3 AFFECTED ENVIRONMENT

This Chapter describes the environmental setting for the proposed Outrigger Telescopes Project and presents a brief summary of those elements of the environment that could potentially be affected by the Proposed Action.

3.1 AFFECTED ENVIRONMENT OF THE PROPOSED ACTION

Section 3.1 provides a description of the existing or present-day environment of Mauna Kea, primarily the summit area located within the approximately 212-hectare (ha) (525-acre (ac)) Astronomy Precinct. The summit area is that portion of the Astronomy Precinct within which most of the existing astronomical observatories are located. The Astronomy Precinct itself comprises a small portion (4.6 percent) of the approximately 4,568 ha (11,288 ac) of the Mauna Kea Science Reserve (MKSR).

3.1.1 Land Use and Existing Activities

In November 1972, Mauna Kea was officially listed on the National Registry of Natural Landmarks as part of the National Natural Landmarks Program. Established in 1962, the program aims to encourage and support voluntary preservation of sites that illustrate the geological and ecological history of the United States, and to strengthen the public's appreciation of American's natural heritage. Mauna Kea is a National Natural Landmark because it is the highest insular mountain in the United States, containing the highest lake (Lake Waiau) in the country and evidence of glaciation above the 3,353-m (11,000-ft) level. Mauna Kea is also recognized as the "most majestic expression of shield volcanism in the Hawaiian Archipelago, if not the world (NPS 2004)."

Standing 4,205 m (13,796 ft) above sea level, Mauna Kea is the highest peak in the Hawaiian Islands and, from its base on the floor of the Pacific Ocean, the highest mountain on Earth. The name Mauna Kea is often translated in English as White Mountain. In Native Hawaiian traditions, however, “Kea” is also the abbreviated form of Wākea, the great sky god who, together with Papa, the Earth mother, and other gods and forces created the Hawaiian Islands. The summit is considered the meeting point of Wākea and Papa. In this cultural context, the island of Hawai‘i was the first-born offspring of this union, the eldest of the islands. Wākea and Papa also became parents of the first Native Hawaiian man, Hāloa, the first ancestor of the Hawaiian people.

3.1.1.1 Mauna Kea Science Reserve (MKSR)

Land Use. The cultural landscape of Mauna Kea remains important to the Hawaiian people. Spiritual beliefs and cultural practices of many Native Hawaiians in the present-day are associated with lands that make up the MKSR. In addition to the cultural significance of Mauna Kea, the high altitude, atmospheric dryness, and minimal seasonal variation provide for ideal astronomical observations. As a result, the MKSR is regarded as one of the best sites in the world for optical/infrared and millimeter-wave telescopes.

The MKSR (see Figure 2-2) encompasses an area of about 4,568-ha (11,288-ac) of State land situated above the 3,660-m (12,000-ft) elevation of Mauna Kea, but excludes the parcels that make up the Mauna Kea Ice Age Natural Area Reserve.

The MKSR is leased by the University of Hawai‘i (UH) from the State of Hawai‘i and is managed by UH. The lease states that the MKSR is to be used "as a scientific complex, including without limitation thereof an observatory, and as a scientific reserve being more specifically a buffer zone to prevent the intrusion of activities inimical to said scientific complex" (State of Hawai‘i 1968). The area where the observatories are located is known as the Astronomy Precinct. The Astronomy Precinct is centered near the middle of the summit plateau while the remainder of the MKSR serves as a buffer area (see Figure 2-3).

The State Land Use Commission has established the boundaries of four State Land Use Districts throughout the State: these are Urban, Rural, Agriculture and Conservation. The MKSR is located in the Conservation District. The Conservation District is the most restrictive of the four land use classifications authorized under Hawai‘i's Land Use Law, Hawai‘i Revised Statutes (HRS) Chapter 205. Conservation Districts are defined to include:

> "areas necessary for protecting watersheds and water sources; preserving scenic and historic areas; providing park lands, wilderness, and beach reserves; conserving indigenous or endemic plants, fish and wildlife, including those which are threatened or endangered; preventing floods and soil erosion; forestry; open space and areas whose existing openness, natural condition or present state of use, if retained, would enhance the present or potential value of abutting or surrounding communities, or would maintain or enhance the conservation of natural or scenic resources; areas of value for recreational purposes; other related activities; and other permitted uses not detrimental to a multiple use conservation concept (HRS § 205-2(e))."

The Department of Land and Natural Resources (DLNR) administers public land within the Conservation District pursuant to HRS Chapter 183C. That chapter makes the following statement of public policy:

> "[t]he legislature finds that lands within the state land use conservation district contain important natural resources essential to the preservation of the State's fragile natural ecosystems and the sustainability of the State's water supply. It is therefore, the intent of the legislature to conserve, protect, and preserve the important natural resources of the State through appropriate management and use to promote their long-term sustainability and the public health, safety and welfare (HRS § 183C-1)."

The Conservation District lands are categorized into four subzones (general, resource, limited, and protective) based on the resource characteristics. The MKSR is contained entirely within the Resource subzone (UH 1999). Resource subzones include lands necessary to ensure the sustained use of natural resources and include lands suitable for parks, outdoor recreational uses, and the like (Hawai‘i Admin. Rules (HAR) § 13-5-13).

Astronomy facilities are a permitted use in this subzone (HAR § 13-5-24). Astronomy facilities in the resource subzone require a board permit and an approved management plan (HAR § 13-5-24).

Existing Activities. Current activities that occur in the MKSR and surrounding areas include cultural and religious activities, astronomical and other scientific research, and a variety of recreational activities. All activities are described in detail as follows.

<u>Cultural and Religious Practices</u>. Many Native Hawaiians view Mauna Kea as a natural temple. The landscape embodies their cultural views and links them to nature and the spiritual world. The ascent up the mountain takes one through various zones or levels of increasing sacredness and proximity to the spiritual beings of great power and importance (*akua*).

Current cultural and religious practices are associated with the existing resources on the mountain, and involve the trails, individual topographic features, burial locations and cultural landscapes. Other contemporary practices include prayer and ritual observances including construction of new altars. See Sections 3.1.2 and 4.1.1 for more information about cultural and religious practices.

<u>Astronomical Research</u>. The MKSR is one of the best locations in the world for ground-based astronomical observations. High on a Pacific island, the mountain is generally cloud-free, providing excellent clear nighttime viewing.

At the present time, 12 observatories operate within the Astronomy Precinct. These include eight major optical/infrared telescopes, a 0.6-m (24-inch (in)) telescope; two single-dish millimeter/submillimeter-wavelength telescopes; and a submillimeter array. In addition, the Very Long Baseline Array (VLBA) Antenna Facility is located outside the Astronomy Precinct at an elevation of 3,719 m (12,200 ft). All of the observatories are used for basic astronomical research. Table 3-1 lists the current Mauna Kea Observatory telescopes. Figure 2-4 shows their location in the MKSR (with exception of the VLBA, which is located at too low an elevation to be shown on this figure).

