua Military Reservation Regional Geology

O‘ahu was formed from two eruptive centers. The remnants of the oldest of these, the Wai‘anae Volcano, forms the Wai‘anae Range on the eastern side of the island. The highest peak in the Wai‘anae Range, Mount Ka‘ala, is south of MMR and rises to an elevation of 4,025 feet (1,223 meters) above msl.

The Wai‘anae Volcano became extinct about 2.75 million years ago. At about this time, the Ko‘olau Volcano, which had been forming beneath the ocean to the east of the Wai‘anae Volcano, began to emerge above sea

level. As with the Wai‘anae Volcano, two rift zones developed, trending to the northwest and the southeast, respectively. As the Ko‘olau Volcano emerged, the saddle between the two volcanoes was filled, mainly with sediments eroded from the Wai‘anae Volcano. Later, it was overlain by basalt flows from the Ko‘olau Volcano. As the Ko‘olau Volcano waned, the saddle area was buried under alluvium from erosion of the volcano. Thus, the saddle area is underlain by alternating basalt flows and alluvial deposits. This saddle area contains the highly productive farmlands of the Central Plateau, an important high-level aquifer, groundwater recharge areas, and several military installations, including SBMR.

The Ko‘olau Volcano accounts for about two-thirds of O‘ahu. The eruptive period of Ko‘olau Volcano ended about 1.8 million years ago. It was followed by deep erosion of the volcano’s caldera, thousands of feet of subsidence, and the first eruptions of the Honolulu basalts that began about 850,000 years ago.

Eruptions of the Honolulu basalts began on the Mōkapu Peninsula near the north side of the Ko‘olau caldera, and then continued to the south to Le‘ahi (Diamond Head), and west to Pearl Harbor. About 40 eruptions occurred in the period from 850,000 years to 6,000 years ago.

Although the last period of active volcanism on O‘ahu ended about 6,000 years ago, the quiet periods between volcanic events during the past 800,000 years have often exceeded 6,000 years, so it is not known for certain that eruptions will not occur again in the future. Small magnitude earthquakes occur frequently as a result of movement of magma into magma chambers beneath volcanoes, and in volcanic eruptions. Active volcanic activity is limited to the Island of Hawai‘i. There are no major active faults. O‘ahu is no longer subsiding and now has the most stable elevation of the major islands in the Hawaiian Island chain.

Physiography

The Mākua Valley is bowl-shaped, with steep side slopes that rise sharply from a relatively broad valley floor. The valley can be subdivided into two parts. A smaller northern lobe of the valley, labeled as the Kahanahāiki ahupua‘a on US Geological Survey topographic maps, is partially separated from the main valley by a ridge. The larger main valley is oriented approximately east-west. The main valley floor contains undulating low hills up to an elevation of about 400 feet (122 meters). Above this elevation, the slope rises steeply to the ridge of the Wai‘anae Range, which is at about 2,100 to 2,900 feet (640 to 884 meters) above msl.

The mouth of the valley slopes gradually to the sea. Farrington Highway, which is on a slightly elevated causeway that crosses the mouth of the valley and separates the beach from the reservation, acts as a linear hydrologic barrier to surface water flow. Runoff from the three streams that drain the valley is channeled through box culverts beneath the highway. The beach extends the entire width of the valley, bounded on both ends by emergent remnants of ancient reefs and by rock outcrops from the extension of the ridges that bound the valley. The beach sand is likely replenished by long-shore currents that transport sand southward from the massive dunes at Ka‘ena Point. Some of the sand may also be supplied by the streams that drain Mākua Valley, although this is probably a much less important source due to the normally low quantity of runoff from the valley.

Geology of Mākua Valley

The ridges and underlying bedrock of the Mākua Valley consist of basalt rocks of the Wai‘anae Volcanics series (Figure 3.8-1). The older part of this sequence, the Pālehua member of the Wai‘anae Volcanics, is exposed in the lower part of the ridge that forms the southern boundary of the valley and probably underlies the valley floor. The higher ridges are formed of the Kamaile‘unu and/or Lualualei members of the Wai‘anae Volcanics (Oki 1998). The valley floor is underlain by Quaternary (less than 1.8 million years old) alluvial deposits of unknown thickness. Near the coast, the surficial deposits consist of beach dune sands underlain by calcareous cemented sands and rubble and the remnants of an emerged ancient reef. The calcareous sand and remnant reef deposits are relatively thin near the shore, where they overlie the Wai‘anae Volcanics (Halliburton NUS 1994). MMR is within the northwest rift zone of the Wai‘anae Volcano and is northwest of the eruptive center of the volcano. As such, the basalt flows generally dip toward the northwest but are intersected by a dense network of vertical or nearly vertical dike intrusions that are visible in the walls of the valley.

Soils

A complex mixture of soils occurs in Mākua Valley as a result of the many microenvironments and variations in slope (Figure 3.8-2). The side slopes of Mākua Valley are too steep to hold more than a thin covering of soil and are generally classified as Rocky or Stony Land. The south-facing slope of the Kahanahāiki Valley, east of Punapōhaku Stream, also is classified as Stony Land, although a small enclave of Helemano silty clay occurs on colluvial deposits in the upper eastern part of this valley. Helemano soils are well-drained silty clays that occur in V-shaped gulches. The erosion hazard is severe to very severe. Most of the channel of Mākua Stream and some of the lower reach of Kaiahi Gulch is

