## 3.7 WATER RESOURCES

The range alternatives are located on two Hawaiian Islands, O‘ahu and Hawai‘i. Rainfall in the Hawaiian Islands is very unevenly distributed and is highly dependent on elevation as well as location. The maximum rainfall occurs at elevations between 2,000 to 3,000 feet (610 to 914 meters) above mean sea level (amsl). Above this elevation, rainfall decreases rapidly so that the high elevations are relatively dry (US Army and USACE 2004).

Water resources include both surface water and groundwater resources, with discussions including:

- Water quality;
- Water quantity (rainfall and runoff, flooding potential, and groundwater yield); and
- Water movement (currents and waves, stream flow, and groundwater movement).

Public comments received during the Mākua EIS scoping process regarding water resource issues include the following:

- Aquatic resource contamination (aquifers, streams, springs, wells, and groundwater);
- Native Hawaiian use of water resources;
- Water preservation for crops;
- Contaminated soil runoff;
- Erosion;
- Frequency of water sampling; and
- Water quality testing.

### 3.7.1 Introduction/Region of Influence

The ROI for surface water is not necessarily the same as the ROI for groundwater. Because groundwater often crosses topographic watershed boundaries, the ROI for surface water is expanded to include the aquifers underlying these watersheds and any aquifers downgradient (in the direction of groundwater flow) from the training and deployment areas. The ROIs for both surface water and groundwater include the downstream and downgradient near-shore areas along the coast where surface water and groundwater, respectively, discharge to the sea.

The MMR ROI for groundwater resources includes the following:

- Upper portion of the freshwater aquifer underlying the watershed and extending offshore; and
- Any additional groundwater resources that may be identified as downgradient of past or present military activities in the Mākua Valley.

#### Mākua Military Reservation

The MMR ROI for surface water resources is the Mākua watershed on the Island of O‘ahu.

#### Pōhakuloa Training Area

The PTA ROI for surface water resources is the Northwest Mauna Loa and the West Mauna Kea watersheds on the Island of Hawai‘i.

### 3.7.2 Hydrologic Setting
### Mākua Military Reservation

#### *Climate*

MMR is on the leeward side of O‘ahu, about 4 miles (1 kilometer) south of Ka‘ena Point. The prevailing northeasterly trade winds, which are present about 90 percent of the time during the summer and about 50 percent during the winter, lose most of their moisture as they blow across the Ko‘olau and Wai‘anae Range s, leaving the Wai‘anae Coast relatively dry. The average annual precipitation at MMR ranges from greater than 50 inches (127 centimeters) on the high ridges to about 15 inches (38 centimeters) near the coast (Nakata Planning Group LLC 2002b).

Monthly average rainfall on the leeward coast ranges from 3 to 4 inches (8 to 10 centimeters) between December and March and less than 1 inch (2 centimeters) from May to September (Stearns and Vaksvik 1935). On the ridges of the Wai‘anae Range, the average monthly winter rainfall approaches 10 inches (25 centimeters) in December and January and decreases to about 4 to 5 inches (11 to 13 centimeters) during the summer. Heavy rainfall on the leeward side of the island is mainly the result of rare Kona storms, which occur mainly during the winter (US Navy, undated). Kona storms tend to originate from low pressure systems that develop west of the Hawaiian Islands. They are characterized by southerly winds, high humidity, and prolonged rainfall, accompanied by thunderstorms.

The 100-year peak 1-hour rainfall at Mākua is estimated to be between 3 and 4 inches (8 and 10 centimeters). The 100-year peak 24-hour rainfall is estimated at between 12 and 14 inches (30 and 36 centimeters). The 24-hour probable maximum rainfall is approximately 50 inches (127 centimeters) (Wu 1967).

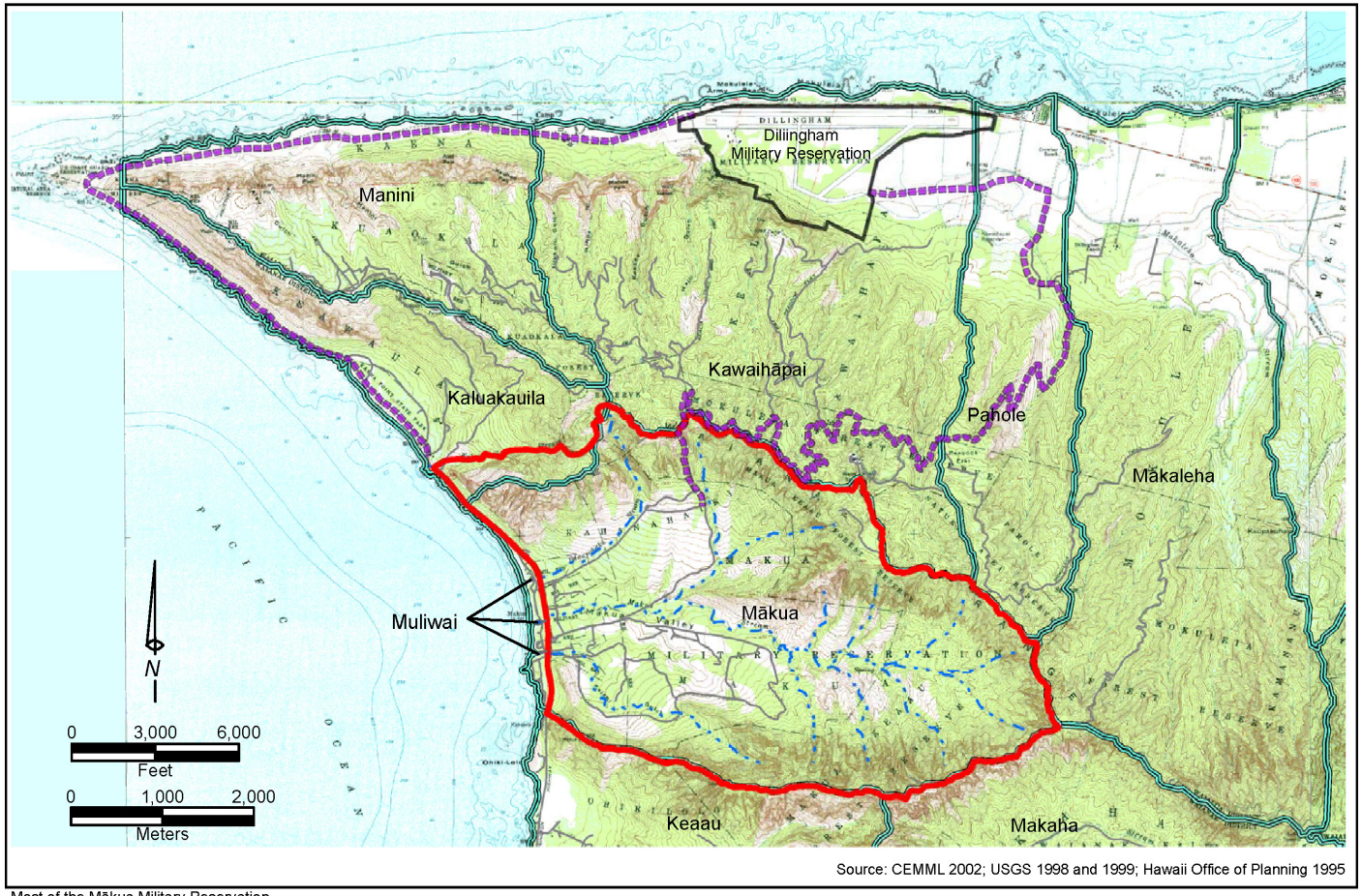
Data from three precipitation gauges installed by the Army in July 1999 at MMR, including one near Farrington Highway (the "portable" station), one at the upper end of the training area (the "range" station), and one on the north rim of the valley (the "ridge" station), indicate that rainfall follows a seasonal pattern, with the highest monthly precipitation occurring from October through April (USARHAW and 25th(L) 2004). However, the limited record shows great variability. Monthly totals from July 1999 to July 2004 ranged from trace to more than 16 inches (41 centimeters) at the lower elevation and from less than 0.5 inch to about 17 inches (1.3 to 43 centimeters) on the ridge. The highest monthly rainfall at the mid-elevation range station during this period was about 9 inches (23 centimeters). Although the total annual rainfall is higher on the ridge than at lower elevations in the valley, the rainfall record indicates that the most intense storms occur at the lower elevations. hourly rainfall exceeded 1 inch (2 centimeters) on seven days at the portable station, on five days at the range station, and on two days at the ridge station. The highest recorded hourly rainfall during the period was nearly 2.2 inches (5.6 centimeters), recorded at the range station.

Based on the approximately 30-year rainfall record from the US Air Force Satellite Tracking Station at Ka'ena Point, just north of MMR, rainfall during the past several years has been unusually low.

### *Surface Water Drainage*

MMR is in the Mākua watershed (HDOH 1998b), which includes the Mākua Valley and a smaller adjacent Kahanahāiki valley (refer to Figure 3.7-1). The following streams drain the valleys:

- Mākua Stream, an intermittent stream, is the principal drainage and discharges to the west along the north side of Mākua Valley;
- Ko'iahi Gulch (also known as Kaiahi Gulch) drains the south side of Mākua Valley;
- Punapōhaku Stream drains Kahanahāiki Valley; and
- Kaluakauila Stream, along the northern boundary of MMR, drains the north side of the north ridge of Kahanahāiki Valley.