<u>Other Scientific Research</u>. Mauna Kea has a number of natural resources of interest to scientists in various disciplines. Geologists study the unique volcanic and glacial history of the mountain and health professionals study the effects of the altitude on the human body. Meteorologists study the weather and atmosphere, and biologists study the native ecosystems found on Mauna Kea.

<u>Recreational Activities</u>. Recreational activities in the MKSR and surrounding areas include sightseeing, skiing and snow play, hiking, and hunting. The factors that make Mauna Kea such a uniquely appealing place to recreational users can also be the cause for health and safety concerns. Visitors must be prepared for the effects of high altitude on their bodies and the possibility of a sudden and severe change in weather. Altitude sickness is primarily caused by a lack of oxygen or hypoxia. At the summit of Mauna Kea, the oxygen content of the reduced atmosphere is a mere 60 percent of that at sea level. The major cause of altitude illnesses is going too high too fast. A preventive measure to altitude illness is acclimatization. Before proceeding up the mountain, UH recommends that visitors spend approximately one hour at the Visitor Information Station (VIS) at Hale Pōhaku to view exhibits and acclimatize to prevent altitude sickness.

TABLE 3-1. THE CURRENT MAUNA KEA OBSERVATORIES

Telescope	Size	Primary Use	Sponsors	Year of Operation
Optical and Infrared Telescopes				
UH 0.6-m Telescope	0.6 m (24 in)	Optical	UH	1968
UH 2.2-m Telescope	2.2 m (7.2 ft)	Optical/Infrared	UH	1970
NASA Infrared Telescope Facility (IRTF)	3.0 m (10 ft)	Infrared	NASA	1979
Canada-France-Hawai'i Telescope (CFHT)	3.6 m (12 ft)	Optical/Infrared	Canada/France/ UH	1979
United Kingdom Infrared Telescope (UKIRT)	3.8 m (12.5 ft)	Infrared	United Kingdom	1979
W.M. Keck Observatory (Keck I)	10 m (33 ft)	Optical/Infrared	California Institute of Technology (Caltech)/ University of California/California Association for Research in Astronomy (CARA)	1992
W.M. Keck Observatory (Keck II)	10 m (33 ft)	Optical/Infrared	Caltech/ University of California/CARA	1996
Subaru /Japan National Large Telescope)	8.2 m (27 ft)	Optical/Infrared	Japan	1999
Gemini North Telescope	8.1 m (26.2 ft)	Optical/Infrared	NSF/United Kingdom/Canada/ Argentina/Australia/ Brazil/Chile	1999
Millimeter/Submillimeter Telescopes				
Caltech Submillimeter Observatory (CSO)	10.4 m (34 ft)	Millimeter/ Submillimeter	Caltech/NSF	1986
James Clerk Maxwell Telescope (JCMT)	15 m (49 ft)	Millimeter/ Submillimeter	United Kingdom/ Canada/ Netherlands	1986
Submillimeter Array	Eight 6-m (20-ft) antennas	Submillimeter	Smithsonian Astrophysical Observatory/Taiwan	2003
Facility Outside the Astronomy Precinct				
Very Long Baseline Array (VLBA)	25 m (82 ft)	Centimeter Wavelength	NRAO/NSF	1992

Source: UH IfA 2002a

Acronyms: NRAO = National Radio Astronomy Observatory; NSF = National Science Foundation.

Sightseeing. Residents and visitors alike visit Mauna Kea to view world-class telescopes, feel the chill of the air, and appreciate the desolate beauty and natural landforms of Mauna Kea. Visitors who decide to drive to the summit often stop to walk around and photograph the surrounding areas. At the summit, the public can visit the W.M. Keck Visitor Gallery to view exhibits and look inside of one of the Keck domes. The VIS offers the option of taking guided tours to the summit. The tour includes stops at both the W.M. Keck Observatory and the UH 2.2-m (88-in) Telescope (UH 1999). The VIS also offers evening stargazing programs on clear nights (UH 1999).

Skiing and Snow Play. Residents and visitors take advantage of long winter periods when snow falls at the higher elevations of Mauna Kea. Outdoor enthusiasts visit the mountain to ski, snowboard, hike, and play in the snow. Others often load their pickup truck with snow to take down to Hilo and build snowmen and play. On a good snow day, there may be as many as 1,000 vehicles and 3,000 individuals traveling to the summit (MKSS 2004a).

The summit road is kept clear of snow by Mauna Kea Support Services (MKSS) staff. Vehicles are typically parked along the roadways and visitors play nearby. The most popular ski and snow play areas are those easily accessed by roadway. The ski run known as Poi Bowl is the most popular because it is accessible by roads at both the top and bottom of the run (UH 1999). Poi Bowl is located directly east of the Caltech Submillimeter Observatory (CSO) (UH IfA 2004b). Skiers typically establish an informal shuttle system where the skier is dropped off at the top of the run and then met at the bottom. If the snowfall is heavy, the area to the east of the summit, known as King Kamehameha run, is used for longer ski runs (UH 1999). However, the bottom of this run is not accessible by vehicle and the skier must hike back to the roadway. Once or twice a year, depending on the snow conditions, a skiing or snowboard competition is held on the mountain (UH 1999). This can result in a significant increase in traffic on the mountain.

The weather patterns for any particular year will determine how much and where snow falls. Typically, snow falls first and melts last from the northern slope of Puʻu Haukea (UH 1999). This is often the only place on the mountain with snow. People tend to hike between snow areas when the snowfall is light.

Hiking. Hiking is most popular in the Mauna Kea Natural Area Reserve and along existing roads. Individuals typically drive up the mountain for a distance before parking and hiking. The Humuʻula-Mauna Kea trail, located on the Hilo side of the mountain, runs from the Humuʻula sheep station to Lake Waiau (UH 1999). Humuʻula is at an elevation of approximately 2,012 m (6,600 ft) (UH IfA 2004b).

Hunting. Hunting is a traditional recreation and subsistence activity in Hawaiʻi. Pigs, sheep, goats, and a variety of game birds are hunted in three-dozen hunting units concentrated in the central portion of the island of Hawaiʻi. Game birds include turkey, pheasants, quails, chukars, and francolins. There are approximately 3,000 licensed hunters living on the island. The Mauna Kea Forest Reserve (elevation over 2,134-m (7,000-ft) is a hunting unit where pigs, goats, sheep and birds can be hunted with archery and firearms (UH 1999).