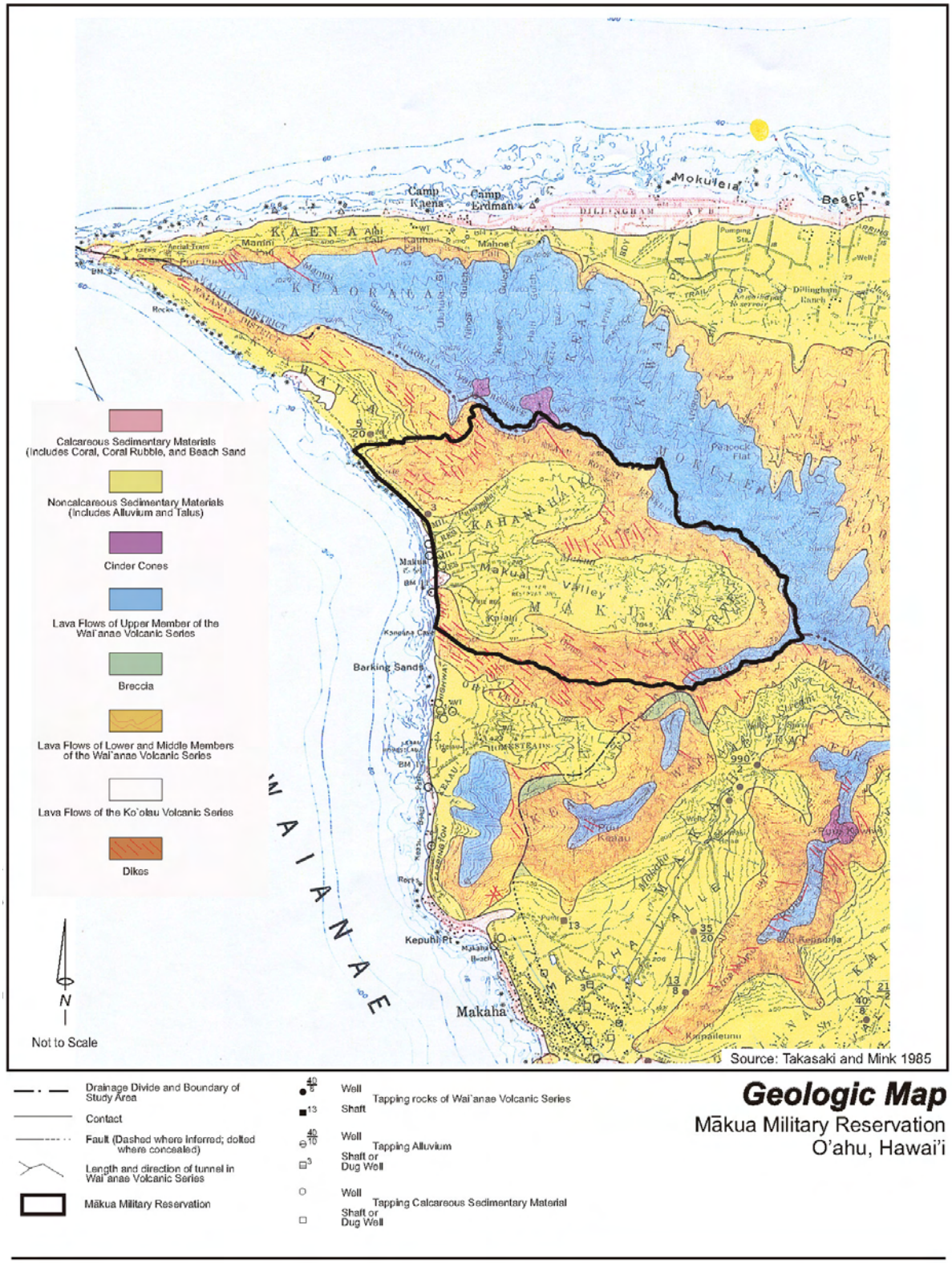


Figure 3.8-1 Geologic Map, MMR

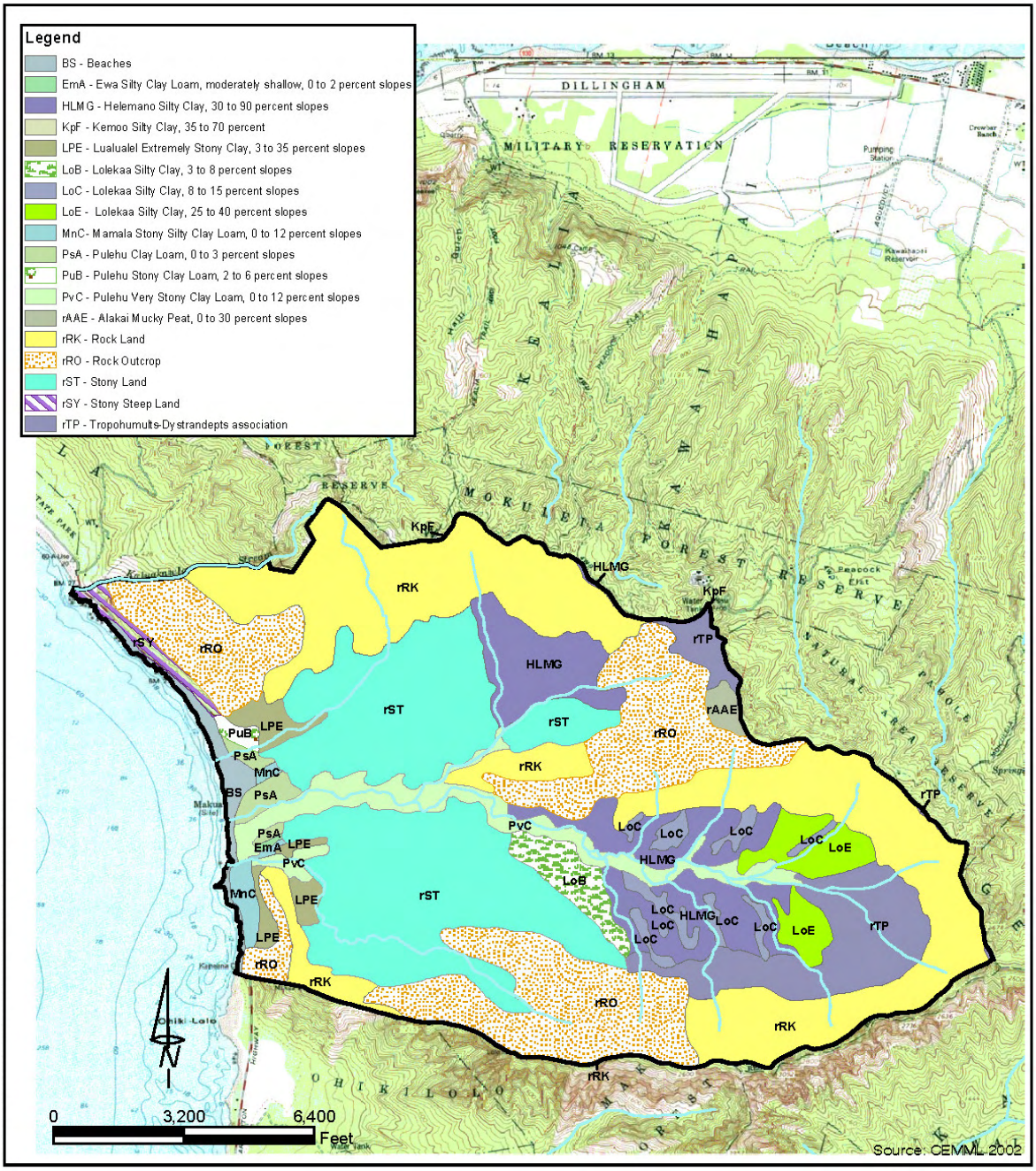


Figure 3.8-2 Soil Map, MMR

underlain by Pulehu very stony clay loam. The soil is developed on alluvial fans and stream terraces. Permeability is slow, and the erosion hazard is slight. The soil is generally about 5 feet (2 meters) thick and underlain by coarse gravelly or sandy alluvium. This soil type is used for sugarcane, truck crops such as ginger and taro, and pasture, but as 3 percent of the surface area is covered by stones, the soil is difficult to work. Pulehu clay soils, with fewer stones, also are found along the low-lying lands inland from Farrington Highway. Some of these soils are developed on land that is subject to flooding. The upper portion of the main lobe of alluvial deposits in Mākua Valley, which includes the OB/OD area and most of the area in which live-fire training exercises occur, is underlain by Lolekaa silty clay soils.

Lolekaa soils vary somewhat depending on the slope and elevation at which they occur. They consist of well-drained soils developed in old gravelly colluvium and alluvium on fans and terraces. According to the Natural Resources Conservation Service (NRCS), annual rainfall in areas with these soils is 70 to 90 inches (178 to 229 centimeters), and these soils occur at elevations from sea level to 500 feet (152 meters). However, mean annual rainfall in the portion of Mākua Valley where these soils occur may be in the range of 40 to 60 inches (102 to 229 centimeters), and the elevation ranges from about 400 to over 1,000 feet (122 to 305 meters). Access to the area in which these soils are mapped has been closed for some time due to military activities and the possible presence of UXO.

Near the mouth of Mākua Valley, at low elevation, are a variety of soils covering small areas. On the middle reaches of both Kaiahi Gulch and Punapōhaku Stream is Lualualei extremely stony clay. These are well-drained soils developed in colluvium on coastal plains, alluvial fans, and talus slopes at elevations up to 125 feet (38 meters). Runoff is medium to rapid, and erosion hazard is moderate to severe. Cultivation is impractical unless the stones are removed.

South of the outlet of Ko‘iahi Gulch (also known as Kaiahi Gulch), between the beach and the ridge, the predominant soil is Mamala stony silty clay loam. These soils form in alluvium deposited over coral limestone and consolidated calcareous sand. The soil is dark reddish-brown, with a consolidated coral or calcareous sand at depths of 8 to 20 inches (20 to 51 cm). The permeability is moderate, runoff is very slow to medium, and erosion hazard is slight to moderate. Figure 3.8-2 shows the soils found within an approximately 500-foot wide corridor along the two principal trails connecting DMR and MMR. A shoreline trail, the Kaena Point Trail, follows an existing paved road for about three miles west of

DMR, after which the road is unpaved, but lies within a broad bench above the elevation of the beach. The other trail, the Kuaokala Access Road and Trail, follows an existing improved road up the north-facing slope of the Wai‘anae Range from the east side of DMR. Near the crest of the range, at an elevation of about 1,500 feet, the trail breaks from the improved road to an existing pedestrian trail that continues to the Kuaokalā Ridge. The trail follows westward along the ridge for about one mile and then descends into Mākua Valley along the west side of Punapōhaku Stream.

Most of the shoreline trail traverses land that is classified as Rock Outcrop, Rock Land, or Stony Steep Land. The following soils are adjacent to or interspersed with the rocky land on the north shore:

- Stony soils (Waialua stony silty clay, Lualualei extremely stony clay, and a quarry);
- Sandy soils (Jaucas sand near the west end of DMR and beach sand); and
- Small patches of other soils (Mokuleia clay loam near DMR and Lualualei clay near Ka‘ena Point).

Along the shoreline trail south of Ka‘ena Point, the trail follows an unpaved road that is in poor condition. The road is highly eroded with deep potholes. The slope above the road is very steep, but most of the road is deeply incised and poorly drained. Near Ka‘ena Point a landslide has removed a short section of the road. The potholed section of trail ends at the northern end of the public beach at Ka‘ena State Park. The trail continues south along the paved Farrington Highway for the remainder of the distance to MMR. Most of the soils within the potholed road segment between Ka‘ena Point and the public beach are classified as Stony Steep Land. The paved portion of the inland trail overlies many soil types, on moderate to steep slopes, but the soils are not exposed. Above 1,500 feet (457 meters), where the pedestrian trail begins, it mainly traverses Kemoo silty clay soils on 35 to 70 percent slopes, or Helemano silty clay soils on 30 to 90 percent slopes. Kemoo soils are well-drained deep soils developed on basalt rocks on uplands, mainly on windward slopes.

The Kemoo soils in the trail alignment occur on side slopes along drainage ways, where runoff is rapid, and the erosion hazard is severe. The soil is thin, and includes eroded spots, stony areas, and rock outcrops. Helemano soils, which have been described above, are also subject to severe erosion. The south-facing ridges in the trail alignment are underlain by Rock Land at the higher elevations and by Stony Land near the valley floor. As the names imply, Rock Land is made up of 25 to 90 percent

exposed rock. The soils that remain between outcrops tend to be very sticky and plastic clays, with high shrink-swell potential. Rock Land is susceptible to sliding when the soil is saturated. Stony land consists of boulders and stones deposited by water and gravity over 15 to 90 percent of the surface, with silty clay loam soils found among the stones. The soils are thin, but generally provide sufficient substrate for plants.

Pōhakuloa Training Area

Regional Geology

The Island of Hawai‘i is the youngest of the Hawaiian Islands and is the only island that is still growing. Therefore, the landscape is younger and less affected by erosion than other islands. Also, the island is larger and higher than the other islands. The bulk of the Island of Hawai‘i was formed from the eruptions of five shield volcanoes. Kohala, the oldest, is extinct. Mauna Kea last erupted about 3,500 years ago and is considered dormant. Hualālai last erupted in 1801. Mauna Loa and Kīlauea are both active.

Physiography

PTA is in the Humu‘ula Saddle between the two major peaks on the Island of Hawai‘i; Mauna Kea lies to the northeast, and Mauna Loa lies to the south. The cantonment area, which is adjacent to Saddle Road that traverses the northeast corner of PTA, is at an elevation of 6,400 feet msl (1,950.7 meters). The slope of the Mauna Kea volcano rises steeply (about a 26 percent slope) from Saddle Road to an elevation of 13,796 feet msl (4,207 meters) over a distance of about 6 miles (14.5 kilometers). The slope of Mauna Loa, by contrast, rises to the southwest at about a 4 percent slope to an elevation of 13,678 feet msl (4,169 meters) over a distance of about 20 miles (32.2 kilometers). To the west of these two peaks is the Hualālai volcano (about 8,690 feet msl, 2,650 meters). Elevations within PTA range from 4,030 to 8,650 feet msl (1,228 to 2,637 meters).

The military vehicle trail from Kawaihae Harbor to PTA runs south inland of Highway 270 and rises to an elevation of about 250 feet (76.2 meters) near the junction with Highway 19. The trail continues east, paralleling Highway 19 along the foot of the Kohala Mountains to the western edge of Waimea (Kamuela). This segment rises to an elevation of about 2,500 feet (762 meters) over a distance of about 10 miles (16.1 kilometers). Near Wai‘aka, on the outskirts of Waimea, the trail turns south and runs west of Highway 190 approximately following the 2,400-foot (731.5-meter) elevation contour until the junction with Saddle Road (Route 200). The trail crosses Highway 190 west of a small volcanic cone called

Nahonaoahe and continues upslope, roughly parallel to Saddle Road, until it reaches PTA at a point near the Pu‘u Ke‘eke‘e cinder cone.