Most of the Mākua Military Reservation lies within the Mākua watershed

**Legend**
- Mākua Military Reservation
- Watershed Boundaries
- Intermittent Streams
- Trails

***Watershed Boundaries and Drainage Features***

Mākua Military Reservation
O'ahu, Hawai'i

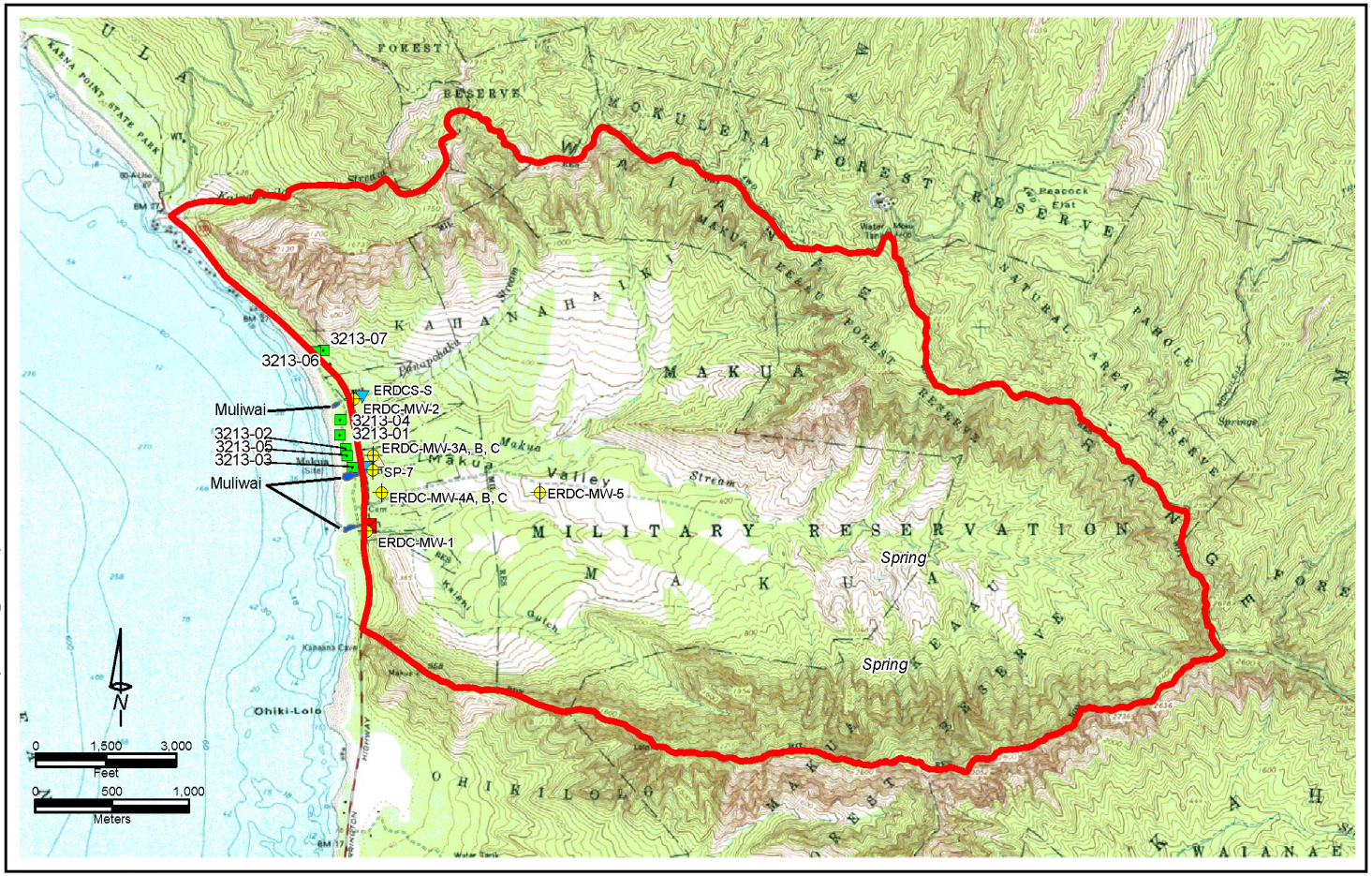
**Figure 3.7-1 Watershed Boundaries and Drainage Features, MMR**

The stream channels cross under Farrington Highway through concrete box culverts and terminate behind the long ridge of dune sand above the shoreline of Mākua Beach. Following a storm, the low areas behind the dunes fill with water to form temporary ponds (*muliwai,* the Hawaiian word for brackish water pools near the mouths of streams created by seasonal barriers of sand or sediment).

The presence of high-level dike-impounded groundwater in the upper portion of the watershed of the Mākua Valley is indicated by several springs in Mākua Valley. Springs occur at points where the groundwater discharges at the ground surface. Two springs are shown on Figure 3.7-2. One is at an elevation of about 800 feet (244 meters), near the course of Mākua Stream, and another is at an elevation of about 1,200 feet (366 meters) on the south side of the valley. Other springs reportedly appear intermittently, depending on rainfall.

Consistent with the low amount of measured rainfall that has prevailed during recent years, personnel at MMR have reported observing no flows in Mākua Valley streams for a number of years, until the storm of February 13 through 14, 2003. However, between February 2003 and March 4, 2004, five stream flow events were observed. As indicated in the Hydrogeologic Investigation Report (Appendix G-1), stream flows were reported in February and April of 2003 and in January, February, and March of 2004. A review of the rainfall record for this period shows that most of these events seem to have been associated with daily rainfall amounts greater than 3 inches (8 centimeters) at the ridge weather station. The first stream flow event, on February 13 through 14, 2003, was the result of higher than usual precipitation at the ridge station but not particularly unusual rainfall amounts at the lower elevations. The stream flows in early 2004, however, followed higher than normal rainfall at the lower elevations, accompanied by moderate rainfall on the ridge. In addition, total rainfall at all elevations was higher in the winter and spring of 2004 than in the preceding four years.

The Wai‘anae Sustainable Communities Plan (City and County of Honolulu 2000b) recommends that a stream conservation corridor be established for Mākua Stream. The plan states that these corridors should be used for natural resources conservation uses and programs, compatible recreational uses, such as walking and gathering native plants and stream animals, and controlled diversion of stream waters for agriculture. Due to existing safety and access restrictions, these plan recommendations are not being applied to MMR at this time. The results of the hydrogeologic investigation indicate that the impacts of past military training on water and sediment conditions in Mākua Stream have been negligible.




Water samples gathered for the hydrogeologic investigation will be used to evaluate the effects of military training

**Legend**

- Automated Stream Sampling/Gauging Station
- Former USGS Stream Gauge
- Water Well
- Monitoring Well
- Stream Gauging Station
- Mākua Military Reservation

***Water Sampling Locations***

Mākua Military Reservation
O'ahu, Hawai'i

**Figure 3.7-2 Water Sampling Locations, MMR**

### Wetlands

Wetlands are "areas that are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (33 CFR 328.3[b]; 40 CFR 230.3[t]). Wetlands may be further classified by association with a particular hydrologic environment, such as coastal areas, streams or lakes, or swamps and bogs.

Several types of wetlands probably occur within the ROI of MMR, including estuarine wetlands (*muliwai* located adjacent to the ocean); palustrine wetlands, which are characterized by native trees, shrubs, or persistent emergent plants associated with seep areas; and riverine wetlands, adjacent to streams. No wetlands have been confirmed or delineated on MMR. Possible riverine wetlands and possible palustrine wetlands associated with Mākua Stream drainage are protected through restrictions on training (USARHAW and 25th ID[L] 2001b). The *muliwai* are on land west of Farrington Highway, which is managed by the State of Hawai'i DLNR.

### Muliwai

*Muliwai* are brackish water pools near the mouths of streams created by seasonal barriers of sand or sediment (Wilcox et al. 1998). They are generally considered to be estuarine wetlands. *Muliwai* form at the mouths of each of the three streams that discharge from Mākua Valley, although the sizes and shapes of the *muliwai* may vary over time, and not all appear to contain water throughout the year. *Muliwai* have cultural and historical significance in the State of Hawai'i. In some areas, *muliwai* have been improved and maintained for aquiculture.

During a typical large storm runoff, the streams that drain the Mākua Valley discharge to the *muliwai* and the water level rises. Eventually the water spills over the sand dune, eroding a channel to the sea, and this quickly drains the ponds. As the flow in the streams decreases, normal wave action on the shore reestablishes the sand dune, again isolating the *muliwai* from the sea. If stream flows are not large enough to overtop the sand dune, the ponded water seeps through the dune sand to the sea. While this seepage is not perceptible, the fact that a small quantity of water has remained during recent years in the southernmost *muliwai,* located at the mouth of Kaiahi Gulch, despite no significant stream flow, suggests that the *muliwai* may be fed by groundwater seepage.

***Muliwai* Investigations** A screening level study of the bottom sediment quality in the *muliwai* was performed by the EPA in 1999 to determine if

there were downstream indications of contaminants from the OB/OD area and if additional site investigation was warranted (Baylor 1999). Twenty sediment samples were collected from 18 locations in the three *muliwai* downgradient of MMR and in three "reference" *muliwai* (Waikomo, Mākaha, and Nānākuli) located south of MMR. Two additional sediment samples were collected from Kaluakauila Stream, which was identified as an off-site background location. The EPA concluded that it did "not appear that the metals in the *muliwai* presented a significant risk to ecoreceptors, or that additional investigation was warranted at that time" (Baylor 1999).

In May 2003, the Army conducted an additional investigation of *muliwai* sediment quality. Sediment samples were collected from the three *muliwai* downstream of MMR, and from two "reference" locations (adjacent upcoast and downcoast streams ) that had been sampled previously in the EPA study. A total of 54 sediment samples were collected, and most were analyzed for a large range of compounds, similar to the range of compounds included in the current hydrogeologic investigation (USACE 2003). The results of the investigation are presented in Appendix G-3.

The study area was determined, in part, by plotting the area of standing water shown in a recent aerial photo of the *muliwai.* A storm on February 14, 2003, resulted in enough runoff that all three of the streams draining Mākua Valley broke through the sand dunes of the respective *muliwai* and drained directly to the ocean. As a result of this event, it is likely that some of the sediment deposited on the bottom or sides of the *muliwai* was eroded and carried to the ocean by the runoff from the February 14 storm event. Sediment samples were collected from depths accessible by manual excavation, as described in Appendix G-3. The results show that, of the explosives analyzed, only RDX was detected, in one of the 54 samples, from the *muliwai* of Punapōhaku Stream, at a concentration of 230 parts per billion.

### *Marine Resources Study*

The Army conducted a marine resources study to determine whether marine resources near Mākua Beach and in the Mākua *muliwai* are contaminated with constituents primarily associated with proposed training activities at MMR. This study also evaluated the potential that activities at MMR contribute to any contamination detected in the marine resources, and evaluated whether the proposed training activities at MMR pose a human health risk to area residents that rely on marine resources for subsistence. The study did not find evidence that there would be any significantly increased health effects associated with lifetime consumption of fish or *limu* from the nearshore areas adjacent to Mākua Beach or from the Mākua *muliwai* (USARHAW and 25thID(L) 2007c). The study also

determined that shellfish are not likely contaminated by chemicals from MMR.

The Army collected samples of edible marine fish from three *muliwai* and two nearshore open water sites to determine if they contain chemical contaminants that may be associated with activities at MMR, and to evaluate the potential health risks associated with human consumption of these organisms. Specimens of target species of fish were collected with nets and by hook and line fishing. *Limu* were collected by hand and only from the nearshore waters at Mākua Beach. An attempt was made to collect shellfish (e.g., crabs, limpets, and sea urchins), but insufficient numbers of individuals were collected to meet the minimum sample mass requirements needed to perform the chemical analyses required in the study.

Whole specimens were preserved by freezing and the samples were analyzed by three laboratories to determine concentrations of dioxins/furans, organochlorine pesticides, volatile organic compounds, semi-volatile organic compounds, and metals. A human health risk assessment was performed to evaluate the threat to human health presented by the chemicals identified in the tissues of the organisms, assuming a range of consumption rates considered to approximate the rates of subsistence and recreational fishermen and their families over a lifetime. The risk assessment compared the risks from consumption of fish collected from *muliwai* and nearshore locations adjacent to MMR to risks from consumption of fish collected from "background" locations away from MMR. No background samples of *limu* were collected; field conditions during the study prevented collection of samples from background locations.