<u>Commercial Uses</u>. Visitors to the area have the option to take commercial tours to the

summit area. Most tour operators take visitors for six to eight hour trips that can include an observatory tour, lunch, hikes to Lake Waiau, and narratives on the area vegetation and natural history. DLNR issues a limited number of Commercial Activity Permits to tour operators. There is an average of 302 commercial operator trips to the summit per month (OMKM 2004). The evening (sunset) tours are limited to 18 vans, approximately 252 people (MKSS 2004a). On a normal day, the commercial (sunset) tours draw an average of 150 participants per evening (MKSS 2004a). In addition, a few tour operators offer day tours several times a week.

3.1.1.2 Hale Pōhaku

Land Use. Hale Pōhaku is located at approximately 2,804 m (9,200 ft) along the Mauna Kea Access Road on the southern slopes on Mauna Kea (see Figure 2-8). Hale Pōhaku is located in the area designated as *Māmane/Naio Forest Ecosystem Management Area* and within a federally designated critical habitat of the endangered *palila*. Hale Pōhaku is currently approved for the use of providing support facilities for science activities, including the Mid-Elevation Support Facilities (including a common building, dormitory, and maintenance area) for astronomers, a Visitor Information Station (VIS) and parking for the public, a construction camp, and a staging area.

Existing Activities. Hale Pōhaku provides accommodations used for sleeping, eating, lounging, research support and minor maintenance functions directly related to telescope operations at the summit. There are currently 72 rooms available for astronomy support personnel and astronomers at the Mid-Elevation Support Facilities (MKSS 2004c). There are also 5 rooms used exclusively by the MKSS food and lodging staff (MKSS 2004c). An additional 32 beds at the construction camp are made available for VIS and Ranger staff, UH astronomy students and staff, and special groups (MKSS 2004c). The construction camp is located below the Mid-Elevation Support Facilities and the VIS at an elevation of approximately 2,743 m (9,000 ft).

Currently, the Mid-Elevation Support Facilities averages 14,600 reservations a year (MKSS 2004a). On average, 40 rooms are occupied daily (MKSS 2004a). In addition, the construction camp cabins average about 5 to 6 MKSS staff each night (MKSS 2004a). During astronomical events of public interest, such as an eclipse, the facilities are often full. Demand also increases when significant milestones are achieved in telescope development. For example, most of the lodging units were occupied with first light preparations for Gemini and Subaru Telescopes in early 1999 (UH 2000b).

Astronomers, technicians and support staff gather in the common building, which includes a kitchen, dining area, lounges, offices and a library. A maintenance area serves as a headquarters for MKSS repair and maintenance activities. MKSS staff at the Mid-Elevation Support Facilities includes 12 personnel supporting food and lodging and 5 personnel in the utility area (UH 2000b). The utility personnel perform road maintenance, snow removal and facility maintenance at Hale Pōhaku.

The VIS is located approximately 183-m (650-ft) below the Mid-Elevation Support Facilities (UH 2000b). The VIS includes an 87-square meter (m^2) (950-square foot (ft^2)) facility, which provides an interpretive center and acclimation point for visitors to the mountain. The VIS also offers guiding tours to the summit and evening stargazing programs. VIS staff includes a manager, 3 interpretive guides, 2 on-call personnel, Kūkahau‘ula summit cones. Included within the area of this reconnaissance survey is Pu‘u Hau‘oki, the summit cone on which the Keck observatory is built. No sites were recorded within the project area for the Outrigger Telescopes or within the Kūkahau‘ula summit area, but 22 shrine sites were located elsewhere on the plateau, including two shrines approximately 135 and 215 m (443 and 705 ft) to the south on the summit plateau. During a reconnaissance survey at the VLBA Observatory site, Hammatt and Borthwick (1988), recorded three probable shrines and one rockshelter (State Sites [50-10-23-]-11076 through 11079); they recommended flagging of the sites and preservation, but no archaeological monitoring. Robins and Hammatt (1990) found no surface sites at the Subaru site on the slope of Pu‘u Hau‘oki adjacent to the Keck site during reconnaissance survey; no further archaeological investigations were recommended there.

Surveys of the MKSR outside the present project area include a 1984 survey of the east/southeast flank of Mauna Kea north of the adze quarry which recorded 20 archaeological sites, all but one identified as shrines (McCoy 1984). The State Historic Preservation Division (SHPD) conducted a survey in 1995 to relocate and evaluate sites recorded in earlier surveys (UH 1999). Eighteen new sites were also identified during this survey. Two years later, a survey located 29 new sites, most identified as shrines (McCoy 1999).

Kam and Ota (1983) found no sites during a reconnaissance survey along the Mauna Kea Observatory Power Line between Hale Pōhaku and the summit. At Hale Pōhaku, stone cabins built by the CCC in the 1930s remain in place. McCoy (1985) documented archaeological sites during surveys in the 1980s. Robins and Hammatt (1990), in preparation for dormitory construction for the Subaru telescope project (Mid-Elevation Support Facilities), revisited three lithic scatters in the project area and scatters and two shrines nearby, all reported by McCoy in 1985, and recommended testing, possible surface collection, and flagging of the shrines. McCoy and Sinoto (McCoy 1991; Sinoto 1987) recorded additional archaeologically significant localities during preparations for the GTE Fiber Optic Cable Project. This project was planned to work around a buffer zone created to protect one of the newly documented localities.

Ethnographic research for the project region includes a report on the background of the Mauna Kea summit region (McEldowney 1982); a cultural synthesis of the Hāmākua District including the summit of Mauna Kea (Cordy 1994); an archival research study for Hakalau National Forest Reserve on the lower east slope of the mountain (Tomonari-Tuggle 1996); a social impact assessment in association with the Saddle Road project (Kanahele and Kanahele 1997); a study of the potential effects of the proposed MKSR Development Plan on Native Hawaiian cultural practices and beliefs associated with Mauna Kea (PHRI 1999); an oral history, consultation study, and archival research (Maly 1998; Maly 1999); an historic and traditional cultural assessment for the Saddle Road project (USDOT 2000), and a cultural impact assessment of the Palila Saddle Road Mitigation Project, a project involving the fencing of two parcels of pasture lands on the lower west and north slopes of Mauna Kea to promote the regeneration of the *māmane* forest as habitat for the endangered native *palila* bird (Tomonari-Tuggle 1996).

3.1.2.3 Summary of Oral Interview Findings

The following summary of findings, in cultural-historical documentation and oral history interviews for Mauna Kea on the island of Hawaiʻi, was prepared by cultural resources specialist, Kepā Maly (*Kumu Pono Associates*). This summary was prepared as a part of the development of the Environmental Assessment (EA) for the Outrigger Telescopes Project on Mauna Kea.