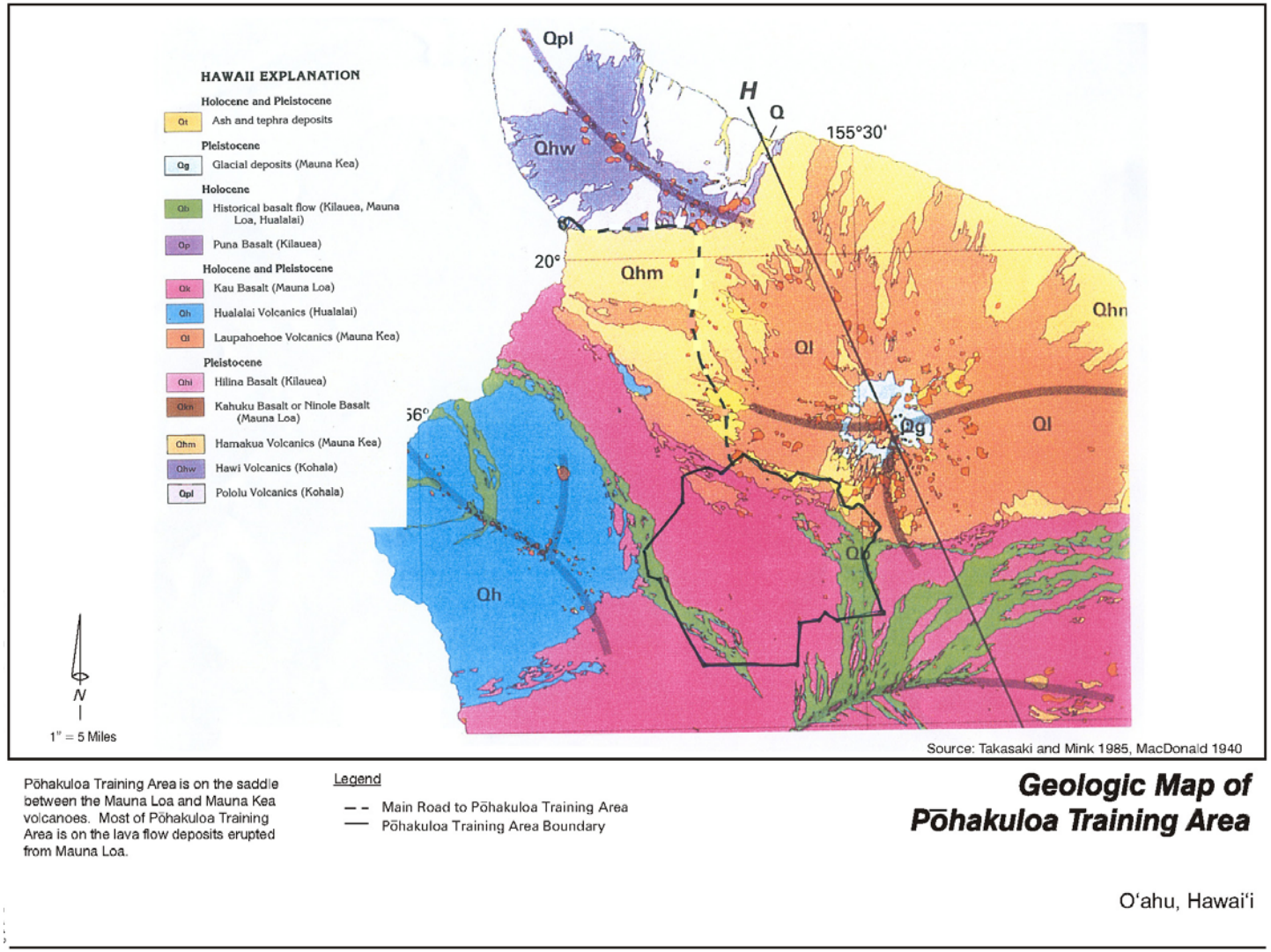
Geology of the Pōhakuloa Training Area

Figure 3.8-3 is a geologic map of the northern portion of the Island of Hawai‘i, showing the locations of PTA and PTA Trail. PTA is on the saddle between the Mauna Loa and Mauna Kea volcanoes. Most of PTA is on lava flow deposits erupted from Mauna Loa, the largest active volcano in the world. Lava from Mauna Loa's last eruption, in 1984, covered 16 square miles (41.4 square kilometers) of land in three weeks. The lava erupted from the Northeast Rift Zone, which extends northeast from the Mauna Loa crater and skirts the southeast boundary of PTA. The lava flowed within 4 miles (6 kilometers) of Hilo (USGS 1997a).

PTA is underlain by overlapping basalt flows erupted from Mauna Loa and Mauna Kea. The three most recent flows responsible for the surface deposits at PTA are Hāmākua flows from Mauna Kea that occurred during the Pleistocene, Laupāhoehoe flows from Mauna Kea that occurred during the Holocene, and Ka‘ū flows from Mauna Loa that have occurred as recently as 1935 (USARHAW and 25th ID[L] 2001c). The more recent flows have not entered the PTA boundary.

These flows have gradually built up a broad, relatively gently sloping surface that appears smooth from a distance but is actually very rough and highly variable in texture close up. There is little woody vegetation, due to a number of factors, including elevation, climate, wind, thin soil, and soil chemistry. Soil forms or accumulates in low areas, on older volcanic flow surfaces, and in areas overlain by volcanic ash deposits. The relatively smooth terrain is broken in places, such as along the western edge of PTA, by small cinder cones. Some of the cinder cones have been quarried for material used in construction or to surface roads.

During volcanic flows, the surface of the lava cools and forms a hard crust, while the lava below the crust continues to flow. Under some the molten lava may run out, leaving behind an empty tubular shell of hardened lava. Some lava tubes are hundreds of feet long and tend to collapse over time or become filled by subsequent flows or sedimentation. Some tubes may become plugged at both ends, leaving a subsurface cavity with no manifestation at the surface. Such cavities are often encountered during drilling in basaltic lava terrain. Some lava tubes can be conduits for water. There are probably many lava tubes underlying PTA, but they have not been mapped and are not accessible to the public.



Pōhakuloa Training Area is on the saddle between the Mauna Loa and Mauna Kea volcanoes. Most of Pōhakuloa Training Area is on the lava flow deposits erupted from Mauna Loa.

Legend

- - Main Road to Pōhakuloa Training Area
— Pōhakuloa Training Area Boundary

Geologic Map of Pōhakuloa Training Area

O'ahu, Hawai'i

Figure 3.8-3 Geologic Map, PTA

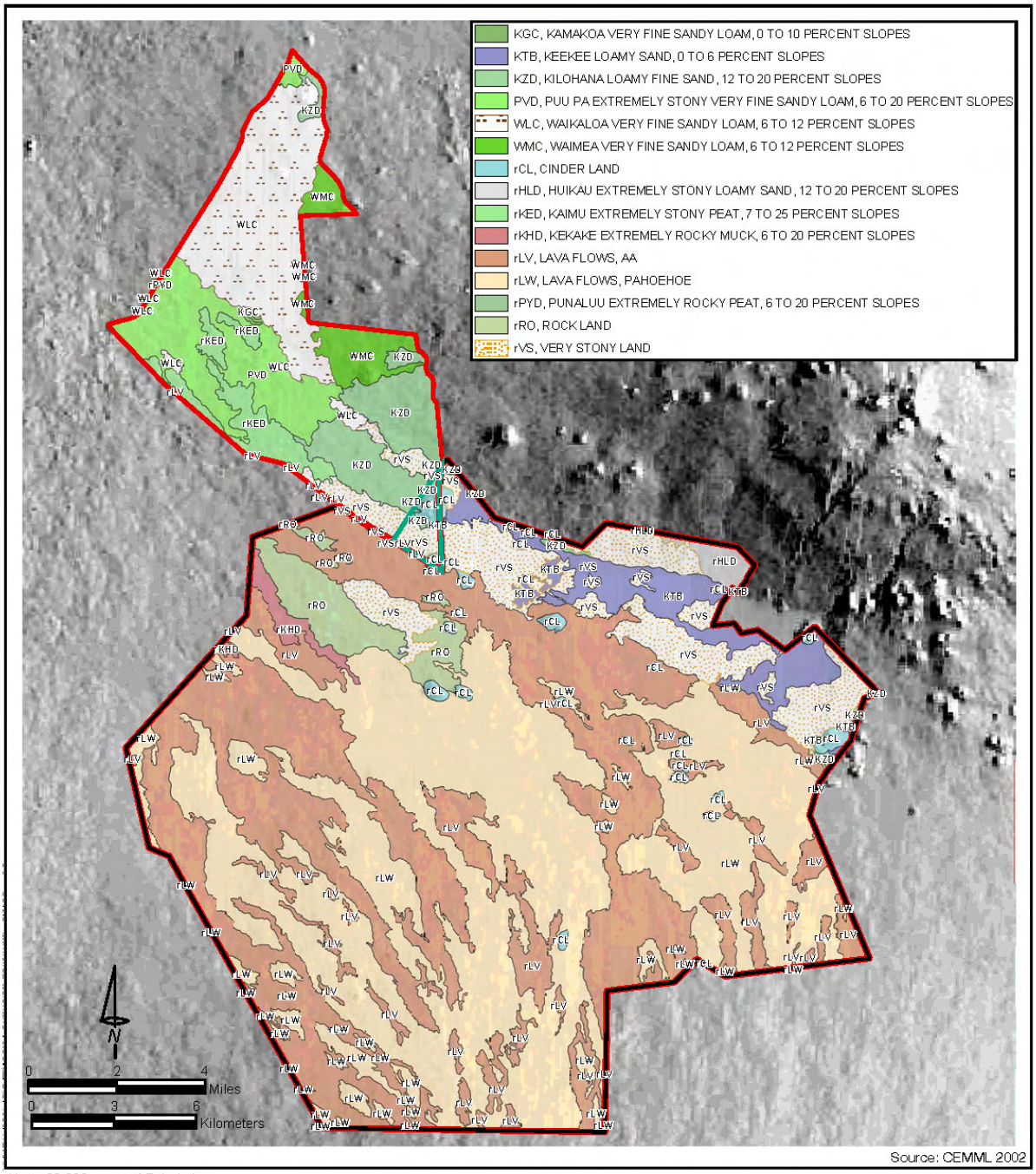
The lower half of the WPAA is within the Waimea Plains, which were formed by lava flows from Mauna Kea that butted up against the older Kohala Mountains. The Kohala Mountains are now covered with a blanket of volcanic ash soils. The lava is predominantly pāhoehoe and ‘a‘ā basalt flows, scoria (cinder), and ash deposits of the Hāmākua Volcanics Series (Wolfe and Morris 1996). Hawaiian basalts have a high iron content, and the composition of many basalts is over 40 percent iron-containing minerals (Wolfe and Morris 1996). In some cases, the high iron content makes it difficult to discriminate ordnance from rock, and weathered basalt cobbles can look similar to oxidized ordnance (Earth Tech 2002). The parcel is dotted with cinder cones associated with the Mauna Kea volcano. The cinder cones are deposited on the upper layer of the Hāmākua Volcanic Series, which is covered by a layer of up to about 3 feet (0.9 meter) of Pahala ash erupted about 39,000 years ago.