The study identified a small increase in cancer risk to people who consume fish collected from *muliwai* or nearshore locations adjacent to MMR compared to background locations. The increased risk associated with consumption of fish collected by subsistence fisherman in the *muliwai* was estimated at seven additional occurrences of cancer per one million people. This is the sum of the risks contributed by all of the individual chemicals detected, most of which contributed very little, because the concentrations were very low compared to the level of cancer threat they present. Most of the cancer risk results from the concentrations of two pesticide compounds (beta and gamma benzene hexachloride (BHC)), and one compound that is a constituent of plastics (bis[2-ethylhexyl] phthalate). These compounds were not detected in fish collected in the background *muliwai*; however, the compounds may not be associated with military training activities at MMR.

The background risk associated with consumption by subsistence fishermen of fish collected in the nearshore waters was estimated at six occurrences of cancer per 100,000 people. Fish caught in the nearshore waters off Mākua Beach contained chemicals concentrations estimated to increase the risk by three occurrences of cancer per 100,000 people. This excess risk was primarily the result of concentrations of the plasticizer bis(2-ethylhexyl)phthalate and the pesticide alpha-BHC, which contributed the equivalent of about two occurrences of cancer per 100,000 people to the total cancer risk in excess of "background." Two additional compounds potentially associated with military activities at MMR (nitroglycerin and RDX) were detected in the Mākua Bay (nearshore waters off Mākua Beach) specimens but not in the background specimens. Concentrations of these two compounds, were detected in two fish specimens, and contributed the equivalent of about one occurrence of cancer per 200,000 people above the background cancer risk associated with eating fish from other waters. It is worth noting that the concentrations of nitroglycerine and RDX are considered uncertain because the levels were extremely low, at or near the laboratory detection limits.

Non-carcinogenic risks were found to be lower for consumption of fish from the *muliwai* adjacent to MMR, or from Mākua Bay, than in the background locations. The study concluded that non-carcinogenic risk levels in the two groups of samples were not significantly different. Concentrations of metals were higher in the background specimens than in the specimens collected near MMR. The single largest contributor to the non-carcinogenic risk was manganese, a metal that is common in natural sediments and especially in Hawaiian volcanic rocks. The non-carcinogenic risks from manganese in background fish were about three times greater than in fish near MMR. The most significant contributors to the total non-cancer risk are naturally occurring metals (copper, aluminum, selenium, vanadium, and zinc, for example). The remaining chemicals associated with human activities tend to contribute very little to the non-cancer risk, with the exception of mercury. Mercury is widely distributed in fish and originates from a variety of sources. Military activities at MMR are not likely to be a significant source of mercury in the environment.

The carcinogenic (and the non-carcinogenic) risks from consumption of *limu* were found to be elevated in the local specimens as a result of the presence of arsenic. The risk assessment indicates that if the arsenic detected in *limu* is in the inorganic form, then consumption by subsistence fisherman of 18.2 grams per day (slightly more than one ounce per day) of *limu* from the *muliwai* near MMR would result in one occurrence of cancer per 100 people.

However, arsenic is well-known to concentrate in *limu* tissues as a result of normal processes unrelated to contamination. Studies of edible seaweed indicate that the arsenic concentrations found in the *limu* from the nearshore adjacent to Mākua Beach are within the range typical of seaweed found elsewhere (FSA 2004). Furthermore, although one species of edible seaweed ("hijiki" found near Japan) has been identified as containing an inorganic form of arsenic that may be toxic to humans, the arsenic present in most edible seaweed species is an organic form that is not toxic to humans (COT 2004).

The marine resources study did not compare the local samples of *limu* against samples from background locations; field conditions during the study prevented collection of samples from background locations. Therefore, it is not certain whether the observed arsenic concentrations are normal for the type of *limu* collected in the study. As noted above, the observed concentrations were within the normal range for edible species of seaweed, generally.

It should be noted that *limu* species do not have roots as terrestrial plants do. *Limu* absorb nutrients and metals from the ambient water column, not from sediment. Arsenic is a natural constituent of seawater. The concentration and toxicity of arsenic in *limu* tissues is not related to the source of the arsenic or to its concentration in seawater, but to the way that a given species of *limu* processes the arsenic that it extracts from seawater. Due to normal water movement and mixing, it is highly unlikely that arsenic concentrations in the water column of Mākua Beach differ from arsenic concentrations elsewhere in Hawai'i. Instead, *limu* remove the tiny amounts of arsenic that are naturally present in the ambient water column and concentrate it in their tissues (Eisler 1988). Review of readily available literature on the subject suggests that most species of seaweed that contain seemingly elevated concentrations of arsenic do not present a health hazard because the arsenic is in an organic form that is not toxic to humans and passes through the digestive system without being absorbed in the blood stream.

### Stream Flow and Flooding

The Flood Insurance Rate Map (FIRM) for the site identifies most of the area east of Farrington Highway as Flood Zone D, which includes areas in which flood hazards are undetermined but possible (FEMA 2004). Modeling described in the Hydrogeologic Investigation Report (Appendix G-1) suggests that the low-lying areas on the west side of the installation would be susceptible to flooding in a large storm. Some of these areas may also be subject to flooding from tsunamis. These are large sea waves generated by infrequent and unpredictable events such as earthquakes or

submarine landslides, which may occur at great distances from the Hawaiian Islands. Tsunamis vary in height, just as earthquakes vary in magnitude, and the area inundated by a tsunami depends on the height of the wave and the nature of the shoreline. Tsunami evacuation maps have been developed to help people identify and avoid the areas that could be inundated in a large tsunami. The US Pacific Disaster Center's (PDC) Civil Defense Tsunami Evacuation Map indicates that the coastal area of Mākua Valley should be evacuated to a distance inland of at least 200 feet (61 meters) from Farrington Highway and to a distance of 800 feet (244 meters) inland in the lowest areas on both sides of Mākua Stream (PDC 2001). This evacuation area corresponds approximately with the lands within an elevation of about 40 feet (12 meters) above mean sea level (msl).

The Farrington Highway is constructed on an embankment or causeway that restricts the natural drainage from Mākua Valley. The highway is about 20 feet (6 meters) above msl and about 10 feet (3 meters) above the channels of the three streams draining Mākua Valley. The box culverts under Farrington Highway are able to accommodate large runoff events, but it is not known what size floods they can carry.

The largest measured flow event on Mākua Stream occurred in 1976, when the peak flow was estimated to be 3,220 cubic feet per second (cfs) (91 cubic meters per second). The US Geological Survey (USGS) has estimated this to be a 50-year flood event, meaning that based on the available streamflow record, a flow of this magnitude is expected to occur on average about once every 50 years. The USGS estimates the 100-year peak discharge on Mākua Stream to be 5,500 cfs (156 cubic meters per second) (Wong 1994). Extrapolation of the historical record of discharge and elevation reported for the gauge in use prior to 1976 suggests that, in a 100-year flood, the height of water in Mākua Stream would be more than 0.5 foot (about 15 centimeters) higher than the elevation recorded during the 50-year flow event, which was reported to be approximately 13 feet (4 meters) above msl at that gauge. This is likely an underestimate of the flood elevation because it does not take into account the actual geometry of the channel or any limitations on the capacity of the channel or culverts, which could impede drainage during unusually high flows.

During the next largest recorded flow event, which occurred on November 14, 1996, the elevation of water at the USGS gauge on Mākua Stream was 16.74 feet (5.1 meters) msl. For comparison, this is approximately the ground elevation at monitoring well SP-7. Because the gauge has been moved several times in the past, the elevations cannot be directly compared; the equivalent elevation relative to the gauge that existed in

1976 is estimated to be about 11.6 feet (3 meters) amsl. The estimated recurrence period of the 1996 event is about seven years.

No information is available about flood damage that may have occurred during the 1976 event. In the 1996 event, water from Ko‘iahi Gulch (also known as Kaiahi Gulch), the stream farthest south, located near the entrance gate, reportedly flooded the parking lot near the entrance gate. However, the culverts beneath the roadway reportedly accommodated the flow easily, and this flooding was apparently not the result of debris clogging the culverts. These anecdotal data suggest that minor flooding may occur relatively frequently at MMR over the long term, even though stream flows have been relatively small in recent years. Alternately, there may be some physical explanation, other than lack of rainfall, for the apparently low flows observed in recent years. One such factor may be the reported increase in the density of vegetation covering the slopes of the valley. An increase in vegetation could have the effect of slowing runoff and allowing more of the incidental rainfall to infiltrate instead of discharging directly to streams.

The February 14, 2003, storm and the subsequent storms that resulted in measurable stream flows are thought to have been associated with “Kona” storms—a relatively infrequent type of weather pattern typically generated in the Pacific Ocean west of the Hawaiian Islands and associated with higher than normal rainfalls (US Navy undated). Because Kona storms tend to move moisture on land from the west, the mountain ranges do not block the rainfall. The observation of higher rainfall at lower elevations in the valley, which occurred in several of the storms in 2004, is consistent with a westerly or southwesterly storm pattern.

The largest stream flow measured in Mākua Stream during the hydrogeologic investigation was approximately 400 cfs (about 11.5 cubic meters per second), on February 27, 2004. The flow measurement was made shortly after 11:00 AM, or about one to two hours after the peak rainfall, based on data from the three rain gauges at MMR. The peak rainfall during this storm occurred between 9:00 and 10:00 AM. The rainfall record indicates that the intensity of the storm decreased with elevation. At the portable station, near Farrington Highway, more than 1.5 inches (3.8 centimeters) were recorded during this interval. At the range station, higher up the valley, about 0.9 inches (2.3 centimeters) were recorded, while at the ridge station, only about 0.45 inches (1.1 centimeters) were recorded (US Army 2004).

### *Surface Water Quality*

There are few historic data on surface water quality at MMR. In part, this may be due to the intermittent nature of stream flow at MMR, which makes collecting a representative sample of stream water difficult. Char (1977) collected water samples from the three *muliwai* on the Mākua Valley streams and from reference locations north and south of Mākua Valley. The samples were analyzed for selected metals and for nitrogen. None of the results exceeded regulatory standards at the time.

Surface water was sampled as part of the current hydrogeologic investigation of MMR during a storm on February 14, 2003 (see Appendix G-1). Samples were collected from the lower reaches of Ko‘iahi Gulch (also known as Kaiahi Gulch), Mākua Stream, Punapōhaku Stream, and from Kaluakauila Stream near the points where the streams exit the installation boundary. Because no substantial runoff-producing storms are thought to have occurred during the past three to five years, the runoff from the February 14 storm could have contained contaminants that were deposited on the soil surface throughout the entire period since the last major storm.