Between August 1996 to February 1999, Maly conducted two detailed studies on Mauna Kea (Maly 1998; Maly 1999). The first study conducted by Maly (1998) reported on findings of archival and historical literature research, and included previously unavailable translations of Native Hawaiian traditions of Mauna Kea and important survey documentation of features on the mountain (reported in the nineteenth century). The study was conducted at the request of Ms. Lehua Lopez, President, Native Lands Institute in partnership with various Hawaiian organizations and *Kumu Pono Associates*. The second study (Maly 1999) was conducted at the request of Group 70 International, as a part of the update of the Complex Development Plan of MKSR and Hale Pōhaku for UH. The 1999 study reported the findings of a detailed oral history and consultation interview program, and also included a detailed overview of archival and historical literature pertaining to Mauna Kea and its place in Hawaiian cultural practices and beliefs.

Preparation of the following summary did not entail further archival literature research. A few supplemental oral history interviews with individuals recommended by Maly were conducted by cultural resources specialist Maria Orr during the development of this EIS. Like Maly's interviews, these interviews addressed the whole mountain, not just the project area. As such, the summary represents findings and recommendations that applies to the whole of Mauna Kea. While the specific proposed Outrigger Telescopes Project was not the focus of the 1998-1999 oral history interview and consultation program, at several points this proposed project was raised in conversations, and some program participants had knowledge of the project. Perhaps of greater importance to this summary is the fact that most Native Hawaiian interviewees—as well as other interview/consultation program participants—addressed all forms of development (existing and future) in their comments regarding on-going uses of Mauna Kea.

Summary of Documentation. Mauna Kea is located on the island of Hawaiʻi. With its summit peak standing at 4,205-m (13,796-ft) above sea level, Mauna Kea is the highest peak in Hawaiian Islands and in the larger Pacific Basin. Because of its prominence on the landscape of Hawaiʻi, Mauna Kea is the focal point of a number of Native Hawaiian traditions, beliefs, customs, and practices. In the region of Mauna Kea—an area extending from around the 3,048-m (10,000-ft) elevation to the summit peaks at Puʻu Kūkahauʻula, and including a plateau-like feature above the 3,505-m (11,500-ft) elevation—and on its slopes extending down to an area once covered in dense forest growth (approximately the 2,700-m (9,000-ft) elevation), are many *puʻu* (hills) and other natural features, many of which are described in various traditions and historical accounts.

Perhaps as a result of its prominence, isolation, and extreme environmental conditions, Mauna Kea's place in the culture and history of the Hawaiian people is significant. This "cultural significance" extends beyond a physical setting, sites, or particular features which have been previously identified in archaeological site studies. Mauna Kea is a prominent feature on the cultural landscape of Hawaiʻi, and it has great spiritual and cultural significance in the Native Hawaiian community.

While conducting research in archival literature, Maly reviewed primary sources, including, but not limited to: traditional Hawaiian accounts of the nineteenth and early twentieth centuries, published in Hawaiian language newspapers and manuscripts (some of which had not been previously translated) (Maly ms. 1992-1998); land use records, including the *Māhele* (Land Division) of 1848, Boundary Commission Testimonies, and historic survey records of the Kingdom of Hawaiʻi (c. 1860-1900); nineteenth century writings of native historians – Malo (1951), Iʻi (1959) and Kamakau (1961, 1964, 1976, and 1991); journals and manuscripts of historic period visitors and historians – Cook (in Beaglehole 1967), Ellis (1963), Douglas (1914), Stewart (1970), Bingham (1969), Remy (1865), Fornander (1917-1919 and 1973) and Westervelt (1963); and secondary historical studies, including McEldowney and McCoy (1982), Cordy (1994), Kanahele and Kanahele (1997), and Langlas and Others (1997).

Native Hawaiian traditions describe the "birth" of the Hawaiian Islands, and the presence of life on and around them, in the context of genealogical accounts. Hawaiian genealogies record that the island of Hawaiʻi was the first born child of Wākea (the expanse of the sky) and Papa-hānau-moku (Papa—Earth-mother who gave birth to the Islands). The same god-beings, or creative forces of nature that gave birth to the Islands, were also the parents of the first man (Hāloa), and from this ancestor, all Hawaiian people are descended (Malo 1951; Beckwith 1970; Pukui and Korn 1973). It is also found in genealogical chants, that Mauna Kea is referred to as "*Ka Mauna a Kea*" (Wākea's Mountain), with the mountain being likened to the first-born of the island of Hawaiʻi (Pukui and Korn 1973). A *mele hānau* (birth chant) for Kauikeaouli (King Kamehameha III) (ca. 1813-1854), describes Mauna Kea in this genealogical context:

O hānau ka mauna a Kea,
ʻŌpuʻu aʻe ka mauna a Kea.
ʻO Wākea ke kāne, ʻo Papa,
ʻo Walinuʻu ka wahine.
Hānau Hoʻohoku he wahine,
Hānau Hāloa he aliʻi,
Hānau ka mauna, he keiki mauna na Kea…

Born of Kea was the mountain,
The mountain of Kea budded forth.
Wākea was the husband, Papa
Walinuʻu was the wife.
Born was Hoʻohoku, a daughter,
Born was Hāloa, a chief,
Born was the mountain, a mountain-son of Kea…

(Pukui and Korn 1973: 13-28)

A review of native traditions reveals that many of the traditions of Mauna Kea are directly attributed to the interaction of the gods with the land and people. In Hawaiian practice, elders are revered—they are the connection to one's past—and they are looked to for spiritual guidance. Because of its place in the Hawaiian genealogies, the landscape itself is considered sacred as it is believed to be home of the gods or ancestral deities.

Additionally, in Hawaiian culture, natural and cultural resources are one and the same. All forms of the natural environment, from the skies and mountain peaks, to the watered valleys and plains, and to the shore line and ocean depths are the embodiments of Hawaiian gods and deities. In both its genealogical associations and its physical presence on the island landscape, Mauna Kea has been, and remains a source of awe and inspiration for the Hawaiian people. Evidence of this sense of awe, is recorded in a traditional Hawaiian proverb which expresses the thought "***Mauna Kea, kuahiwi ku ha'o i ka mālie"*** – *Mauna Kea (is the) astonishing mountain that stands in the calm* (Pukui 1983).