The term “Pahala ash” has been widely used to describe nearly all the thick soils on Hawai‘i, although it technically refers to ashes erupted from Mauna Loa or Kīlauea that were deposited mainly on the southern flanks of the island. Ash deposits along the Hāmākua coast are mainly from older explosive eruptions of Mauna Kea.

Soils

Pōhakuloa Training Area. Soils are thin and poorly developed on PTA. Recent lava flows cover about 80 percent of the land surface. The low precipitation, rapid runoff, and high altitude reduce the rate of weathering, and the high slope and wind tend to prevent soils from accumulating. Figure 3.8-4 shows the soil types within PTA. About 88,000 acres (35,612 hectares) of PTA are classified by the US NRCS as lava flows, of which about half are ‘a‘ā flows and half are pāhoehoe flows. An additional 1,400 acres (567 hectares) are classified as cinder land. About 12,500 acres (5,059 hectares) are classified as either rock land or very stony land. The remaining approximately 10,000 acres (4,047 hectares), almost all of which is along the northern boundary of PTA near Saddle Road within training areas 1 through 17 and 22, are classified as soils formed on volcanic deposits.

The predominant soil is Keekee loamy sand on 0 to 6 percent slopes, which accounts for nearly 7,500 acres. This is a mildly to strongly alkaline soil consisting of stratified sand developed in alluvium from volcanic ash and cinders. Permeability is rapid, and runoff is slow. The hazard of wind erosion is moderate to severe. Similar sandy soils developed on slightly steeper slopes are found in the same general vicinity, including Huikau extremely stony loamy sand on 12 to 20 percent slopes, and Kilohana loamy fine sand on 12 to 20 percent slopes.



About 88,000 acres of Pōhakuloa Training Area are classified as lava flows of which about half are 'a'ā flows (highly fractured and blocky) and half are pāhoehoe flows (dense, smooth, or ropy).

Legend

- Pōhakuloa Training Area Boundary
- P7 West Pōhakuloa Training Area Land Acquisition Area
- 1010 Land Acquisition Area
- P3/P4 Pōhakuloa to Kawaihae Trail

Soils Map
Pōhakuloa Training Area

Island of Hawai'i, Hawai'i

Figure 3.8-4 Soils Map, PTA

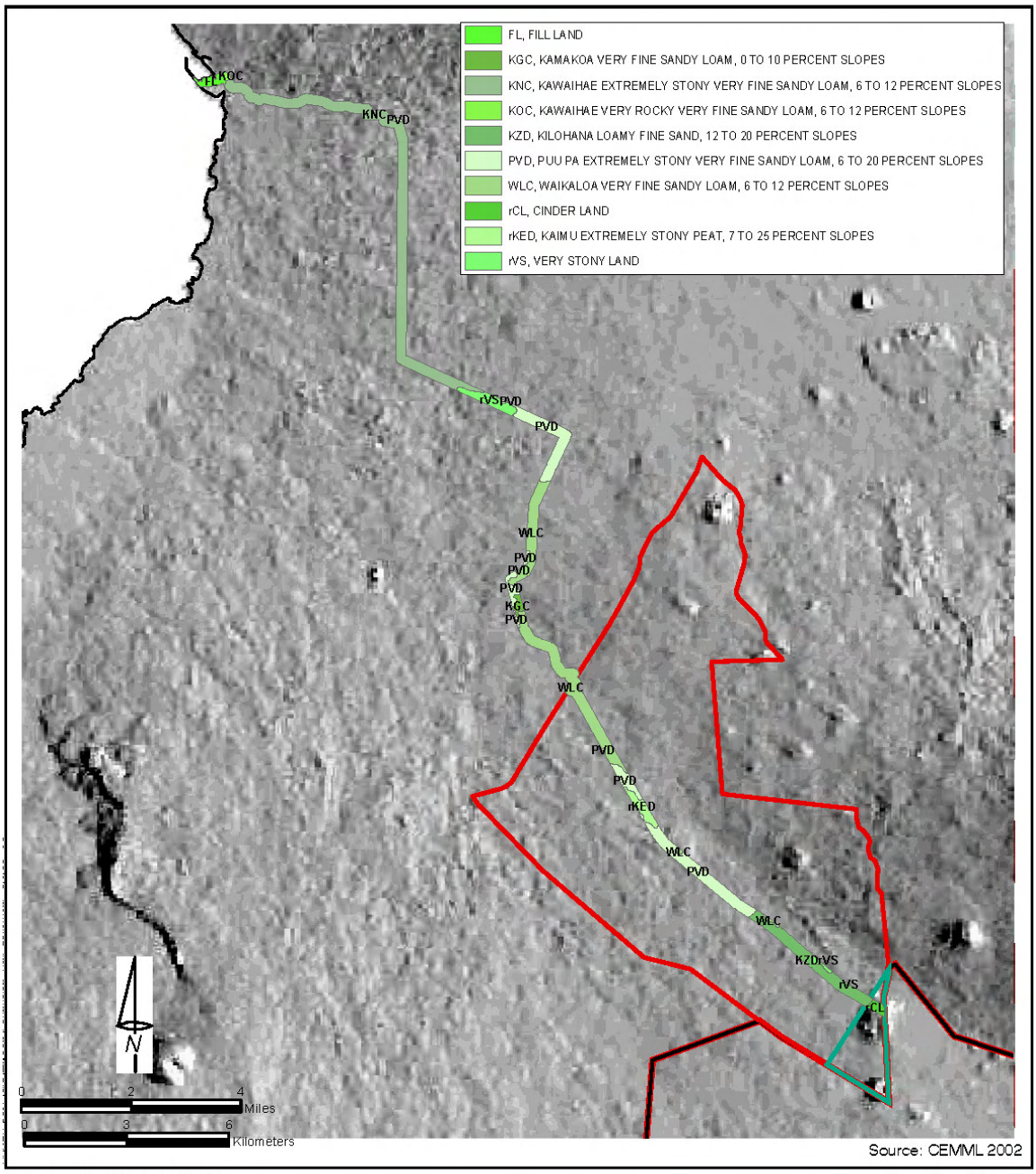
The proposed CALFEX range at PTA would be in the Twin Pu‘u area, covering about 1,000 acres (405 hectares). Most of the area is pāhoehoe lava, with the northern portion rock land. Cinder cones are at the northern and southern edges of the proposed range.

Shallow gulches dissect the parcel; the largest of these are Waiki‘i Gulch and ‘Auwaiakeakua Gulch. The soft, permeable soils form thicker deposits in some areas. The Pu‘u Pa soils contain a calcium carbonate cemented layer in some areas that impedes percolation of water. Although there are no perennial streams, rainfall keeps the subsoils moist along the gulches. There are areas of peat soil, where rapid cycles of vegetation growth and a moist, temperate environment have caused organic material to accumulate. The Waikaloa and Pu‘u Pa soils are easily eroded by wind and water.

Kawaihae to PTA Trail. Figure 3.8-5 shows the soils along PTA Trail. From Kawaihae Harbor to about midway to Waimea, PTA follows the route of an existing military vehicle trail. The Kawaihae Harbor area is built on imported fill and is paved over. The foot of the slope just east of Kawaihae Harbor is composed of Kawaihae very rocky very fine sandy loam (KOC). The trail continues upslope over Kawaihae extremely stony very fine sandy loam on slopes of 6 to 12 percent (KNC). Kawaihae soils are moderately deep, somewhat excessively drained soils that formed in material weathered from volcanic ash. The soils have a very weak structure and are very friable (crumble easily). The soil occurs at elevations up to 1,500 feet (457.2 meters) on the leeward side of Hawai‘i, where rainfall is 5 to 20 inches (12.7 to 50.8 centimeters). These soils are used mainly for grazing.

About 3 miles (5 kilometers) from Kawaihae Harbor, and just east of Kemole Falls, the trail turns south from the highway and approximately follows the 1,200-foot (366-meter) elevation contour. The route crosses the former Lalamilo Firing Range, just downslope of a rock wall, following the western boundary of the Pu‘u Pā Military Maneuver Area (Earth Tech 2002). The underlying soil on this traverse is still the Kawaihae extremely stony very fine sandy loam

About 4 miles (6 kilometers) south of the highway, near Kamakoa Gulch and about 1 mile (1.6 kilometers) northeast of Waikoloa, the trail turns nearly straight upslope in the direction of the Saddle Road Junction, continuing along the southern boundary of the Pu‘u Pā Maneuver Area, and rising about 800 feet (244 meters) in 3 miles (5 kilometers). A road from here crosses the rock wall and ends at a water tank and two wells. The lower portion of this upslope segment is underlain by Kawaihae



Soils along the Pōhakuloa Training Area trail. From Kawaihae to the Pōhakuloa Training Area Boundary.

Legend

- Pōhakuloa Training Area Boundary
- P7 West Pōhakuloa Training Area Acquisition Area
- 1010 Land Acquisition Area
- Hawai'i Coast Line

Soils Map
Pōhakuloa to Kawaihae Trail

Island of Hawai'i, Hawai'i

Figure 3.8-5 Soils Map, PTA – Kawaihae Trail

extremely stony very fine sandy loam, which lines the gulch. Just beyond the water tank, the road crosses the gulch and continues on very stony land (rVS) from an elevation of about 1,400 feet (427 meters) to about 1,600 feet (488 meters).

At about the 1,600-foot (488-meter) elevation contour, the trail crosses about 1 mile (2 kilometers) of Pu‘u Pa extremely stony very fine sandy loam on 6 to 20 percent slopes (PVD). Like the Kawaihae soils, Pu‘u Pa soils are moderately deep, well-drained soils that formed in material weathered from volcanic ash, have a weak structure, and are very friable. They are distinguished from Kawaihae soils mainly by occurrence at elevations between 1,000 to 2,500 feet (305 to meters), where slopes range from 6 to 100 percent and annual rainfall is 20 to 35 inches (51 to 89 centimeters). Permeability is moderately rapid, and runoff is medium. The soils are used mainly for pasture. At an elevation of about 1,900 feet (579 meters), the trail turns abruptly south again for about 4 miles (6 kilometers), following an existing unpaved track for about 2 miles (3 kilometers), and then continues above the 1,800-foot (549-meter) contour, where there is no existing track, until it intercepts a paved road. The trail continues upslope along the paved road for a distance of about 4 miles (6 kilometers), alongside ‘Auwaiakeakua Gulch, to the ‘Auwaiakeakua Water Tank at Highway 190.