A total of 61 samples were collected. Forty samples were collected with an automated sample collection device installed in Mākua Stream, and twenty-one samples were collected manually from the four streams. The samples were analyzed for a variety of analytes, although not all samples were analyzed for the same suite of analytes. Sixty samples were analyzed for total suspended solids, and 57 were analyzed for metals and explosives. Selected samples were analyzed for the full suite of analytical parameters. One set of samples from each stream was analyzed for dioxins and furans. The samples analyzed for the full suite of parameters were selected mainly from among the samples collected early in the runoff event, the reasoning being that the initial stream flow would have the greatest likelihood of containing contaminants.

State of Hawai‘i water quality standards for inland waters are contained in the Hawai‘i Administrative Rules, Title 11, Chapter 54 (HAR 11-54-04). These include a list of numerical standards for specific toxic pollutants and “narrative” standards. Where applicable, the results of the surface water sampling in the hydrogeologic investigation have been compared against the numerical standards for acute toxicity in freshwater listed in the Hawai‘i Administrative Rules. Except for some metals, none of the samples had concentrations that exceeded the acute toxicity standards. The acute toxicity standards for aluminum, copper, nickel, and zinc were exceeded in some of the samples, and some samples contained combined (hexavalent and trivalent) chromium concentrations above the numerical

acute toxicity standard for hexavalent chromium. Trivalent chromium is the dominant form in most natural waters with neutral pH. The toxicity of trivalent chromium is far lower than that of hexavalent chromium. HAR 11-54 standards for chronic toxicity, which refers to an average concentration not to be exceeded in any 24-hour period, were exceeded for selenium and heptachlor in some of the samples.

Note that many of the reported metals concentrations were "total" metals, from unfiltered samples; the acute and chronic toxicity standards apply only to dissolved metals. Also, both acute and chronic toxicity are measures that are usually applied to waters below point effluent discharges in order to regulate those discharges. Exceedances of acute toxicity standards for metals in the discharges from intermittent streams are not unexpected under natural conditions in the absence of human sources of contaminants, as a result of oxidation of naturally occurring minerals. This is especially true of those minerals that are abundant in the soils of the area, such as aluminum, chromium, and nickel. The application of chronic toxicity standards to intermittent stream discharges is especially problematic. These standards are directed toward protecting human and environmental receptors from long-term exposures to low concentrations that may be significant over long periods of time. The opportunities for such exposures do not occur at MMR.

The regulatory standard for combined forms of dissolved inorganic nitrogen (nitrate + nitrite + nitrogen) was exceeded in some samples analyzed for nitrate only (nitrate is expected to be the dominant nitrogen species in waters exposed to atmospheric oxygen at neutral pH). The allowable standard for short duration during wet season flows is 0.30 mg/L, and several samples contained concentrations above 1.0 mg/L. Nitrate may be derived from plant and soil materials, and to a lesser extent from degradation of explosives. Since intermittent stream flows are expected to transport large loads of sediment and weathered organic material that has accumulated on the land surface during periods between significant rainfall events, it is not surprising to observe slightly elevated nitrate levels in natural intermittent stream flows for short periods of time.

Flows in the intermittent streams of Mākua Valley fit the state definition of Class 2 Inland Freshwaters. The objective for Class 2 waters is to "protect their use for recreational purposes, the support and propagation of aquatic life, agricultural and industrial water supplies, shipping, and navigation." The objectives provide guidance where numerical standards have not been defined. With regard to the intermittent streams at Mākua Valley, protection for support and propagation of aquatic life is assumed to imply protection of either marine aquatic life or aquatic life in the *muliwai*.

Stream water is not used for drinking, and drinking water standards, such as the EPA maximum contaminant limits (MCLs), are not considered applicable to the stream water in Mākua Valley. Nevertheless, water sample results have been compared to MCLs and EPA Region IX Preliminary Remediation Goals (PRGs) for tap water because they represent conservative health-based standards that would be protective of human health if the water were used for drinking. In general, the tap water PRGs are set at a more conservatively low level than MCLs. Also, PRGs have been established for more compounds than have MCLs.

In the sample collected from Ko‘iahi, or Kaiahi, Gulch at the beginning of the flow event in February 2003, four chlorinated pesticides were detected at concentrations above the EPA Region IX tap water PRGs. In four samples from Mākua Stream, benzene, thallium, and iron were detected at concentrations above the tap water PRGs. In one sample from Punapōhaku Stream, two pesticides and thallium were detected at concentrations above the PRGs. Other chemicals were also detected, but the concentrations were generally below the PRGs.

In some samples, compounds were detected for which PRGs have not been established, including various isomers of dioxins and furans (isomers are molecules with the same chemical formula but different chemical structures). A tap water PRG has been established for the most toxic isomer of dioxin (2,3,7,8-TCDD), and the concentrations of other dioxin isomers can be expressed as equivalent concentrations to that isomer.

The equivalent concentrations of dioxins and furans detected in the stream water sample from Kaiahi Gulch exceeded the EPA Region IX tap water PRG for the 2,3,7,8-TCDD isomer, when the 1989 EPA toxicity equivalency factors were used to calculate the equivalent toxicity of the OCDD and OCDF dioxin and furan isomers, respectively. If the toxicity equivalency factors published in 1997 by the United Nations are used instead, the equivalent concentrations are lower than the tap water PRG. The tap water PRG is 0.5 picograms per liter, which is one millionth of one millionth of a gram per liter. The equivalent concentration in the sample from Ko‘iahi, or Kaiahi, Gulch was about two times the standard. However, the concentration was within the human health risk range considered acceptable by EPA. Since dioxins and furans are present in background soils, and because the stream water samples contained suspended sediment that was analyzed along with the water, it is likely that the dioxins and furans in the stream water samples reflect sediment-borne concentrations of these chemicals.

As with dioxins, the chlorinated pesticides detected in the stream water samples are highly insoluble in water. These pesticides were likely bound to soil particles that were carried into the stream channel by surface runoff. The combined cancer risks represented by the pesticide concentrations detected in the sample from Ko'iahi, or Kaiahi, Gulch (assuming, as above, that the unfiltered stream water could be a source of drinking water), is $1.6 \times 10^{-05}$. This value is about 16 times the one per one million cancer risk threshold, but within the excess cancer risk range of $10^{-06}$ to $10^{-04}$ that is considered acceptable by EPA.

Of the metals, only iron and thallium, both noncarcinogens (chemicals that do not cause cancer), were detected above their respective tap water PRGs. As discussed further in Section 3.8, Geology and Soils, some metals, such as iron, are naturally present in Hawaiian soils at high concentrations. Thus, the presence of iron above the tap water PRG probably resulted from the iron contained in soil particles entrained in the unfiltered samples. Thallium exceeded the PRG in only two samples.

Of the compounds that were detected in the surface water samples at concentrations below their respective tap water PRGs, the most frequently detected were gasoline components, including benzene, toluene, ethylbenzene, and isomers of xylenes (the so-called BTEX compounds). Several other volatile organic compounds were also detected that may be associated with petroleum fuels. The low concentrations of gasoline or fuel constituents are not surprising because gasoline-powered grass-cutting equipment is routinely used at MMR.

Of 57 samples collected during the February 2003 event, only 3 had detectable concentrations of explosive compounds: perchlorate (detected in two samples) and 2,4-DNT (detected in one sample). Perchlorate was detected in two duplicate samples from Kaiahi Gulch at concentrations of up to 2.6 µg/L. This is less than the tap water PRG of 3.6 µg/L. Perchlorate is used as a propellant in some munitions and may be present in small quantities in the high explosive mixtures of munitions. It is highly soluble in water. 2,4-DNT (2,4-dinitrotoluene) is a high explosive similar to TNT (2,4,6-trinitrotoluene) and can either be present in munitions or can result from the chemical breakdown of TNT. Since TNT is more common in munitions than DNT and because so few explosives were detected, the more likely explanation for the presence of DNT is that it results from TNT degradation. The DNT was detected at concentrations of up to 3.1 µg/L in two samples from Mākua Stream. This is below the tap water PRG of 73 µg/L for 2,4-DNT.

The results from the samples collected in the later events in January and February 2004 showed similar results. RDX was detected in four samples from Mākua Stream, at concentrations of up to 1.7 µg/L, but was not detected in samples from the other streams. The drinking water PRG for RDX is 0.61 µg/L, and the detected concentration of RDX was below the PRG in two of the samples. No dioxins were detected in Ko‘iahi, or Kaiahi, Gulch samples from the 2004 events. Most of the dioxin detections in the 2004 flow events were in samples from Kaluakauila Stream.

As expected, total metals concentrations generally increased with sediment concentration. This is likely because the metals are a constituent of the minerals in the sediment. Lead and arsenic do not appear to follow this trend so closely, but neither compound was detected frequently. For example, lead was detected in only nine samples from three streams during the 2004 flow events, while arsenic was detected in only seven samples, all from Mākua Stream.

The Hydrogeologic Investigation Report also includes a comparison of the data to EPA Region V Ecological Data Quality Levels for Surface Water, and to State of Hawai‘i Tier I action levels for rainfall less than 200 centimeters per year (the Hydrogeologic Investigation Report is included as Appendix G-1 of this EIS).

### *Coastal Water Quality*

Coastal water quality and live coral may be affected by sediment discharged from streams and by nutrients or toxic chemicals carried in stream runoff. The HDOH maintained monitoring station 184 near the beach at the north end of Mākua Valley between July 1970 and October 1975, during which time it collected samples to measure physical, chemical, and microbiological parameters. Although this station was well north of Mākua Stream, Char (1977) noted that, based on one study of ocean currents in the area, the discharge from streams draining Mākua Valley would mix rapidly with the receiving ocean waters and that water quality should be similar everywhere along the beach.

Currently, all marine waters in Hawai‘i are classified as either Class A or Class AA, based on protection of water quality (HAR Chapter 54 11-54). Class A waters are considered to require less protection, and lower water quality standards apply to them.

Studies of coral reefs in many areas of the Hawaiian Islands have been undertaken or are ongoing, but there are no current studies of the corals adjacent to Mākua Valley (CRAMP 2003; Dollar 1999). Evidence of

damage to corals offshore of Mākua Valley was from sedimentation following the flood in February 1976 (Chave, no date). Sediment can affect live coral in a number of ways, including covering the organisms, blocking light, and causing abrasion. The coral reportedly was showing evidence of recovery from the effects of sedimentation by September 1976 (Char 1977). At the time, erosion of roads in the OB/OD area was thought to be a major source of the high sediment loading observed during this storm, and the MMR roads were subsequently hardened with crushed coral to reduce erosion. Increased grass cover in Mākua Valley since this time may also have helped to reduce hill slope erosion rates.

### *Groundwater Occurrence and Flow*

Mākua Valley is within the Kea‘au subunit, the most northerly of the five subunits that make up the Wai‘anae Hydrologic Unit. The Kea‘au subunit is bounded on the north by the Mokulē‘ia subunit, in which DMR is located, and the Mākaha subunit, which includes the Mākaha Valley. The Kea‘au subunit functions primarily as a groundwater management concept. The sustainable yield of the Kea‘au subunit is estimated at 4 million gallons (15 million liters) per day, based on general estimates of the proportion of the total rainfall that recharges groundwater (Takasaki and Mink 1985).