One of the important cultural descriptors of knowledge of a landscape, and its significance in Hawaiian beliefs and customs, are place names. There are many place names on the landscape of Mauna Kea that remind us of the broad relationship of natural landscape to the culture and practices of the Hawaiian people. A number of the place names recorded for this mountain landscape are associated with Hawaiian gods. Other place names are descriptive of natural features and resources, or document events that occurred on the mountain. The occurrence of place names, extending from the shoreline to the summit of Mauna Kea, is important in that it demonstrates the Hawaiian familiarity with the sites, features, and varied elevations of the mountain. Early traditional and historic accounts, as well as a number of historic survey maps from ca. 1862-1892, identify sites and features on Mauna Kea that bear the names of Hawaiian gods and goddesses who were intimately associated with the history of the mountain. This is particularly so in the summit region of Mauna Kea, where a number of landscape features are directly associated with Hawaiian gods and deity.

Summary of Oral Interviews. Between September 25th and December 21st, 1998, Maly conducted a total of fifteen tape-recorded and supplemental oral history interviews with twenty-two participants. All but two of the interviews were conducted on the island of Hawai'i. Additionally three historic interviews (recorded between 1956 and 1967) were translated from Hawaiian to English by Maly and transcribed. With those interviews, representing three primary interviewees, the total number of interviewees represented in Maly's 1999 study totaled twenty-five participants. Most of the formal interview participants were of Hawaiian ancestry (many of whom had generational attachments to lands which lay on the slopes of Mauna Kea). Those interview participants who were not Hawaiian had personal experience on Mauna Kea dating back to the 1920s.

Also, during the process of conducting the formal recorded interviews, Maly spoke with more than 100 individuals who were known to him or were identified as: (1) having knowledge about Mauna Kea; (2) knowing someone who could be a potential interviewee; or (3) who represented Native Hawaiian organizations (in alphabetical order – *Hui Mālama I Nā Kūpuna o Hawai'i Nei*, the island of Hawai'i Council of Hawaiian Civic Clubs, *Ka Lāhui Hawai'i*, the Office of Hawaiian Affairs, and the SHPD) with interest in Mauna Kea. A number of those contacts resulted in the recording of informal documentation regarding Mauna Kea, or generated written responses as formal communications. Notes, written up during various conversations, added information to the historical record of, and recommendations pertaining to, Mauna Kea, and were cited in *Appendices B, C, and D* of Maly 1999. The scope of work for these studies focused on current and any proposed observatory development on Mauna Kea. Neither interviewees nor consultant participants were asked about any other forms of development on Mauna Kea. The following points summarize key recommendations of interview and consultation program participants:

- All but one interview-consultation participant stated that they would prefer no further development of observatories on Mauna Kea. Of those who had this preference, a few expressed reservations about further development, but did not rule out the possibility. High visibility of observatory features and impacts on *pu‘u* were raised as issues by many interviewees.

- Protection of the landscape and view planes (*e.g.*, *pu‘u* to *pu‘u* and cultural resources) needs to be addressed.

- The general consensus of all participants—often voiced with deep emotion—was that the State of Hawai‘i and UH should be thankful for what they have been able to use, and they should use what they have wisely.

- Before trying to establish guidelines for Native Hawaiian use and practices on Mauna Kea, the State of Hawai‘i and UH and other facilities/users of Mauna Kea must establish and adhere to their own guidelines and requirements for use of Mauna Kea.

- When addressing the varied resources in the summit of Mauna Kea, the State University and other agencies and users must look beyond the summit. In a traditional Hawaiian context, Mauna Kea comprises two major land units that extend from sea level, through the mountainous region and on to the summit of Mauna Loa. Mauna Kea is Hawai‘i—there would be no Hawai‘i had Mauna Kea not first been born. What occurs on the summit of Mauna Kea, filters down to, and has an impact on what is below.

  The native system of *ahupua‘a* management (which may be likened to an integrated resources management planning approach) needs to be incorporated into planning for any future activities on Mauna Kea.

- Complete work and studies that were required as a part of the original master plan, and keep commitments.

- Protocols for the collection of cultural data, data analysis, and any resulting recommendation should be stated, including recommendations that will be implemented. Archaeological sampling of sites should be limited and plans developed in consultation with knowledgeable cultural practitioners.

- Use of existing facilities and infrastructure needs to be monitored to ensure that further damage (*e.g.,* impacts to *pu‘u*, view planes, cultural sites and practices, and geological resources) to the cultural-natural landscapes does not occur.

- A plan for access to, and use of, traditional sites and resources (*e.g.*, Keanakāko‘i) needs to be formulated in consultation with native practitioners and families who share generational ties to Mauna Kea, and who still practice their culture and religion on Mauna Kea.

- The State of Hawai‘i, UH, and other sub-lessees and users of the Mauna Kea facilities and resources should form a sustainable partnership with community members.

- Key participants in this partnership should include knowledgeable Native Hawaiian families who share generational ties to Mauna Kea, and other individuals known to be knowledgeable about Mauna Kea’s various resources.

- Such a partnership should have more than an “advisory role,” and would focus on formulating culturally sensitive management guidelines and protocols for users of Mauna Kea.

Partnership programs could also implement further literature research and oral history documentation for Mauna Kea; develop site preservation and resource monitoring plans; and design educational-interpretive programs for Mauna Kea.

- Restore documented traditional Hawaiian place names to appropriate features and use them thereafter.
- Develop a plan for the restoration of the natural environment on Mauna Kea. For many interviewees, this includes maintaining hunting populations of introduced herbivores, which can help keep alien plant species under check.
- Seek out and speak with members of the Hawaiian community who have generational ties to Mauna Kea prior to undertaking any new projects. Then take their beliefs, practices, feelings, and recommendations into account in reaching management decisions.

3.1.2.4 Cultural Environment

Historic Properties. Historic properties that are located in the vicinity of the project area include a national historic landmark, an historic district, archaeological sites, historic buildings, and traditional cultural properties.

The proposed location for construction of the Outrigger Telescopes lies within the cluster of three cinder cones that form the summit of Mauna Kea. On the basis of archival documentary studies undertaken between 1979 and 1999, the State archaeologists at the SHPD have concluded this cluster of cones is an historic property that probably bore the name Kūkahauʻula (SHPD 1999). This single landscape feature is now called Puʻu Hauʻoki, Puʻu Kea, and Puʻu Wēkiu. Their conclusion is based on evidence that at least a part of the summit cluster was named for Kūkahauʻula, a figure who appears in legends about Mauna Kea as an ʻaumakua (family deity) of fishermen (Maly 1998; Maly 1999). The names Kūkahauʻula, Līlīnoe, and Waiau appear on an 1884 map of the region. In addition, Kūkahauʻula is given as the name of the highest peak in 1873. A detailed description of historically recorded names for the summit cluster is provided in the historic preservation plan for Mauna Kea (UH 2000b). NASA, in consultation with the SHPD, has agreed that this cluster of cones satisfies the criteria to be eligible for listing as an historic property in the National Register of Historic Places. This property is also discussed below under Traditional Cultural Properties.