The soil along about the last 7 miles (11 kilometers) of this segment is mainly Waikaloa very fine sandy loam on 6 to 12 percent slopes (WLC). The Waikaloa soil is interspersed with Pu‘u Pa and Kamakoa very fine sandy loam on 6 to 12 percent slopes (KGC). Waikaloa soils are deep to very deep, well-drained soils that formed in basic volcanic ash. Slopes range from 2 to 20 percent. The mean annual rainfall is about 15 inches (38 centimeters). The soil has weak structure throughout the profile and is friable. Depth to bedrock is greater than 5 feet (1.5 meters). A strongly cemented layer containing calcium carbonate occurs in most locations at a depth of about 4 feet (1 meters).

Highway 190 marks the western boundary of the WPAA. The rest of the route, through the WPAA, is generally straight up the slope. The route passes over approximately equal amounts of Waikaloa and Pu‘u Pa soils, encountering a short segment underlain by Kaimu extremely stony peat on 7 to 25 percent slopes (rKED). The Kaimu soil occurs south of Popoo Gulch and east of Ke‘āmuku, at an elevation of between 3,200 and 3,400 feet (975 and 1,036 meters). The Kaimu soil is moderately deep, somewhat excessively drained, and highly organic. This soil formed in organic material mixed with minor amounts of basic volcanic ash in ‘a‘ā

lava. The soil occurs in areas where the mean annual rainfall is about 35 inches (89 centimeters).

About 3 miles (5 kilometers) downslope from the 1010 Parcel, at an elevation of about 4,300 feet (1,311 meters), the trail encounters Kilohana loamy fine sand on 12 to 20 percent slopes (KZD), interspersed with very stony land. The Kilohana soil is deep, somewhat excessively drained, and forms in material weathered from volcanic ash. Kilohana soils are on uplands, generally at elevations of 5,000 to 6,500 feet (1,524 to 1,981 meters) with slopes of 12 to 20 percent. Mean annual rainfall is about 30 inches (76.2 centimeters), and depth to bedrock is more than 6 feet (2 meters). The soils are very highly permeable and runoff is slow. Outcrops of ʻaʻā lava flows are common. In the 100 Parcel, the trail intercepts Keʻekeʻe Road, an unpaved road that runs along the northwest side of Puʻu Keʻekeʻe cinder cone, where the soils are classified as cinder land.

3.8.3 Soil Contamination

Past and current activities at MMR and PTA have resulted in contamination of soil by explosives and other chemicals. The following is a brief summary of the results of past and recent studies that provide information about the nature and extent of soil contamination. The focus of these studies is on work done at MMR. Much of the information on PTA is from studies done in support of the 2004 SBCT EIS. PTA findings are summarized below.

Mākua Military Reservation

Ordnance Use, 1929 to 1950

A 1984 Installation Assessment indicated that the Army began acquiring Mākua Valley in 1929 (USATHAMA 1984). The beach and other areas of the Waiʻanae coast were used for joint Army and Navy maneuvers during the 1930s, but the land was returned to the territory of Hawaiʻi between 1940 and 1941. After the attack on Pearl Harbor in December 1941, the valley was again used for military training. Since then, it has reportedly been used for aerial bombing practice, ship to shore artillery practice, amphibious landing training, and live-fire exercises involving small arms and artillery (Char 1977). The range continued to be used after World War II and through the Korean War. Range clearing operations were conducted in 1949 and 1950 to remove UXO, and approximately 11,000 rounds of artillery, mortars, and bombs, plus bulk explosives, were reportedly detonated either in place or in the OB/OD area (USATHAMA 1984; Sox 1977).

Waste Disposal Open Burn/Open Detonation Area

Shown in Figure 3.11-1, the OB/OD area at MMR is an inactive RCRA treatment facility in delayed closure status from the HDOH, Solid and Hazardous Waste Branch. The area is downslope of the access road. Army, Air Force, Navy, and Marine Corps personnel used this area from the 1960s into the 1990s. This site was reportedly the only safe disposal site in Hawai‘i for hazardous materials. Ammunition was doused with large amounts of fuel and waste oils in the bottom of a trench and ignited using incendiary grenades, blasting caps, or time bombs (Char 1977). Larger munitions (such as mines) were buried in specially designed trenches and detonated. Trenches were used only once, and each detonation consumed approximately 1 ton (908 kilograms) of waste. Detonations could be sequenced in 15-second intervals (USATHAMA 1984). After destruction of the munitions, the trenches were inspected to ensure complete destruction and were backfilled with soil. No nuclear, radiological, chemical, or biological agents were disposed of at the OB/OD area (Geotechnical and Structures Laboratory 2002).

The OB/OD area had three primary purposes, including the mass destruction of unserviceable ordnance; engineer training with large demolition and mine munitions, such as bangalores; and the burning of excess propellant (Char 2003). Quantities of ordnance disposed of in the OB/OD area varied from year to year, but approximate total quantities disposed of per year included 12 tons (11 metric tons) by the Army, 6 tons (5 metric tons) by the Air Force, and 60 to 70 tons (54 to 64 metric tons) by the Navy.

The last time ammunition was destroyed by open burning at the OB/OD area in 1992. Unserviceable munitions are now shipped back to ammunition depots in the CONUS for final disposition (Akasaki 2003).

Results of Past Soil and Sediment Investigations

Several studies of sediment and soil have been conducted over the years. Char (1977) collected shallow soil and sediment samples from the ordnance impact area at MMR and background sites and determined metals concentrations in the samples, in an attempt to estimate the rates of metal loading due to sediment transport to the ocean. Char estimated an annual sediment discharge rate from Mākua Valley of approximately 1,000 metric tons (1,100 tons) per year. These results were consistent with the average sediment yield estimated by the state of Hawai‘i for leeward O‘ahu of 670 pounds/acre/year (250 kilograms/acre/year) applied to the 4,000-acre (1,619-hectare) area of the valley (HWRRS 1975).

Char estimated that the rate of sediment loss from the 4-acre (2-hectare) active portion of the OB/OD area alone was about 100 metric tons (110 tons) per year, because of the exposed disturbed soils at the site. He also noted that actual sediment yields could vary widely from year to year depending on rainfall. Since that time, roads have been improved with crushed coral to reduce erosion, and grassy vegetation cover in the valley has increased. These changes may have significantly reduced erosion rates in the OB/OD area and from the valley side slopes in general.

In 1993, a soil and groundwater investigation was conducted by Halliburton NUS (1994). The investigation was intended to characterize potential impacts associated with past OB/OD operations and to support the RCRA Subpart X permitting process for the OB/OD area; Subpart X addresses closure requirements for miscellaneous RCRA sites, including OB/OD areas. The sediment and soil samples were analyzed for semivolatile organics, metals, cyanide, sulfides, energetics, nitrates/nitrites, and nitrites. The investigation report concluded that none of the soil or groundwater samples from outside the OB/OD area contained contaminant concentrations above health-based criteria.

In 1999, the EPA and the HDOH performed an investigation of sediment samples from the *muliwai* west of Farrington Highway (Baylor 1999). Samples were collected from the pond bottom sediments and analyzed for metals. The investigation found that cadmium, chromium, and copper exceeded the NOAA Effects Range-Low and nickel exceeded the NOAA Effects Range-Medium in both the Mākua and reference *muliwai* samples. The NOAA Effects Range is a measure of the risk to ecological receptors and designates chemical concentrations as low, medium, or high. Because it is known that concentrations of some metals are naturally elevated in Hawaiian soils, and because elevated concentrations of these metals were found in the reference (background) *muliwai* location, the investigation report could not determine whether the elevated metals concentrations originated from human activities or were naturally occurring.

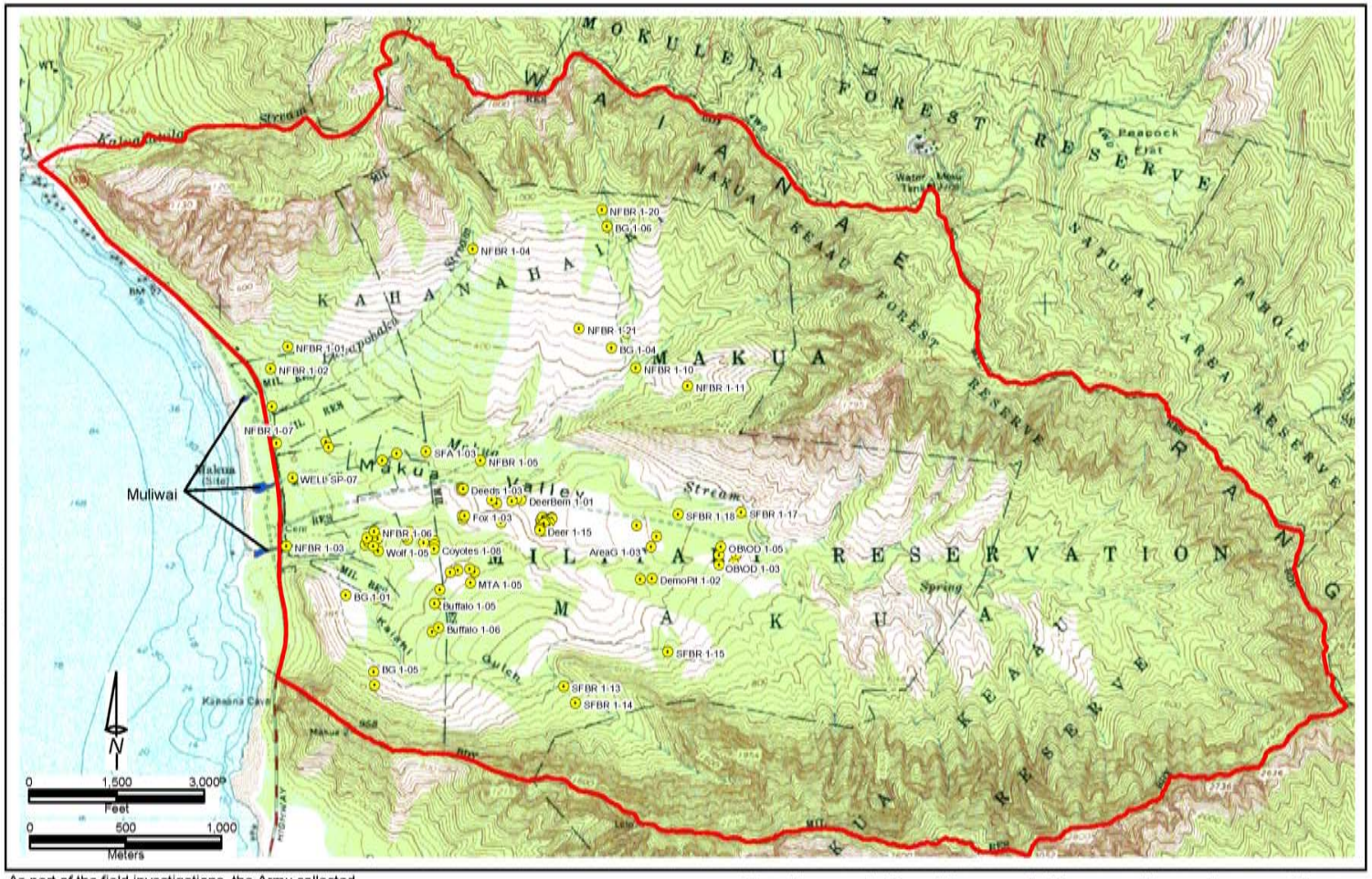
Scope of the 2002/2003 Hydrogeologic Investigation

The Army initiated a hydrogeologic investigation to further characterize soils, sediment, surface water, and groundwater at MMR. Figure 3.8-6 shows locations of soil sampling points within MMR, and Figure 3.8-7 shows locations of background soil sampling points outside MMR. The following discussion is based on the Draft Hydrogeologic Investigation Report for MMR (USACE 2006) that is presented in Appendix G-1. Groundwater monitoring and data interpretation are expected to continue after completion of this EIS.