Groundwater in the upper portion of Mākua Valley is believed to occur primarily in dike-impounded conditions. Some of the rainwater that falls on the higher elevations in the Wai‘anae Range seeps into joints and fractures and along bedding in the volcanic deposits until it is blocked by vertical sheets of basalt that were intruded into the existing volcanic rock along fractures. The dike-impounded groundwater contained in the basalts that line the valley flows into the sedimentary deposits that fill the valley and is a primary source of recharge to the alluvial aquifer. These valley fill deposits consist of permeable sediments interbedded with less permeable sediments. These sediments were the result of cycles of deposition, followed by erosion, and further deposition over thousands of years. As the sea level receded relative to the land, some of the sediments that had been deposited on the sea bottom were eroded away. These changes in depositional conditions produced differences in permeability of the sediments that affect groundwater flow.

There were reportedly two tunnels in the southern part of upper Mākua Valley (Stearns and Vaksvik 1935), and Kelly and Quintal (1977) provide a map showing two tunnels near a parcel owned by Lincoln McCandless, a water engineer. The tunnels were reportedly at an elevation of about 1,100 feet (335 meters) and produced about 750 gallons (2,839 liters) per day, which was piped to the lower valley. There is reportedly no remaining

evidence of the tunnels (Kelly and Quintal 1977). The tunnels may have been located near one of the five springs that reportedly were in Mākua Valley (Kelly and Quintal 1977). One of these five springs was recovered during field investigations following the July 2003 prescribed burn. USGS topographic maps indicate springs in the upper valley, at about 1,200 feet (366 meters) elevation on the south wall of the valley and at about 700 feet (213 meters) elevation near the head of Mākua Stream. Springs may indicate locations where dike-impounded groundwater spills to the surface; the elevations of the springs depend on the configurations of the dikes.

The USGS installed six shallow monitoring wells in 1962 near Farrington Highway, five near the mouth of Mākua Stream and one near the mouth of the Ko‘iahi Gulch (also known as Kaiahi Gulch) Stream. Most of the wells were drilled to a depth of 10 or 20 feet (3 or 6 meters), while one was drilled to a depth of 90 feet (27 meters) (USGS no date). Two additional wells, one for Ka‘ena State Park and one belonging to the Air Force, were installed near the north side of Kahanahāiki Valley, near Farrington Highway. The Air Force well was drilled to a depth of 50 feet (15 meters) from a land surface elevation of 26 feet (8 meters). The state park well was drilled to a depth of 80 feet (24 meters) from a land surface elevation of about 60 feet (18 meters).

During drilling, groundwater was first observed in the state park well at a depth of about 8 feet (2 meters). Subsequent monitoring indicates that the groundwater elevation ranges from about 6.5 to 7.5 feet (approximately 2 meters). Each of these wells appears to have intercepted groundwater at depths of less than 10 feet (3 meters). The groundwater was present in a layer of clinkers (loose volcanic material ejected from a volcano that resembles dense pumice) and fractured ‘a‘ā lava within the Wai‘anae Volcanics formation. The yield of the state park well was tested at 100 gallons (379 liters) per minute (USGS no date).

### *2002-2003 Hydrogeologic Investigation*

The Army began the hydrogeologic investigation of MMR to obtain additional data to evaluate existing conditions. The investigation included installing nine monitoring wells and rehabilitating an existing monitoring well that was installed as part of the 1994 Halliburton study (Halliburton NUS Corporation 1994). Representative groundwater samples were periodically collected from these ten wells to evaluate trends in water quality and groundwater elevation over time.

In addition to monitoring groundwater quality, the wells are intended to help with the following:

- Identification of groundwater depths at points throughout the floor of the valley;
- Identification of groundwater flow pathways; and
- Evaluation of the role that groundwater may play in the transport of contaminants in the subsurface at MMR.

The thickness of the sedimentary deposits that overlie the basalt bedrock has not been determined, but it likely extends to at least 300 feet below sea level near the shoreline. Within the depths that were explored during the current hydrogeologic investigation, the sedimentary deposits observed include alluvium and colluvium, reef deposits, and possible windblown sands. The hydrogeologic investigation focused on the freshwater in the uppermost portion of the aquifer, generally above an elevation of 100 to 150 feet (30 to 45 meters) below msl.

The direction of groundwater flow in the alluvial aquifer beneath Mākua Valley had not been determined prior to the current hydrogeologic investigation. The presumed direction of flow of this basal groundwater was toward the ocean, although local variations were expected to occur. The term basal aquifer refers to "a lens of freshwater that floats on saltwater within an aquifer, with the freshwater head in the aquifer near sea level" (Nichols, Shade, and Hunt 1996). Also, high-level groundwater (impounded behind dikes) generally was expected to flow downward from recharge areas on mountain ridges toward the basal aquifer, through fractures and by overflowing the dikes. It has been theorized that there may be a tenuous hydraulic connection, through the volcanic dike system, between high-level groundwater in the Mākaha Valley and high-level groundwater in the Mākua Valley (WRRC 1992). The presumed direction of flow, toward the northwest, was described as "from Mākaha to Kea'au, and then into the ocean," possibly based on interpretation of the elevations of groundwater in wells in the Mākaha Valley. However, the nature and significance of this connection, if it exists, is unknown.

To further investigate groundwater flow conditions, nine new monitoring wells were installed at five locations, including one upland location (ERDC-MW-5) and four locations near the western boundary of the installation (ERDC-MW-1, ERDC-MW-2, ERDC-MW-3, and ERDC-MW-4).

Well ERDC-MW-5 was installed about 7,500 feet (2,300 meters) inland from the shoreline. A thick sequence of clayey alluvial and colluvial sediment was encountered from the surface to a depth of 220 feet (67 meters) below the ground surface (bgs). Within these deposits, there was

no evidence of coarse sedimentary layers or perched groundwater. From 295 feet (90 meters) to 320 feet (97 meters) bgs, a deposit of fine-grained silty sand was encountered. Groundwater was not observed at this depth. Groundwater was first observed when a layer of gravel, in a silty matrix, was encountered at a depth of about 295 feet (90 meters). The boring was extended to a depth of about 360 feet (110 meters). The gravel, a well-rounded, poorly sorted stream gravel, increased in size with depth. Sediments above the gravel are of such low permeability for water that they effectively confine the water contained in the gravel layer and keep it under pressure. The low permeability of the alluvium would not only resist upward flow of groundwater but also downward flow.

Three of the well sites close to the western boundary of the installation (ERDC-MW-1, ERDC-MW-2, and ERDC-MW-3) are adjacent to the three streams that drain MMR. The fourth (ERDC-MW-4) is near the range control facility just north of the entrance gate. One existing well (SP-7), which is near Mākua Stream, was rehabilitated and was also included in the monitoring well network. ERDC-MW-3 and ERDC-MW-4 each consist of a cluster of three monitoring wells screened at different depths. The wells are identified as A, B, and C, from shallowest to deepest. The wells were installed to different depths in order to determine if there are differences in groundwater quality associated with depth. Table 3.7-1 shows the location and screen interval for each monitoring well.

**Table 3.7-1**
**Monitoring Well Screened Depths and Elevations**

| Well Number | Well Location | Screen Depth (feet, bgs) | Screen Elevation (feet, msl) |
|---|---|---|---|
| ERDC-MW-1 | Near mouth of Kaiahi Gulch | 6 to 36 | +3 to –27 |
| ERDC-MW-2 | Near mouth of Punapōhaku Stream | 6 to 36 | +3.5 to –26.5 |
| ERDC-MW-3A | Near Range Control Office, south of mouth of Mākua Stream | 15 to 45 | +3 to –27 |
| ERDC-MW-3B | Same as MW-3A | 44 to 69 | -26 to –51 |
| ERDC-MW-3C | Same as MW-3A | 70 to 100 | -52 to –82 |
| ERDC-MW-4A | North of mouth of Mākua Stream | 15 to 45 | +3 to –27 |
| ERDC-MW-4B | Same as MW-4A | 45 to 70 | -27 to –52 |
| ERDC-MW-4C | Same as MW-4A | 70 to 100 | -52 to –82 |
| ERDC-MW-5 | Approximately one mile east of MW-4 | 215 to 320 | +20.35 to –84.65 |
| SP-7 | Side of Mākua Stream, near mouth. | 12 to 22 | +5.39 to –4.61 |

Valley fill deposits probably extend to much greater depths than the depths to which the wells were drilled. Since the shoreline wells were completed to a maximum depth corresponding to an elevation of 82 feet below msl, and the inland well, ERDC-MW-5, was drilled to a depth corresponding to an elevation of about 225 feet (69 meters) below msl (143 feet [44 meters]

lower in elevation than the deepest shoreline well), and because the bedrock basement of Mākua Valley probably slopes to the west, it seems that the bedrock basement is quite a bit deeper near the shoreline than the depths of the wells installed there.

Although no clear correlation between subsurface layers in different portions of the investigation area have been established, the elevation of the top of the gravel layer encountered at ERDC-MW-5 (62 feet [19 meters] below msl) and the elevation at which the basalt boulders were encountered in the shoreline wells (about 50 feet [15 meters] below msl) are similar enough to suggest that the gravels and the basalt boulders were deposited at about the same time. Therefore the gravels and basalt boulders may represent parts of the same laterally connected aquifer.

#### *2002-2003 Hydrogeologic Investigations of Groundwater Elevations*

Six rounds of groundwater sampling were completed for the hydrogeologic investigation (in December 2002, January/February 2003, April 2003, June/July 2003, September 2003, and December 2003/January 2004). The results are presented in detail in Appendix G-1 and are summarized here.

Groundwater depths and elevations in the monitoring wells are presented in Table 3.6-4 in the Draft Hydrogeologic Investigation Report (Appendix G-1). Groundwater depths were measured in the wells at the time of sampling.

Based on recorded data, the groundwater gradient appears to be in the general direction of the ocean from ERDC-MW-5, with a magnitude on the order of about 10.5 to 11.5 feet (3.2 to 3.5 meters) over a distance of about 7,500 feet (2,300 meters), or about 0.0015 foot per foot. The direction of the groundwater gradient and rate of groundwater flow is discussed further in the context of groundwater modeling below.

Two well clusters (ERDC-MW-3A, -3B, and -3C, and ERDC-MW-4A, -4B, and -4C) provide information about vertical hydraulic gradients in the aquifer at these locations from January 2003 to April 2003. Differences in the elevation of groundwater in wells screened at different depths in an aquifer suggest the possibility that there may be a vertical component of flow in the aquifer because groundwater tends to flow in the direction of the portion of the aquifer with the lowest groundwater elevation. Groundwater gradients are of interest because they help in understanding groundwater flow pathways and groundwater travel times. These results indicate that small changes in vertical flow patterns probably occur in the

aquifer over time. However, the dominant pattern is the horizontal flow from points higher in the valley toward the ocean.