National Historic Landmark. The Mauna Kea Adze Quarry is listed as a National Historic Landmark by the National Park Service under National Register No. 66000285. It was designated as a landmark in December 1962 as the largest pre-industrial quarry in the world, used by Hawaiians before Contact to obtain basalt for stone artifacts. The quarry complex was recognized as containing religious shrines, trails, rockshelters, and petroglyphs. Little research had been conducted at the quarry at the time of its designation and no boundaries were established for the landmark. Bishop Museum research under the direction of Patrick McCoy in 1975 and 1976 identified over 300 archaeological localities within the quarry, established dates for its use, defined the extent of the area in which evidence of pre-Contact quarrying was conducted, and investigated methods of stone procurement used at the quarry.

Proposed National Historic District. The SHPD has stated that it intends to propose the summit region of Mauna Kea for inclusion in the National Register of Historic Places as an historic district, because "it encompasses a sufficient concentration of historic properties (*i.e.,* shrines, burials and culturally significant landscape features) that are historically, culturally, and visually linked within the context of their setting and environment" (SHPD 1999). NASA agrees that the summit region meets the criteria for eligibility for inclusion in the National Register of Historic Places.

Pu'u Hau'oki is a culturally significant landscape feature within the district. The boundaries of the district are recommended to coincide with the "extent of the glacial moraines and the crest of the relatively pronounced change in slope that creates the impression of a summit plateau surrounding the cinder cones at or near the summit (*i.e.*, generally above the 3,536 to 3,658-m (11,600 to 12,000-ft) contour)" (SHPD 1999). The historic district thus encompasses all but a tiny portion of the Science Reserve, but also extends slightly downslope to include additional land on all sides of the mountain and particularly to include the area around Lake Waiau and the primary quarry and workshop area of the Mauna Kea Adze Quarry. The district includes 101 known archaeological sites or site complexes (93 within the Science Reserve), at least three traditional cultural properties, and a number of additional landscape features that may qualify as traditional cultural properties.

Archaeological Sites. No individual archaeological sites have been identified within the proposed project area on Pu'u Hau'oki. Surveys to date have identified 93 archaeological sites within MKSR. Seventy-six of the sites are shrines, four are adze-manufacturing workshops with shrines, and three are stone piles that served as markers. One burial site and four possible burial sites (marked by cairns) have also been identified outside the proposed project area, but within MKSR. Five sites are of unknown function (McCoy 1999).

Sites identified within MKSR fall into four categories.

<u>Shrines</u>. Shrines in MKSR are located on ridgetops or at breaks in the slope on the northern slopes near 3,962 m (13,000 ft), and on the eastern and southern slopes near 3,840 to 3.901 m (12,600 to 12,800 ft). Shrines consist of a single stone upright or a group of uprights, some with associated stone pavements or prepared courts. Shrines have not been found on the tops of cinder cones (McCoy 1999).

<u>Adze Quarrying and Manufacturing Workshops</u>. Although most of the sites associated with the Keanakāko'i quarry are located within the Mauna Kea Ice Age Natural Area Reserve, four adze manufacturing workshops have been found within MKSR. Each workshop also has one or more shrines (McCoy 1999).

<u>Burials</u>. Within MKSR, one burial site has been identified on the summit of Pu'u Mākanaka (McCoy 1999). Four other possible burial sites also have been noted: one on the rim of Pu'u Līlīnoe, and three on the rim of an unnamed cinder cone (McCoy 1999). In addition, oral histories refer to burials on the northern and eastern slopes of Mauna Kea (Maly 1999).

<u>Markers</u>. There are three stone mounds (two cairns and an informal pile of stones) distinct in style from the burial cairns, which appear to be survey markers or markers left by unknown visitors (McCoy 1999).

The Mauna Kea Ice Age Natural Area Reserve (NAR) to the south of the Science Reserve includes a trail, the Mauna Kea-Humu'ula Trail, and two major site complexes: Waiau (Site 21440) and the Mauna Kea Adze Quarry (Site 4136). The Waiau complex includes a number of shrines and rockshelters, including one with petroglyphs, on the slopes around the glacial lake. The Adze Quarry complex includes features associated with procurement of basalt for tool manufacture, stone workshop localities, by-product concentrations (mounds of flake debitage and concentrations of waste flakes, adze rejects, cores, and discarded hammerstones), shrines, and rock overhangs used as shelters.

Hale Pōhaku includes several shrines and scatters of stone artifacts within its boundaries and near the edges of the property.

Architectural Resources. No historic architectural resources have been identified within MKSR (PHRI 1999). The stone cabins at the Hale Pōhaku, south of the Science Reserve, are more than 50 years old and the SHPD considers these two buildings to be historic properties (SHPD 2001).

Traditional Cultural Places. Documentary archival research and oral history interviews with *kupuna* familiar with the mountain and cultural practitioners have identified several traditional cultural places that may be eligible for the NRHP on Mauna Kea. At one level the entire mountain is a traditional cultural property, but there are also particular landscape features on the mountain that hold individual traditional importance within Hawaiian culture. The oral history research conducted by Maly documents the association of these places with the practices and beliefs of the living Native Hawaiian community and how they are important in maintaining the continuing cultural identity of the community, while the archival research, as well as the oral interviews, documents how they are rooted in its history. The three places that have been identified by the SHPD as traditional cultural properties are:

Kūkahau'ula summit cones (Site 21438). These cones (including Pu'u Hau'oki) are considered eligible for the NRHP because of their association in Native Hawaiian mythology with Wākea, the sky god and ancestor of the Hawaiian people, and with Kūkahau'ula, a male deity, who has been identified as a form of the god Kū and the lover of Poli'ahu. Kūkahau'ula is also identified in Hawaiian traditional histories and genealogies as a chief, an 'aumakua (family deity) of fishermen, and the husband of Līlīnoe. The summit is thus associated with the activities of Hawaiian deities, and appears as the focal point in numerous legends and oral histories. These cones are also critical landscape elements in maintaining the integrity of Mauna Kea.

Pu'u Līlīnoe (Site 21439). This summit plateau cone to the southeast of Kūkahau'ula is considered eligible for the NRHP because of its association with Līlīnoe, sister of Poli'ahu, and goddess of mist, who manifests herself at this location. Līlīnoe is also identified in traditional histories as a chieftess, who secluded herself on Mauna Kea and was buried in a cave near the summit. She is believed to be an ancestress of some Hawaiian people living today. This cone is also associated with Queen Emma's journey of spiritual and physical cleansing to Mauna Kea in about 1881. A *heiau* or possible burial platform is reported to have formerly been present near this cone.