As part of the investigation, 102 surface/near-surface soil samples were collected and analyzed. To assist in evaluating the fate and transport of any chemicals that may be present in surface soils at MMR, 11 streambed sediment samples were collected. Eighteen subsurface soil samples also were collected and analyzed to assist in evaluating vertical migration of chemicals from the surface to the subsurface. These subsurface soil samples were collected from borings drilled in areas with the greatest likelihood of surface soil contamination as a high bias for subsurface transport modeling. As part of the investigation of vertical transport, soil samples were collected from vadose zone soils at various depths to gauge the moisture in the soil column. The surface/near-surface, streambed, and subsurface soil samples were analyzed for metals, explosives, volatile organic compounds (VOC), semivolatile organic compounds (SVOCs), chlorinated pesticides, polychlorinated biphenyls (PCBs), nitrates/nitrites, organophosphate, and other anions. Summary tables showing the concentrations of detected compounds are presented in the Draft Hydrogeologic Investigation Report in Appendix G-1. In addition, Appendix G-2 contains charts that show the distributions of the metals and selected explosives concentrations in the samples.

Most, if not all, of the metallic elements included in the analytical suite used in the hydrologic study occur naturally in soils in the study area, because they are present in the minerals in the basalt rock from which the soils derive. The range of concentrations of each element depends on the mineral content of the rock, as well as the nature of the soil-forming process. Some Hawaiian soils, including those found at MMR, are highly enriched in aluminum, iron, and manganese, for example.

The soil sample results were statistically compared to EPA Region IX PRGs for soils at industrial sites. This statistical evaluation included a calculation of the 95 percent UCL of the sample data set. The 95 percent UCL in a set of samples representative of a site is considered by the EPA to be a conservative estimate of the average concentration in the soils at a site. The industrial soil PRGs are conservative health-based concentrations, designed to be protective of the health of workers in an industrial exposure setting. The assumptions used in setting the industrial soil PRGs included that adult workers would be exposed to these concentrations for a normal work week over a period of 20 years, without ill effects.



As part of the field investigations, the Army collected and analyzed 102 surface/near-surface soil samples and 20 muliwai sediment samples.

Legend

- Soil Sample Points
- Mākua Military Reservation

Soil and Sediment Sampling Locations

Mākua Military Reservation
O'ahu, Hawai'i

Figure 3.8-6 Soil and Sediment Sampling Locations, MMR

Background soil samples were collected at six locations.

Background Soil Sampling Locations

Legend

Background Sampling Location

Mākua Military Reservation

Mākua Military Reservation
O'ahu, Hawai'i

Figure 3.8-7 Background Soil Sampling Locations, MMR

The health effects are separated between carcinogenic and non-carcinogenic effects, and both types of effects may be involved for some chemicals. The effects of exposures to multiple chemical hazards can be cumulative, although the ways in which chemical effects interact can be quite complex, and assessment of these cumulative effects requires sophisticated analysis. The PRGs were developed to be used as a screening tool to determine if further sophisticated analysis of the health effects at a site may be needed. Generally, if PRGs are not exceeded at a site, there is no need to do further sophisticated analysis, because significant health effects are not likely to occur as a result of the concentrations present.

Pōhakuloa Training Area

Scope of the 2002 Pōhakuloa Training Area Investigation

The USACE, Sacramento District, conducted a surface soil and surface water investigation at PTA from November 12 to November 14, 2002, in support of the SBCT EIS. Study objectives were to support the description of current conditions and to provide evidence of the effects of past training activities on surface soils and surface water. The investigation was not intended to be a comprehensive study of the distribution of contaminants on the ranges.

A total of 46 soil samples were collected from Range 5 (the Grenade Range), Range 9 (the Engineering Demolition Range), Range 10 (temporary Range 9 (the Engineering Demolition Range), Range 10 (temporary impact area), Range 11 (impact area), various firing points (firing points 309, 311, 420, 802, and 804), and Range Control (considered to be an ambient background site). No surface water was observed and, therefore, no water samples were collected. Greater discussion on the investigation findings are found in the SBCT EIS.

3.8.4 Mākua Military Reservation Contaminants of Concern

During training, explosive munitions residues, fragments of metal casings from munitions items, and projectiles (including lead-antimony alloy bullets) are deposited on the ranges. The surfaces of metal fragments and projectiles may dissolve slowly and leach metals, including lead, antimony, iron, nickel, and others, into the soil and water. Munitions contain a number of chemical constituents, depending on the types of munitions, including explosives, metals, plastics, and other constituents. While most of the original chemicals are burned or vaporized when the munitions are fired or detonated, some of the material may not be fully destroyed, leaving residues that may be deposited on the soil.

3.8.5 Chemical Residues from Past Activities Mākua Military Reservation

Explosives

The results of the MMR hydrogeologic investigation (Appendix G-1) indicate that three surface soil samples contained detectable concentrations of RDX (400 to 700 µg/kg). The samples were collected from the OB/OD area and the demolition pits area, where past disposal practices, rather than detonations from CALFEX exercises, may account for some or all of the detected RDX.

In addition, samples from five locations contained concentrations of 2,4-DNT from 0.28 mg/kg to 76 mg/kg. In one of these locations, 2,6-DNT was also detected at 0.14 mg/kg. DNT is a component of some high explosives mixtures, but it is also a product that forms from the breakdown of TNT in the environment. HMX was detected in two of the soil samples in which RDX was detected at concentrations of 0.37 mg/kg and 0.5 mg/kg. Only one surface soil sample contained a detectable concentration of 2,4,6-TNT at 0.34 mg/kg. None of these concentrations of explosives were found at concentrations greater than the respective industrial soil PRGs, indicating that none of the individual explosive analytes poses a health threat under the assumptions of the PRGs.

While these results suggest that there are no significant concentrations of explosives residues in soils from past live-fire training, the soils were further analyzed to evaluate whether these results are reasonable based on what we know about the quantities of explosives used in live-fire exercises. The analysis was based on the data from studies performed by the USACE Cold Regions Experimentation Lab (CREL) (Jenkins, no date; Jenkins et al. 2000). Since it contains calculations and technical detail that may interest only a few readers, the analysis is presented in Appendix G-2 of this report and is summarized below.

The work performed by CREL demonstrates that small quantities of explosives residues remain unburned after proper detonation of high explosive ordnance items. These residues represent a minute fraction of the original explosive mass, but the unburned residues from many explosives detonations could accumulate over time. Larger quantities of residues result from explosives that do not detonate properly and must be blown in place by Explosive Ordnance Demolition personnel using an external explosive charge. The analysis presented in Appendix G-2 suggests that explosives concentrations would be undetectable in soils over most of the live-fire training area. The total mass of the residue of the most abundant explosives compound, RDX, resulting from a typical

CALFEX, is estimated to be in the range of about 0.2 gram. When dispersed in surface soils, the concentration would be negligible. It would require the total RDX residue from about 100 CALFEXs to contaminate one cubic yard of soil so that the concentration exceeded the EPA Region IX industrial soil PRG. The same result applies to the other common explosives compounds: TNT, DNT, and HMX. Therefore, the observed low concentrations in soil samples from the hydrogeologic investigation are consistent with expectations.

Metals

In addition to explosives residues, metals contained in various munitions may also be deposited on the ranges as a result of live-fire training activities and past disposal practices. Among the metals present in some explosives are lead and mercury. Lead is also used in the projectiles of small arms ammunition.

Appendix G-2 summarizes the analytical results of metals in surface soil samples, compared to Region IX industrial soil PRGs. The table includes the average concentration, the 95 percent UCL, and the carcinogenic and non-carcinogenic risk factors for each metal. The results in the table are further compared to concentrations in background soils from a study of soil on the Island of Hawai‘i (Halbig et al. 1985). Background metals concentrations in soils on the Island of Hawai‘i may differ from those in Mākua Valley, or elsewhere on O‘ahu, but they provide an indication of the normal range in soils derived from Hawaiian basalts.

Comparison of the metals concentrations to background concentrations in soils from the Island of Hawai‘i shows that the 95 percent UCL for most of the metals in samples from MMR are within the background range (Halbig et al. 1985). The exceptions are arsenic, lead, and selenium. Referring to Table 1 in Appendix G-2, it can be seen that of these three metals, only arsenic exceeds the industrial soil PRG based on a carcinogenic endpoint.

Referring to the frequency distribution graphs for these metals in Appendix G-2, it can be seen that although the arsenic concentrations tend to be skewed to the right side of the graph, with one sample containing a concentration of 19 mg/kg, there is no separate peak in the arsenic graph that would suggest that arsenic is present above background levels in the MMR soils. Arsenic is used in rodenticides and wood preservatives and is a common contaminant in developed areas of O‘ahu. Based on these observations, it appears that although some of the arsenic found in the soil samples may not be from mineral sources, the arsenic is widely distributed, perhaps as a result of past use of pesticide. If it derived from

military activities, there would likely be localized occurrences of higher than average concentrations in areas where military activities are focused, and this does not appear to be the case.