The elevation in ERDC-MW-5, which is inland of the other wells, was measured at 14.64 feet (4.46 meters) msl on January 24, 2003. The fact that the elevation of groundwater in ERDC-MW-5 is higher than the gravel and sand units and rises within the depth of the clayey silt deposits suggests that the groundwater may be under confining pressure. This observation and the presence of a thick sequence of fine sediments above the gravel unit, including clays and silts that are expected to have very low permeability, suggest that most of the recharge to this aquifer may come from another area of the valley. ERDC-MW-5 is on a topographic high point that separates the Mākua Stream drainage from the drainage of Ko‘iahi, or Kaiahi, Gulch. If the gravel unit is relatively horizontal and extends inland to the surrounding basalt bedrock walls of the valley, then the recharge to this aquifer unit may be primarily from deep infiltration through conduits in the bedrock the forms the sides of the valley.

#### *2002-2003 Hydrogeologic Investigations of Groundwater Quality*

The results of six rounds of groundwater sampling between December 2002 and January 2004 indicate that few compounds are present in the groundwater at concentrations that exceed either EPA primary drinking water standards or tap water PRGs.

In the first round of groundwater sampling, completed in December 2002, the explosive compound RDX was detected in only one well (ERDC-MW-4A; see Figure 3.7-2), at a concentration of 0.620 µg/L. This was just above the PRG of 0.610 µg/L. RDX was detected in the same well in the next sampling round at a concentration of 0.48 µg/L. Another explosive compound, 2,4,6-TNT, was detected in December and January from this well at 0.61 and 0.28 µg/L. These concentrations are well below the PRG of 2.2 µg/L.

Benzene was detected at a concentration of 0.92 µg/L in ERDC-MW-3B, slightly above the PRG of 0.35 µg/L but below the MCL of 5 µg/L. Benzene was detected again in this well in the second round of sampling in February 2003 at a similar concentration; benzene was not detected in the other two wells screened above and below this well at the same location. Other fuel constituents, including xylenes, ethylbenzene, and toluene, and 1,2,4-trimethybenzene, were detected at least once in all of the wells but at concentrations at least two orders of magnitude below the respective PRGs.

Heptachlor epoxide, an organochlorine pesticide, was detected in ERDC-MW-3C in the second round of sampling (but not in the first round) at a concentration of 0.039 µg/L, which is above the PRG of 0.007 µg/L but less than the MCL of 0.20 µg/L. Endosulfan I, another chlorinated pesticide, was also detected in this well in the second round of sampling, at a concentration of 0.45 µg/L, well below the PRG of 220 µg/L.

A number of dioxin isomers were detected in groundwater samples collected in December 2002 and February 2003. As described for the surface water samples, the dioxin results were converted to 2,3,7,8-TCDD equivalent values for comparison to the EPA tap water PRG for 2,3,7,8-TCDD. 2,3,7,8-TCDD equivalent concentrations for the combined dioxin and furan isomers were less than the tap water PRG in most of the samples except those from ERDC-MW-2 and ERDC-MW-5. In ERDC-MW-2, the sum of the 2,3,7,8-TCDD equivalent concentrations for all of the dioxin and furan isomers detected resulted in an equivalent concentration of 5.53 x $10^{-07}$ µg/L, which slightly exceeds the tap water PRG of 4.5 x $10^{-07}$ µg/L. In the sample from ERDC-MW-5, the sum of the equivalent concentrations was 6.84 x $10^{-06}$ µg/L, which is about 15 times the tap water PRG. These concentrations are within EPA's acceptable health risk range. Additionally, the samples were unfiltered and may reflect concentrations of dioxins and furans bound to entrained soil particles, which would normally be removed by filtration if the water were used for drinking. Note also that these particle-bound contaminants may have been introduced to the well during well construction.

Similar results for organic chemicals (other than dioxins and furans) were observed in groundwater samples from the April and June/July 2003 monitoring rounds. Benzene was detected below 1 µg/L in ERDC-MW-3B in April and June (the drinking water standard is 5 µg/L). The chlorinated pesticides alpha-, beta-, and delta-BHC were detected in ERDC-MW-3B in April 2003, at concentrations less than 1 µg/L and only slightly above their respective tap water PRGs. The chlorinated pesticide endosulfan I was detected in ERDC-MW-3C at less than 1 µg/L in April 2003 and far below the tap water PRG of 220 µg/L. Perchlorate, a highly soluble explosive compound, was detected at a concentration of 1.5 µg/L in ERDC-MW-4B in June 2003, which is less than half the tap water PRG of 3.6 µg/L. Perchlorate was not detected in groundwater prior to June 2003. Bis(2-thylhexyl)phthalate, a plasticizer, was detected at 14 µg/L in ERDC-MW-4C. However, the result was flagged as uncertain because the result was lower than the laboratory reporting limit. Toluene (a gasoline constituent) was detected sporadically in several wells in April and June 2003, at concentrations below or slightly above 1 µg/L, including in ERDC-MW-3C in April 2003, and in ERDC-MW-2 and ERDC-MW-4B

in June 2003. Toluene was also detected in a rinsate sample, suggesting that the toluene may have been introduced from atmospheric contamination or some other source not associated with groundwater.

The metals arsenic and thallium were detected in some wells. Arsenic was reported at concentrations above tap water PRGs in samples from ERDC-MW-3C, ERDC-MW-4A, ERDC-MW-4C, and ERDC-MW-5 in the first sampling round, at concentrations ranging from 0.0027 mg/L to 0.0097 mg/L. The tap water PRG is 0.000045 mg/L, which is below the analytical method detection limit. However, none of the detected concentrations exceeded the MCL for arsenic, which is 0.010 mg/L, although the concentration in ERDC-MW-5 was nearly at the MCL. Interestingly, arsenic was not detected in any of the samples collected after the first round of sampling. This suggests that the arsenic may have been introduced during drilling and well construction.

Thallium was reported in the first round of sampling only in ERDC-MW-5, at 0.012 mg/L. It was reported only in ERDC-MW-5 again in the second round of sampling but at a much lower concentration of 0.00019 mg/L. It was not detected in ERDC-MW-5 in the subsequent rounds of sampling but was detected in ERDC-MW-4A and ERDC-MW-4B in the third round, at concentrations of 0.009 and 0.006 mg/L. In the fourth round, it was detected only in ERDC-MW-3B and only in one of two duplicate samples, at a concentration of 0.00034 mg/L. The tap water PRG for thallium is 0.0024 mg/L, and the MCL is 0.002 mg/L. Therefore, thallium exceeded the MCL only in the sample from ERDC-MW-5 in the first round of sampling.

Overall, the groundwater sampling data show that sporadic detections of trace levels of several groundwater contaminants have been observed, but the results suggest that the groundwater does not contain concentrations that present a significant risk to human health. The explosives RDX, TNT, and perchlorate were detected only in wells ERDC-MW-4A and ERDC-MW-4B. Benzene was detected in well ERDC-MW-3B, and the pesticides heptachlor epoxide and endosulfan I were detected only in well ERDC-MW-3C. Dioxins were detected above PRGs in two wells but were detected at lower concentrations in all wells, suggesting a ubiquitous source. The sources of some of the detected compounds, including pesticides and dioxins, is uncertain because they are likely to be chemically bound to sediment or soil particles and therefore may have been introduced during drilling or well construction, rather than being transported by groundwater. Further, long-term sampling has been proposed to help reduce the uncertainty associated with sporadic or anomalous detections and to confirm trends.

### *Vadose Zone Monitoring*

The vadose, or unsaturated, zone is what lies between the ground surface and the water table (or a confined aquifer). In the vadose zone the pores between the sediment particles are not saturated with water or are only temporarily saturated (as after a heavy rain). In the vadose zone, groundwater is either moving downward by gravity or is held in place by capillary forces.

In the hydrogeologic investigation at MMR, several borings were drilled to install water collection devices (lysimeters) in the vadose zone to test the quality of the water present within that zone.

Lysimeters were installed in two borings placed in the OB/OD area and in one boring placed near the junk car pit. These sites were selected for lysimeter sampling because they were considered to be more likely to provide an indication of the downward migration of contaminants over time. Soil samples were collected from the borings at 5-foot (1.5-meter) intervals, and then lysimeters were installed at selected depths in the borings. The borings were intended to be drilled to 50 feet (15 meters), but the actual depths of some of the borings were limited by materials encountered in the holes. For example, a large rock was encountered in one boring in the OB/OD area at a depth of 45 feet (14 meters), and another large rock was encountered at 25 feet (8 meters) in the other boring. The second boring was drilled through the rock, until gravel was encountered at 45 feet (14 meters). The boring at the junk car pit stopped at 20 feet (6 meters) due to the presence of gravel and rocks. Lysimeters were installed at depths of 30 feet (9 meters) (SB1A) and 45 feet (14 meters) (SB1B) below the surface in one boring and at depths of 30 feet (9 meters) (SB2A) and 42 feet (13 meters) (SB2B) in the other boring in the OB/OD area. One lysimeter was installed at a depth of 19 feet (6 meters) (SB3A) in the boring at the junk car pit.

Lysimeters allow the repeated collection of samples over time, as soil pore water continues to accumulate in the porous cup. Pore water samples were collected in April and July 2003. In both rounds of lysimeter sampling, some of the lysimeters were dry or contained insufficient water to enable analysis of all of the analytes intended (explosives, nitroglycerine, metals, and volatile organic compounds).

The results are presented in the Hydrogeologic Investigation Report. Only four chemicals (the chlorinated volatile organics carbon tetrachloride and chloroform and the explosives RDX and HMX) were detected at concentrations above the EPA Region IX tap water PRGs, which were used as a conservative reference for comparison. RDX was detected in one

of the shallow lysimeters at the OB/OD area (SB1A), at concentrations of up to 4,800 µg/L, and in the other shallow lysimeter (SB2A) at a concentration of 27 µg/L. RDX was detected in the deeper lysimeter at the OB/OD area (SB1B) at a concentration of 2,900 µg/L. This sample also contained 2,700 µg/L of HMX. The deep lysimeter in the other boring at the OB/OD area contained 33 µg/L of RDX. HMX was detected in the other lysimeters at the OB/OD area, at concentrations ranging from 2.9 to 1,400 µg/L. Two other explosives, 2,4-DNT and tetryl, were detected at low concentrations in some samples from the OB/OD area. Of the explosives, only tetryl was detected in the lysimeter in the junk car pit, at a trace concentration.

These results indicate that RDX and several other contaminants have migrated to depths of at least 50 feet (15 meters) below the surface beneath the OB/OD area. The maximum depth of migration of RDX or other compounds was not determined, but given the low permeability of the sediments beneath the OB/OD area, which impedes the downward movement of groundwater, it is likely that the concentrations would decrease substantially with depth. Because the OB/OD area was used for disposing of large quantities of explosives, these results are not likely to be representative of the rest of the training area, and in fact the results from the junk car pit suggest that much lower concentrations of contaminants are present in the vadose zone there, even at shallow depths.