Waiau (Site 21440). This property, covering the glacial lake, Waiau, and the slopes around it, southwest of Kūkahau'ula, is considered eligible for the NRHP because of the association of the sacred waters of the lake with the god Kāne. Its waters are also associated with the lake goddess, Waiau, the sister or ward of Poli'ahu and Līlīnoe, who manifests herself here or directly with Poli'ahu as her spring. The water is also associated with events important in the broad patterns of Hawaiian culture; in particular as a source of sacred water used for ceremonial and healing practices. Waiau is also the repository of the *piko* (umbilical cord) of newborn children of some families.

Other traditional places identified by Maly that may qualify include:

Pu'u Poli'ahu. This summit plateau cone to the west of Kūkahau'ula might be eligible for the NRHP because of its association with the white snow goddess, Poli'ahu, sister of Līlīnoe. However the association of the cone with the goddess is not noted on any maps prior to 1892 and thus the SHPD concludes that this may be a post-Contact designation and not a traditional Native Hawaiian attribution.

Pu'u Mākanaka and *Kaupō*. These two prominent cones at the northeast edge of the summit plateau are particularly noted as traditional burial sites.

Kūka'iau-'Umikoa Trail. This historical foot and horse trail, connecting the main populated area of Hāmākua with Waiau on the south side of the summit, was used as a route to the summit from the north side of the mountain.

Mauna Kea-Humu'ula Trail. An historical foot and horse trail, connecting from the Humu'ula Sheep Station in the Saddle with the mountain summit through the adze quarry and past Waiau, was used as the major access route to the summit from the south.

Cultural Values/Traditional Cultural Practices/Contemporary Religious and Cultural Practices. Cultural values and traditional cultural practices include intangible resources that are important to a culture. Contemporary cultural practices relate to current beliefs or practices. Traditional cultural practices on Mauna Kea are associated with resource locations (*e.g.*, stone, water, hunting), trails, individual topographic features, burial locations, and cultural landscapes. A number of contemporary cultural practices have been identified. These include prayer and ritual observances, including the construction of new altars and subsistence and recreational hunting (Maly 1998). The spiritual and cultural significance of Mauna Kea is described in detail in Maly (1998) and Maly (1999) as follows.

Stone. Use of the Mauna Kea adze quarry complex (Keanakāko'i) was ongoing through the early 1800s until stone tools were replaced by metal tools. When local residents traveled to Mauna Kea in the 1930s and 1940s with their elders, the quarries were pointed out as one of the significant cultural features of the mountain.

Water. The water of Waiau, in the Mauna Kea Ice Age Natural Area Reserve, has been associated with the god Kane and is considered important to the on-going practices of native healers and practitioners. Some families have been reported as taking the *piko* (umbilical cords) of their children to Lake Waiau.

Trails. Oral historical evidence describes the use of trails, often by horseback, on Mauna Kea in the late 19th and early 20th century. Trails ascended Mauna Kea from most of the *ahupua'a* on its slopes. Many of the trails converged at Waiau. Interviews indicate that local elders traveled to Mauna Kea to worship in the summit region, to collect water from Waiau for healing, to procure stone for tool making, and to take cremated human remains to the summit or to Waiau.

Topographic Features. A number of topographic features on Mauna Kea have cultural significance. Pu'u Kūkahau'ula (Pu'u Wēkiu, the summit peak of Mauna Kea) is identified as a repository of *piko* (umbilical cords) and of cremated remains, and is associated with navigational practices and historical surveys. Puʻu Poliʻahu and Puʻu Līlīnoe are associated with Hawaiian goddesses considered to be ancestral to some Native Hawaiian local inhabitants.

Burials. Oral histories describe burial sites in cinder cones and other natural features from about 2,134 to 3,658 m (7,000 to 12,000 ft) on Mauna Kea. Puʻu Mākanaka and the Kaupō vicinity are particularly noted as burial sites. In addition, modern use of the summit for the release of cremated remains has been reported in oral histories. While cremation of remains is not a traditional Hawaiian practice, taking a loved one's remains to a special landscape is an ancient Hawaiian custom that has adapted to allow for its continuation into modern times.

Landscapes. Mauna Kea continues to be viewed as a place with spiritual and healing qualities. The summit of Mauna Kea has been referred to as *wao akua* (a region or zone of deities). It is so named because of the cloud cover, which concealed from view the activities of the deities when they walked upon the land. It is the focal point of numerous traditional and historical Hawaiian practices and narratives. In earlier times, the area above the forest line was considered so sacred that one could not be pursued by enemies there. Some of the names for the mountain landscape are associated with Hawaiian gods, while others describe natural features and resources. The mountain region of Mauna Kea from about the 1,829-m (6,000-ft) elevation to the summit is considered a sacred landscape by some Native Hawaiians. Mauna Kea also has been described as the *piko* or origin point for the island of Hawaiʻi. According to Kanahele and Kanahele (1997), the three *puʻu* are named for three sister goddesses of water: Poliʻahu (snow); Līlīnoe (mist); and Waiau (lake). Poliʻahu and Līlīnoe are located within MKSR.

Navigational Traditions. Although the archival and historical literature does not refer to the features of Mauna Kea as being associated with navigational traditions, the deities associated with the mountain have celestial body forms and some were invoked for navigational practices. Celestial observations were made from Mauna Kea or utilized alignments with prominent features on Mauna Kea.

3.1.2.5 Religious Practices

In Native Hawaiian society, cultural and religious practices and observances are inseparably intertwined; the good favor of the gods (*na akua*) is sought before every endeavor, from the very mundane tasks to the most fearsome ventures. *Na akua* were believed to dwell in earthly forms such as the *puʻu* on Mauna Kea and the waters spouting from the earth or running in the streams. Additionally, Native Hawaiians deified their family ancestors as *na ʻaumakua*. *Na ʻaumakua* took the form of animals such as sharks, owls, hawks, and many others, who were also asked to support and assist in the coming effort. Traditionally, every undertaking of Native Hawaiians, from planting taro to waging war, was permeated with the devout worship of the formal deities and the *ʻaumakua*.

Native Hawaiians also delineated the inland areas of the islands according to the right, or restriction, of access by the *makaʻainana*, or commoner, and the presence of the deities. Thus, *wao kanaka* is an inland area of lower elevation where the *makaʻainana* can inhabit or move about freely. *Wao kele* is the upland forested area into which the *makaʻainana* can enter for the purpose of gathering materials for their daily lives. Above the *wao kele* is the *wao akua*, also called the *wao ke akua*, which is believed to be inhabited by *na akua*; here, the *maka'ainana* hesitated to enter, and only did so with prayer and great respect. The *wao akua is* generally the desert region above the tree line or *wao kele*, and is believed to be inhabited by *na akua*; hence, the name. Some cultural practitioners believe that only persons of the ʻaliʻi (chiefly) class and the highest priests or *kahuna nui* were permitted to enter the *wao akua*. An area inhabited by *na akua* may also be called *po*. The summit of Mauna Kea from about the 2,804 m (9,000 ft) level is considered *wao akua*, a sacred region, with *kapu*, or restrictions in what may be done on the land.