As shown in Table 1 in Appendix G-2, although the hazard index for the combined non-cancer risks for the individual metals is 1.7, which exceeds the threshold of 1.0 that is sometimes used as a basis for assessing non-cancer risks, the metals that contribute to this result include iron, aluminum, and manganese, all of which are present at typical background soil concentrations. This is further supported by the frequency distribution graphs for these metals in Appendix G-2, which indicate normal distributions. If the contributions of these metals are ignored, then the overall hazard index for the metals is well below 1.0, and no further action is required.

Dioxins

Dioxins were detected in a large number of surface soil samples at MMR and could be a potential group of chemicals of concern. As with the results from the groundwater samples, the reported concentrations of the various isomers of dioxins were converted to their respective equivalent toxicity values relative to the 2,3,7,8-TCDD isomer, for comparison to the EPA Region IX industrial soil PRG. For the 102 surface/near-surface soil samples reported in the USACE April 2003 report, the mean TCDD equivalent concentration was 0.00266 μg/kg with a 95 percent UCL of 0.00743 μg/kg. Using this potential exposure level, the carcinogenic occupational risk value is 4.64 times 10^{-7}, which is a considerably lower risk than the EPA's conservative 1 times 10^{-6} acceptable risk standard for occupational part-time exposure to these soils. Furthermore, similar concentrations of dioxins were detected in soil samples from background locations outside the boundaries of MMR. Dioxins are known to be widely distributed in the environment from atmospheric deposition from a variety of sources (for example, burning of plastics), and the detected concentrations do not indicate a significant on-site source of the dioxin.

Other Chemicals of Potential Concern

Other chemicals that were detected in the surface/near-surface soils included volatile organic compounds, such as benzene, semivolatile organic compounds, and pesticides. These chemicals were found in few samples, and at low concentrations that were less than the PRGs and do not significantly add to the combined non-carcinogenic or carcinogenic risk value; therefore, they are not considered to be health-based chemicals of concern from past or present activities at MMR.

Many organochlorine pesticides degrade very slowly in the environment and may persist for many years after they are no longer in use. The USGS has found high levels of organochlorine pesticides in sediment and fish tissue in urban and mixed land use sites on O‘ahu (Brasher and Anthony 1999). USGS scientists note that aldrin, chlordane, and heptachlor were heavily used as termiticides in urban areas of O‘ahu until they were banned in the 1980s, and DDT was widely used until 1972. All of these pesticides have been detected at low concentrations in samples from MMR. Dieldrin was also detected in some samples; although it was not widely used in Hawai‘i, dieldrin’s presence may be attributable to the fact that aldrin rapidly degrades to dieldrin in the environment.

Pōhakuloa Training Area

Explosives

The USACE conducted a surface soil investigation in 2002, collecting 46 samples at PTA. The sampling detected six explosives included 2,4,6-TNT; 2,4-DNT (a degradation product of TNT); RDX, HMX, nitroglycerin, and perchlorate. Four samples had detectable concentrations of TNT, ranging from 0.8 to 1.5 mg/kg. None exceeded the industrial soil PRG of 57 mg/kg. The detections were in three samples from the Range 9 Demo Area and in one sample from Range 5. Three samples contained 2,4-DNT, at concentrations ranging from 0.18 to 2.0 mg/kg. The industrial soil PRG for 2,4-DNT is 1,200 mg/kg. Perchlorate was detected in one sample, from firing point FP309 in the northwest corner of Training Area 8. The concentration was below the industrial soil PRG. Of these six explosives, five samples of RDX exceeded its industrial PRG of 15.6 mg/kg.

Metals

Metals occur naturally in soils, and Hawaiian soils are no exception. However, human activities may also contribute to the background levels of metals in soils. Even in natural conditions, metals concentrations are expected to vary. One reason for different concentrations of metals in soils from different areas of PTA is that different lavas may have different compositions and concentrations of metals. Soils at PTA are relatively thin, poorly developed, and have not had much time to be mixed or redeposited. Therefore, the metals concentrations in soils developed on different flows of different ages may vary. Frequency distribution plots can be used to help identify the normal ranges of metals in soils and to identify unusually high concentrations. The high concentrations may be from natural sources, too, but if the concentrations are very different from the “typical” range of concentrations, then it is more likely that the metals are from human sources.

Among the metals that were analyzed in the samples, the most abundant metals in basalt minerals are aluminum, barium, chromium, iron, nickel, and zinc. Other metals would generally be expected to be present at lower concentrations. Except for iron, none of these metals were detected at concentrations above the industrial soil PRGs. Chromium, nickel, and zinc were detected in one sample from Range 11 at much higher concentrations than in the other samples but still less than the industrial soil PRGs. Iron did not exceed the industrial PRG in any samples. Zinc showed a clustered distribution in the range of 100 to 200 mg/kg, with a few much higher detections. The highest detected concentrations were in samples from Range 5 and Range 11.

Looking at other, less abundant metals, most were detected at concentrations below their respective industrial soil PRGs. The highest concentrations were generally detected in a single sample from Range 11 (R11TANK-01), or in samples from Ranges 9 or 10. Exceptions to this were beryllium and selenium, higher concentrations of which seem to be randomly distributed. In fact, the highest concentrations of these seemed to be in the "background" samples from near the Range Control office.

The highest lead concentrations were detected in samples from Ranges 9, 10, and 11. Two samples (one from Range 10, and sample R11TANK-01) contained concentrations above the industrial soil PRG.

Based on these results, it appears that both elevated metals concentrations and detectable explosives concentrations were generally found in the impact areas of Ranges 5, 9, 10, and 11. Few of the concentrations exceeded industrial soil PRGs.

The combined noncancer occupational health risk associated with exposure to the observed metals concentrations from the soil investigation is 0.9, or just below the threshold of 1 for no further action. Excluding the calculated values for iron, aluminum, and manganese, i.e., known naturally occurring metals, the combined risk would be 0.29, which mainly results from lead. The combined carcinogenic risk from metals is 7.0×10^{-6}. This is above the one in one million cancer risk threshold, but within the range of 10^{-4} to 10^{-6}, which is considered acceptable under some circumstances.

Other Chemicals of Potential Concern

From samples collected at PTA, metals, explosives, and several semi-volatile organic compounds (phthalate esters and polynuclear aromatic hydrocarbons) were detected. The phthalate esters are plasticizers and are ubiquitous in the environment. They may have been present because of plastic parts in munitions. PAHs are also common in the environment at

low concentrations. They are a product of combustion of heavy organic compounds, including wood, oils, and tars. None of the semi-volatile organics exceeded industrial soil PRGs, although benzo (a) pyrene was detected in one sample from the Range 9 Demo Area at 0.190 mg/kg, which is close to the industrial soil PRG of 0.211 mg/kg.

3.8.6 Geologic Hazards
Mākua Military Reservation

Seismic Hazards

Seismic hazards can occur when people or structures are present in an area subject to fault rupture, strong ground motion, or ground failure that happens as a result of a seismic event. Most earthquakes in the Hawaiian Islands are the result of volcanic activity beneath the Island of Hawai‘i. Some are caused by intrusion of molten rock (magma) into fractures in the earth’s crust, which forces the surrounding rock to move out of the way. This movement occurs frequently and generally results in small earthquakes. Other earthquakes are thought to result from settlement or collapse of the rock surrounding magma chambers. This type of movement can produce large earthquakes, but it happens infrequently (USGS 1997).

The USGS has estimated that there is a low (about 10 to 12 percent) chance of an earthquake causing ground shaking, with a peak bedrock acceleration in excess of 10 percent of gravity in the next 50 years (USGS 1996). Bedrock transmits seismic wave energy relatively efficiently compared to soft, loose sediments, so ground shaking is usually least in areas underlain by bedrock. However, the intensity of ground shaking can be magnified by soft alluvial sediments, such as underlie Mākua Valley. Also, loose sandy sediments with a high water table are subject to liquefaction in a strong earthquake. These conditions may exist in the lower portion of the valley, closest to the Farrington Highway; no formal delineation of liquefaction-susceptible areas has been performed.

Slope Failure

Steep slopes at the margins of the Mākua Valley may be subject to slope failures, such as rock slides; however, most of the land area used for military training has moderate slopes. Figure 3.8-8 shows areas with slopes greater than 30 percent.

Pōhakuloa Training Area

Seismic Hazards

The Island of Hawai‘i is the locus of most of the earthquake activity that occurs in the Hawaiian Islands. A magnitude 7.2 earthquake in 1975 that originated beneath Kīlauea was the largest earthquake to originate in

Hawai‘i during the past century. Hazards associated with earthquakes include ground shaking, liquefaction, landslides, and tsunamis. The 1975 earthquake generated a tsunami that killed two people and damaged property along the coast (USGS 1997a).

The USGS has prepared maps showing the horizontal ground acceleration in firm rock, as a percentage of the acceleration of gravity, for a given probability of exceedance within a given number of years. Acceleration is the rate of change in speed or direction of an object, and it is what makes buildings come apart in a strong earthquake. A 10 percent probability of exceedance in the next 50 years means that there is a 10 percent chance that a larger event will occur in the next 50 years. PTA is in an area in which there is a 10 percent probability that an earthquake will cause a ground acceleration of more than 40 to 60 percent of gravity in the next 50 years, with the likely size of the earthquake increasing to the south, in the direction of Kīlauea and the south coast.