The soil samples from the boreholes in which the lysimeters were installed did not contain detectable concentrations of the explosives that were detected in the pore water samples from the lysimeters. The only explosive that was detected in the soil samples was perchlorate (which was not included in the analytical suite for the lysimeter samples). RDX, HMX, 2,4-DNT, and tetryl were not detected in the soil samples. This suggests that only very small quantities of these compounds are carried downward, dissolved in percolating water, and that the concentrations in soils are low because the amount of water present in the soil is low.

This probably explains why RDX was not detected in the borehole samples. For example, suppose that the porosity of the sediments in the vadose zone is about 30 percent of the volume of the sediments and that the pores are only 25 percent saturated with water. For sediments with a density about two and a half times that of water, the soil moisture content under these conditions would be on the order of about one percent of the weight of the soil. The maximum concentration of RDX detected in the pore water samples was about 3,000 µg/L, which is about three parts per million by weight. One percent of this, which is the amount that would be present in an equivalent weight of soil, would be only 30 parts per billion

in soil, which is well below the detection limit of RDX in soil. Under these conditions, if nearly all of the RDX were present in the pore water, then the RDX would not be detected in a soil sample containing this pore water.

RDX tends to bind to the surface of soil particles if the soil contains natural organic material. But most of the natural organic material in most soils is found in the surface layer of the soil. The amount of natural organic material tends to diminish greatly with depth below the root zone of plants. Therefore, if the RDX were deposited on the ground surface, most of it would be expected to bind with the natural soil organic matter in the top soil, and a relatively small percentage would dissolve in soil pore water and be carried downward through the soils. At depths of 30 to 50 feet (9 to 15 meters), the amount of RDX that binds with the sediment particles would be much less than in the surface soils, and a larger percentage of RDX would remain in the soil pore water. There is no indication that RDX has migrated to the depth of the groundwater aquifer beneath the OB/OD area; RDX was not detected in groundwater from MW-5, the well nearest to the OB/OD area.

### *Results of Numerical Modeling of Groundwater Flow*

A numerical model of the Mākua Valley groundwater flow system was developed as part of the current hydrogeologic investigation and is described in Appendix G-1. The model represents the flow system in three dimensions, and covers an area of about 6.5 square miles (16.8 square kilometers) representing the entire Mākua Valley. The model was constructed with 12 layers, so that hydraulic parameters could be varied with depth. Based on estimates from available published studies, recharge (from rainfall ) was assumed to equal four million gallons per day, and was assumed to originate from zones with three different rates of recharge, resulting from different rainfall amounts controlled mainly by elevation.

Once the model was calibrated so that it gave a reasonably close representation of observed water levels, it was used to estimate flow rates along migration pathways within the valley. For example, based on the assumptions of the model, it was estimated that it would take about 66 years for groundwater to travel from a point in the aquifer beneath the OB/OD area to the shoreline.

### *Results of Numerical Modeling of Contaminant Transport*

The numerical groundwater model was used to estimate the travel time and change in concentration of chemical contaminants injected into groundwater at a particular point in the valley. The estimate of travel time takes into account the chemical dispersion (mixing and spreading out) of

the chemical in the water as it is carried along the groundwater flow path, and the model can also be used to account for the retardation (delay) of the chemical when it interacts chemically with sediment particles in the aquifer. RDX was selected to represent the worst-case scenario for chemical transport from the live-fire training area because it is not only the most prevalent explosive compound but it also has a relatively high toxicity, is not very interactive with sediments and soils (so travels at about the same rate as groundwater), and degrades relatively slowly in the environment. All other explosives compounds used in the live-fire exercises are expected to have less of an impact on groundwater at the installation boundary than RDX.

The results of these simulations indicated that if RDX continuously entered the water table beneath the entire 5-acre (2-hectare) OB/OD area at a concentration of 0.16 mg/L, assuming no retardation in the aquifer (worst case), the concentration at the shoreline would be 2 µg/L (slightly above the tap water PRG of 0.61 µg/L) after 50 years. The decrease in concentration in this scenario is entirely the result of dispersion. The model indicated that the plume would migrate much more slowly if a retardation factor were applied. Additional simulations were performed based on the assumption that up to 8 grams of RDX residue would be generated per year in the CCAAC from live-fire exercises. It was further assumed that 43 percent of this amount would reach the water table, resulting in a groundwater concentration beneath the CCAAC of 0.16 mg/L. The groundwater model indicated that, with no retardation, the concentration of RDX in groundwater at the installation boundary after 50 years would be 1.5 µg/L. With retardation taken into account, the plume would migrate much more slowly, and concentrations would not be measurable at the installation boundary after 50 years. In addition, modeling runs for density-dependent flow and transport are included in Appendix H-2 of the Hydrogeologic Investigation Report, included as Appendix G-1 of this EIS. The estimates provided by these additional runs were similar to those described above.

The modeling results are based on a number of simplifying conservative assumptions that may result in an overestimate of the concentrations in groundwater over time. These include the assumption that there is a constant source of RDX entering groundwater and that there is no further degradation of the chemical after it reaches groundwater. Due to the relatively slow rate of groundwater flow and the effects of dispersion, the results suggest that the existing monitoring wells would likely show a very slowly increasing trend in concentrations (over many years) in monitoring wells located along the installation boundary if a plume were indeed migrating downgradient of a source of groundwater contamination.

Although no such trend has been identified during the current hydrogeologic investigation, the model results suggest that it may be too soon to observe such a trend.

### Pōhakuloa Training Area Climate

The climate at PTA is classified as cool and tropical (upper montane to alpine). The 29-year average annual precipitation at BAAF on the northern portion of the installation is 14.7 in (37.3 centimeters), ranging from 10 to 16 inches (25 to 41 centimeters) across the installation. Most of PTA is above the thermal inversion layer and is not influenced by the trade wind-orographic rainfall regime. Moisture carried by the summer easterly trade winds is lost as precipitation with an increase in elevation and rarely reaches PTA (USARHAW and 25th ID[L] 2001c). The highest monthly precipitation generally occurs in winter in conjunction with Kona storms. Occasionally, moist air trapped below the inversion layer will rise into the Saddle Region in the later afternoon. Precipitation from condensation then can occur and may equal that from rainfall.

### Surface Water Drainage

PTA lies within the Northwest Mauna Loa and the West Mauna Kea watersheds, which drain to the northern Hualālai and southern Kohala coasts, respectively (Mink and Lau 1993) (Figure 3.7-3). The WPAA and the PTA Trail are mainly within the West Mauna Kea watershed. The two watersheds are underlain by aquifer "sectors" of the same name.

There are no surface streams, lakes, or other bodies of water within PTA boundaries due to low rainfall, porous soils, and lava substrates. Intermittent stream channels quickly dry after rainfall stops. Rainfall, fog drip, and occasional frost are the main sources of water that sustain plants and animals in the dryland habitat of PTA and WPAA.

There are no perennial streams within 15 miles (24 kilometers) of PTA. However, there are at least seven intermittent streams that drain surface water off the southwestern flank of Mauna Kea and lie within the same drainage area as PTA. Popo's Gulch is the closest stream to PTA boundaries. The stream converges with 'Auwaiakeakua Gulch to drain surface water toward the Waikoloa community to the west of PTA. There are three intermittent streams located within 2 miles (3.2 kilometers) of the cantonment area (Waikahalulu Gulch, Pōhakuloa Gulch, and an unnamed gulch) which collect runoff from the southern flank of Mauna Kea (US Army and USACE 2004).

Lake Waiau, near the summit of Mauna Kea, is the nearest known surface water body. There are also three freshwater springs, Hōkūpani Spring, Waihu Spring, and Liloe Spring, in Pōhakuloa Gulch on the slope of

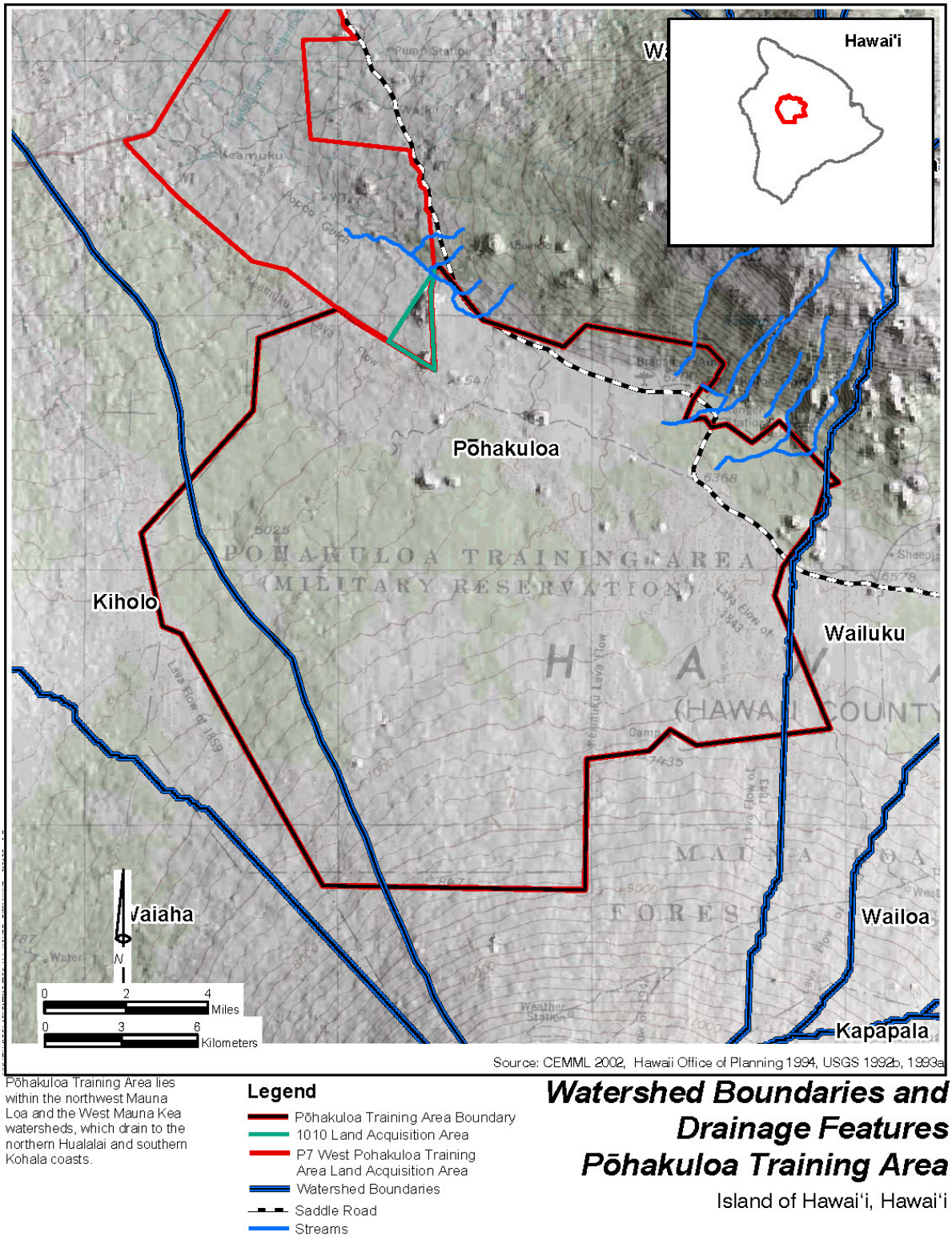



**Figure 3.7-3 Watershed Boundaries and Drainage Features, PTA**

Mauna Kea (USARHAW and 25th ID [L] 2001c, 1996). In the past, PTA used the springs as potable water sources under a nonexclusive rights agreement with the State of Hawai‘i. The springs are not currently used to meet the water needs of PTA. As discussed in Section 3.13.5, all water used at PTA is trucked in, thus no local PTA water resources are consumed at this time.