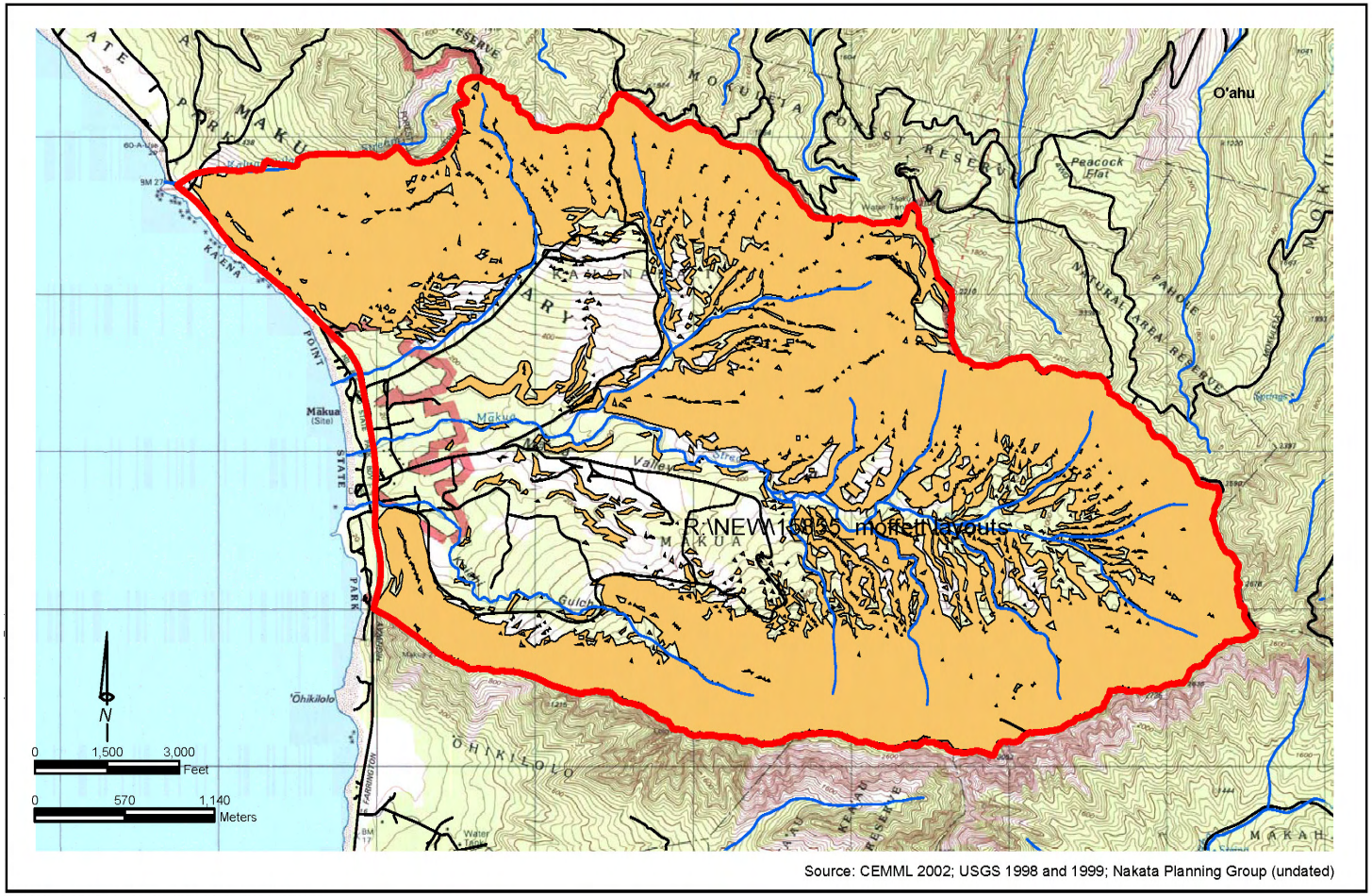
Slope Failure

In the PTA area of the Island of Hawai‘i, areas with slopes greater than 30 percent are primarily limited to the slopes of Mauna Kea, north of Saddle Road, and to the southern portion of PTA, on the north-facing slope of Mauna Loa (Figure 3.8-9).

Volcanic Eruption Hazards

The USGS has divided the Island of Hawai‘i into Lava Hazard Zones based on the probability of coverage by lava flows. Other hazards from volcanic eruptions are not classified in this system. Zone 1 has the highest risk and Zone 9 has the lowest. PTA overlies areas categorized as zones 2, 3, and 8 (County of Hawai‘i 2002a). Zone 2 includes areas in which 15 to 25 percent of the land area has been covered by flows since 1800; the eastern margin and northeastern corner of PTA are in Zone 2. Zone 3 has had 1 to 15 percent coverage by lava flows since 1800; most of PTA is in Zone 3. Zone 8 has had no lava coverage over the past 750 years, and only a few percent of the area was covered in the past 10,000 years. Zone 8 represents areas near or north of Saddle Road that are underlain by lava erupted from Mauna Kea. PTA Trail is located entirely within Zone 8.

Infrequently, Hawaiian volcanoes erupt explosively. In 1790, Kīlauea erupted explosively, creating a surge of hot gases and fine dust that killed a group of Hawaiian warriors and their families near the summit.



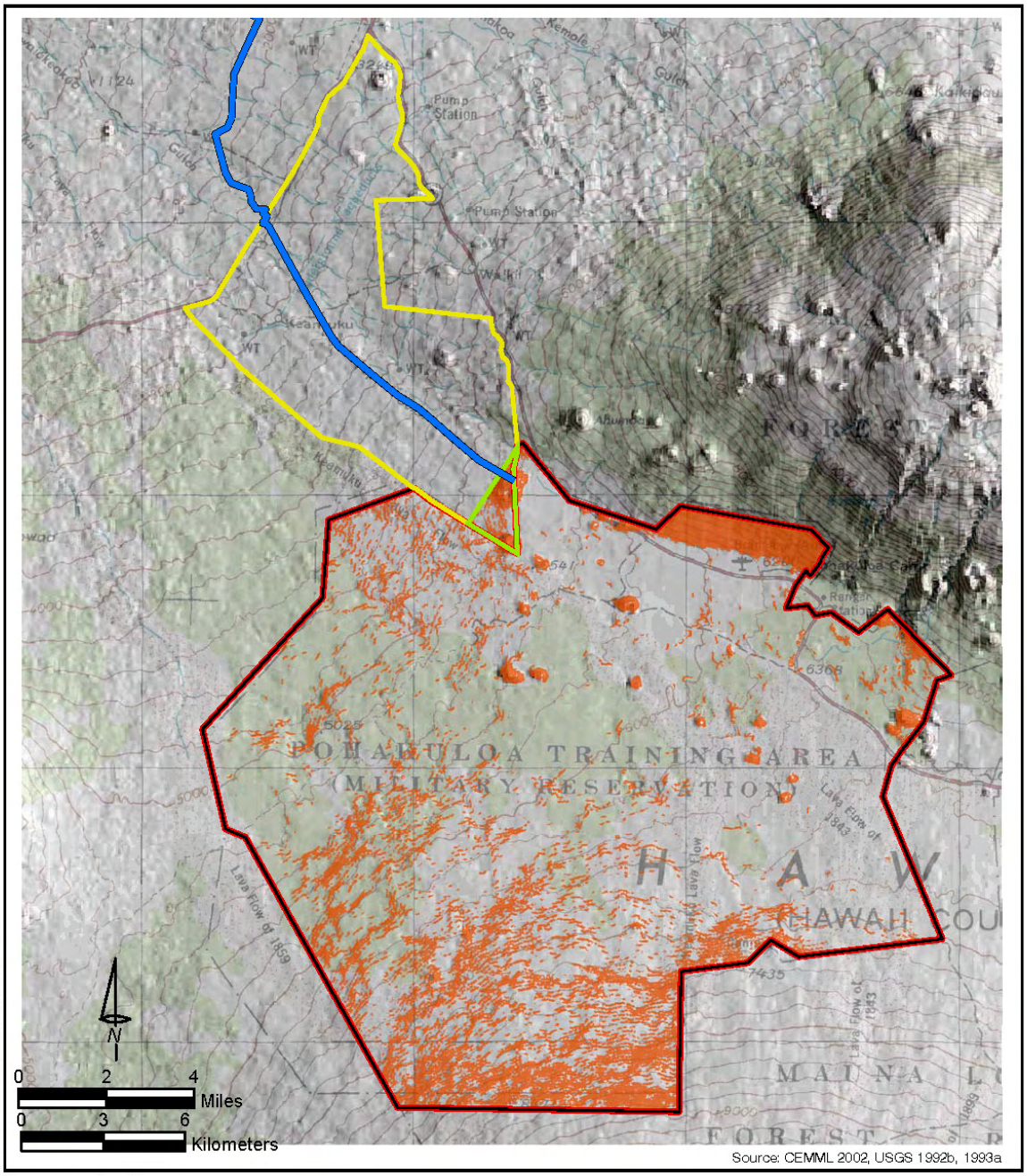
Steep slopes at the margin of Mākua Valley may be subject to slope failures such as rock slides.

Legend
- Mākua Military Reservation
- State Land Use District Boundary
- Rivers
- Roads
- Slopes Greater than 30 Degrees

Steep Slopes

Mākua Military Reservation
O'ahu, Hawai'i

Figure 3.8-8 Steep Slopes, MMR



Slopes greater than 30 percent are primarily limited to the slopes of Mauna Kea, north of Saddle Road, and to the southern portion of Pōhakuloa Training Area on the north-facing slope of Mauna Loa.

Legend

- Pōhakuloa Training Area Boundary
- P7 West Pōhakuloa Training Area Acquisition Area
- 1010 Land Acquisition Area
- Slopes Greater than 30 Percent
- P3/P4 Pōhakuloa to Kawaihae Trail

Steep Slopes at Pōhakuloa Training Area

Island of Hawai'i, Hawai'i

Figure 3.8-9 Steep Slopes, PTA

earthquake generated a tsunami that killed two people and damaged property along the coast (USGS 1997a).

The USGS has prepared maps showing the horizontal ground acceleration in firm rock, as a percentage of the acceleration of gravity, for a given probability of exceedance within a given number of years. Acceleration is the rate of change in speed or direction of an object, and it is what makes buildings come apart in a strong earthquake. A 10 percent probability of exceedance in the next 50 years means that there is a 10 percent chance that a larger event will occur in the next 50 years. PTA is in an area in which there is a 10 percent probability that an earthquake will cause a ground acceleration of more than 40 to 60 percent of gravity in the next 50 years, with the likely size of the earthquake increasing to the south, in the direction of Kīlauea and the south coast.

Slope Failure

In the PTA area of the Island of Hawai‘i, areas with slopes greater than 30 percent are primarily limited to the slopes of Mauna Kea, north of Saddle Road, and to the southern portion of PTA, on the north-facing slope of Mauna Loa (Figure 3.8-9).

Volcanic Eruption Hazards

The USGS has divided the Island of Hawai‘i into Lava Hazard Zones based on the probability of coverage by lava flows. Other hazards from volcanic eruptions are not classified in this system. Zone 1 has the highest risk and Zone 9 has the lowest. PTA overlies areas categorized as zones 2, 3, and 8 (County of Hawai‘i 2002a). Zone 2 includes areas in which 15 to 25 percent of the land area has been covered by flows since 1800; the eastern margin and northeastern corner of PTA are in Zone 2. Zone 3 has had 1 to 15 percent coverage by lava flows since 1800; most of PTA is in Zone 3. Zone 8 has had no lava coverage over the past 750 years, and only a few percent of the area was covered in the past 10,000 years. Zone 8 represents areas near or north of Saddle Road that are underlain by lava erupted from Mauna Kea. PTA Trail is located entirely within Zone 8.

Infrequently, Hawaiian volcanoes erupt explosively. In 1790, Kīlauea erupted explosively, creating a surge of hot gases and fine dust that killed a group of Hawaiian warriors and their families near the summit.