One perennial stream occurs downstream of the PTA. This is Waikoloa Stream, which begins in the Kohala Mountains, runs north parallel to State Highway 19, and discharges into Kawaihae Bay through the Wai‘ula‘ula Gulch (State of Hawai‘i 2002d). The proposed PTA Trail route crosses Waikoloa Stream near the rock wall south of Highway 19, in the upper reach of Wai‘ula‘ula Gulch.

#### *Wetlands*

Due to low rainfall, porous soils, and lava substrates, there are no surface streams, lakes, wetlands, or other bodies of water within PTA.

#### *Stream Flow and Flooding*

The cantonment and airfield areas of PTA, north of Saddle Road, are on land that slopes gently to the west. Under some circumstances, the runoff from the south slope of Mauna Kea could exceed the drainage capacity of the area and result in temporary flooding or localized ponding. However, the soils in the area are permeable, and the underlying lava flows contain sufficient secondary permeability (fractures and large openings related to cooling and emplacement of the lava) for rapid infiltration to the subsurface.

The civil defense tsunami evacuation map in the area of Kawaihae Harbor shows the evacuation area as extending inland beyond the Kawaihae-Mahukona Road (Highway 270) to an elevation of about 50 feet amsl (PDC 2001). The area west of the highway and north of the road to Spencer Beach Park, including the harbor, lies within the evacuation zone (US Army and USACE 2004).

#### *Surface Water Quality*

According to Hawai‘i’s 1998 305(b) report, most of the state’s water bodies have variable water quality that declines when stormwater runoff carries pollutants into surface waters. The most significant surface water pollution problems in Hawai‘i are siltation, turbidity, nutrients, organic enrichment, toxins, pathogens, and pH from nonpoint sources, including agriculture and urban runoff (EPA 1998c).

Few data on surface water quality are available for the PTA watersheds. There are no perennial streams within PTA. Waikoloa Stream flows across Mauna Kea near the northern boundary of the West Mauna Kea watershed. According to the EPA 303(d) List of Impaired Waters in Hawai‘i prepared under the Clean Water Act, Waikoloa Stream water quality is impaired, although not threatened, due to the presence of nutrients (nitrogen- and phosphorous-containing compounds), pathogens (coliform bacteria), and turbidity (HDOH 2004).

Marine waters north of Wai‘ula‘ula Point are considered to be Class A waters rather than Class AA. The objective of Class A marine waters is to protect recreational and aesthetic uses. Pelekane Bay/Kawaihae Harbor are identified on the 303(d) list as impaired water bodies due to turbidity and were assigned low priority for development of total maximum daily loads (TMDLs) (HDOH 2004). Construction of the Kawaihae Harbor in 1995 had adverse effects on coral growth and water quality due to changes in sediment inputs in Pelekane Bay (Tissot 1998).

### Coastal Water Quality

Marine waters north of Wai‘ula‘ula Point are considered to be Class A waters, rather than Class AA. Pelekane Bay is considered to be an impaired waterbody due to turbidity from erosion on overgrazed lands in the watershed above it. Construction of the Kawaihae Harbor in 1995 resulted in changes in coastal current patterns, increased sediment concentrations, and diverted stream channels that discharge to Kawaihae Bay (Makahuna and Makeāhua streams). Construction involved placing fill on the alluvial fan of the Makahuna Stream and disturbing offshore sediments. The breakwater was constructed in such a way as to make use of the existing coral reef, and the area inside the reef/breakwater was deepened by dredging. Studies performed afterward that focused on Pelekane Bay, just south of the new harbor facility, indicated that these activities had an adverse impact on coral growth and water quality, in part because of changes in sediment inputs (Tissot 1998).

### Groundwater Occurrence and Flow

Groundwater occurrence on the Island of Hawai‘i is not well studied due to the younger age of the island, continuing volcanic activity, and the greater thickness of the volcanic deposits. Rainfall is the primary source of groundwater recharge on the Island of Hawai‘i. The geology of the island is characterized by highly permeable lavas from which little or no runoff occurs. Most of the precipitation percolates relatively quickly to the underlying groundwater body and then moves seaward, discharging into the coastal waters (Stearns and MacDonald 1946). The Island of Hawai‘i has the highest recharge rate among the Hawaiian Islands, with a rate of 246.4 cubic yards (188.4 cubic meters) per second (Lau 1983). Sustainable

yields for each of the island's aquifers are considerably less and are described below for each aquifer system underlying PTA (US Army and USACE 2004).

According to the classification scheme proposed by Mink and Lau (1993), PTA lies above two aquifer systems: the West Mauna Kea and the Northwest Mauna Loa aquifer sectors.

The northern portion of PTA and PTA Trail lie within the Waimea aquifer system of the West Mauna Kea aquifer sector. The Waimea aquifer system includes the entire West Mauna Kea aquifer sector, which has an area of 70 square miles (699.25 square kilometers). The southern boundary from Puakō Point to the Humu'ula Saddle is the trace of the Mauna Loa/Mauna Kea geologic contact. The northern boundary from Kawaihae to Waimea follows the Mauna Kea/Kohala contact. From Waimea the boundary strikes southeasterly along a weak rift zone to the summit of Mauna Kea (Mink and Lau 1993). The West Mauna Kea aquifer system is dry, but Waikoloa Stream, which rises in the Kohala Mountains, flows across Mauna Kea lavas near the northern boundary. A basal groundwater lens reaches to about 4 miles (6 kilometers) inland in the area. Beyond this point, the water becomes high-level groundwater, although the mode of occurrence is not understood. Wells at about 1,200 feet (366 meters) elevation develop freshwater. Near Waiki'i and Waimea the groundwater level stands about 1,500 feet (457 meters) above sea level. Slightly thermal basal water is found along the Kawaihae to Waimea road below an elevation of 1,000 feet (305 meters). At the coast, basal springs discharge brackish water (Mink and Lau 1993). The Waimea aquifer system has an estimated sustainable yield of approximately 24 mgd (91 million liters per day (mld) (HDLNR 1995).

The majority of PTA lies within the Northwest Mauna Loa aquifer sector, which has an estimated sustainable yield of 30 mgd (114 mld) (HDLNR 1995). The Anaehoomalu aquifer system comprises the entire Northwest Mauna Loa aquifer sector and has a total area of 291 square miles (754 square kilometers). The sector boundaries reach from the 7-mile (11-kilometer) length of coast to the summit of Mauna Loa and the saddle between Mauna Loa and Mauna Kea. All rocks within the aquifer sector belong to Ka'ū Basalt. The total length of the sector is 37 miles (60 kilometers) from the coast to the saddle, the first 18 miles (29 kilometers) of which is a narrow corridor between the Hualālai and Mauna Kea volcanoes. The width of the corridor is about 5 miles (8 kilometers). High-level groundwater likely occurs at elevations greater than 1,200 feet (366 meters) amsl, although this has not been shown yet (Mink and Lau 1993). The basal lens, extending about 4 to 5 miles (6.4 to 8 kilometers) inland, is brackish except possibly near the inland periphery. Basal

springs and anchialine ponds are common along the coast (Mink and Lau 1993).

Few data are available to evaluate groundwater conditions at PTA. Most of the USGS groundwater sampling and observation wells on the island are located along the coast. Groundwater has not been found at levels lower than 1,000 feet (305 meters) below ground level on the Island of Hawai‘i (USARHAW and 25th ID[L] 2001c). The Island of Hawai‘i contains high water levels in the rift zones of Kilauēa and Kohala volcanoes.

High-level groundwater (perched groundwater) is groundwater that is held at levels above the basal water table by rocks that are relatively impermeable, including intrusive rocks, ash beds, dense lava flows, soil, alluvium, and ice. High water levels, possibly associated with a buried rift zone of Hualālai Volcano or fault scarps draped with lava flows, are present along the western coast of the Island of Hawai‘i. Areas of high water levels also are found along the northern and eastern flanks of the Mauna Kea and on the southern flank of Mauna Loa (USGS 2000a).

There is evidence of perched groundwater within the aquifer sectors underlying and adjacent to PTA (Stearns and McDonald 1946). The highest perched water in the Hawaiian Islands is Lake Waiau on Mauna Kea, at an elevation of 13,007 feet (3,965 meters) amsl. It is thought that the lake is perched on ground ice (Stearns and MacDonald 1946).

Based on regional hydrogeological information, it is believed that the groundwater beneath PTA occurs primarily as deep basal water within the older Pleistocene age basalts (US Army and USACE 2004). Exploratory well drilling was conducted in March 1965 by the DLNR near the PTA cantonment area. A test hole, (Pōhakuloa test hole T-20) located half a mile west of Mauna Kea State Park at an elevation of 6,375 feet (1,943 meters) msl, was drilled to a depth of 1,001 feet (305 meters) below ground surface (bgs). No groundwater was encountered in this test hole (US Army and USACE 2004).

There are limited data for groundwater quality for PTA due to the absence of a significant number of monitoring wells in the inland area of the island. In general, the quality of the natural fresh water in Hawai‘i’s basaltic aquifers is considered to be good (Lau 1983). Groundwater quality is threatened by saltwater encroachment and contamination from agricultural and other land uses.

Since August 1989, the HDOH has issued the “Groundwater Contamination Maps” for Hawai‘i. These maps identify locations where groundwater contaminants have been detected and confirmed. The maps identify the locations of current and historic contaminated wells and wellfields (an area where many wells in proximity share the same

groundwater source) on each island. According to these maps, most of the well locations where contamination is detected on the Island of Hawai‘i are located along the eastern coast of the island. Groundwater quality on the island generally diminishes towards the coasts due to increased saltwater intrusion. Detected contamination levels reported in the HDOH maps are below existing federal and state drinking water standards established for the protection of public health and do not pose a significant risk to humans (HDOH 1999b). Groundwater quality beneath PTA is likely of higher quality due to its distance inland from the coast.