The presence of shrines and monuments in the summit region of Mauna Kea indicates that certain religious observances or worship services were conducted there. However, there is, of course, no written record or descriptions of those ceremonies, and with the advent of Christianity as the overriding religious influence in Native Hawaiian society virtually all knowledge of the nature of such observances has been lost. Persons knowledgeable about Native Hawaiian culture and practice have expressed to NASA their belief that no credible knowledge exists today about the particular observances traditionally practiced on Mauna Kea.

NASA was able to consult with a number of contemporary religious practitioners who continue to pay homage to the deities enshrined in their earthly forms on Mauna Kea and to the *'uhane* or spirits of their ancestors whom they believe also reside or visit the sacred grounds (see Table 3-2). Those contemporary practitioners consider themselves as *na koa*, or warriors, whose enduring task is to protect the mountain from unwarranted intrusion, particularly under the present circumstances. They ardently believe that Mauna Kea is inhabited by *akua* or *'uhane* and that the development on the summit is an invasion by ordinary man into the sacred realm. The practitioners find that the presence of the observatory domes on the summit, and the noise emanating from them and created by the vehicular traffic, is destructive of the silence and spiritual ambience that is necessary to their proper religious observances. Additionally, the domes obscure their view of certain stars, thus interfering with the practitioners' proper alignment with them for worship, and preventing an unobstructed 360-degree view of the summit region and the neighboring mountains.

Each *pu'u*, at the summit and at the lower elevations, has a cultural and spiritual significance; most are named for the *akua*, whose forms are represented by the *pu'u*, stars, and other formations of nature. Moreover, they do not stand alone; they each have a relationship to the other *pu'u* that is meaningful to the practioners. By orienting their worship with the alignment of the *pu'u* the practitioners are able to determine whether they are in a spot that is propitious for worshipping *na akua* and seeking their assistance. The presence of the observatory domes, and the removal of the top of Puʻu o Kukahauʻula (recently named Puʻu Wekiu) interferes with the practitioners' ability to achieve that correct orientation.

In spite of the evidence to the contrary, the practitioners believe that the effluent from the observatories does in fact enter the aquifer and has caused the green coloration of Lake Waiau's water. This coloration interferes with their ability to see the reflection of the stars on the water and is disruptive of their religious observances.

The practitioners, and many other families in the community, continue to carry the umbilical cords (*piko*) of their newborn children to the summit for concealment.

TABLE 3-2. SOURCES OF INFORMATION ON NATIVE HAWAIIAN RELIGIOUS PRACTICES

Date	Information Source
January through February 2004	EIS Scoping comments received at five Public Scoping Meetings and in writing
February 20, 2004	Interview with Libert Landgraf conducted for NASA by Maria Orr
March 14, 2004	Telephone interview with Charlie Wakida conducted for NASA by Maria Orr
April 4, 2004	Interview with Kealoha Pisciotta conducted for NASA by Maria Orr
August through September 2004	Public comments on the Draft EIS received at six Public Meetings and in writing
November 15, 2004	Interview with Kimo Pihana conducted for NASA by Walter Heen
November 22, 2004	Interview with Koa Ell conducted for NASA by Walter Heen
November 26, 2004	Interview with Malia Craver conducted for NASA by Walter Heen
December 5, 2004	Interview with Hanalei Fergerstrom, Keoni Choy, Auntie Eleanor Ahuna, and Kalei Victor conducted for NASA by Walter Heen. Lanny Sinkin was also present.
January 2004 to present	Information gathered by Maria Orr during the development of the EIS
1996 to present	Information gathered by Kepā Maly (*Kumu Pono Associates*) in cultural-historical documentation and oral history interviews.

This is a deeply spiritual activity, and the *piko* may be concealed anywhere on the summit. The location of the *piko* is known only to the families, who mark the site by the alignment of physical features, including the *pu'u* and other geographic characteristics, as well as the stars. Thus, the ability to achieve orientation through the alignment of the *pu'u* is critical. In keeping with this tradition, each family considers itself as caretaker of a sector on the mountain in the vicinity of the *piko* location.

Many families erect family shrines (*'ahu*) and others visit the adze quarry to engage in their cultural and religious rituals.

The practitioners consider their observances as being in place of those ceremonies lost in antiquity. They are "adaptations" of present day practices to allow them to worship *na akua* and *na 'aumakua* in proper fashion and with proper reverence. One of those adaptations is the spiritual observance of the winter solstice begun in 1998. The practitioners interviewed deemed it proper, as part of the protest against the development on the summit, to observe the solstice, much as they believe their ancestors observed the passage of the seasons. The event is observed by gathering at Pu'u Huluhulu at a lower elevation of the mountain and proceeding on foot up to the summit with chants and prayers. During that first observance the practitioners erected a *lele* or altar on the summit. NASA understands that this action in the realm that these practitioners deem sacred was a mark of protest.

The practitioners assert that the cumulative impact assessment must include consideration of the developments' impact on the whole mountain, "from the bottom up," not merely the impact on the top.

These practitioners stress that their right to access the mountain is of fundamental importance. It is an absolute requirement for their cultural and religious observances. Although they know of no denials of access at the present time, they are fearful that such will come in the future. Even now, they are concerned about a partial limitation: groups numbering more than eight, including groups of Native Hawaiians, are required to obtain a permit before going up to the summit. [Note: This appears to refer to a policy of the NARS Commission of the DLNR. This policy applies only to the Natural Area Reserve on Mauna Kea, not to the Mauna Kea Science Reserve in which the observatories are located.]

3.1.3 Biological Resources and Threatened and Endangered Species

For the convenience of the reader, and only to facilitate this discussion, Mauna Kea has been divided into four areas based upon elevation:

- At the highest elevations of the mountain is the area defined as the "*Summit Area Cinder Cones*" consisting of Pu'u Wēkiu, Pu'u Kea, and Pu'u Hau'oki—the location of the W.M. Keck Observatory site and the proposed Outrigger Telescopes Project. The "*Summit Area Cinder Cones"* extends from the true summit of the mountain on Pu'u Wēkiu at about elevation 4,205 m (13,796 ft) down to approximately elevation 4,084 m (13,400 ft).
- Next is the area immediately below the summit defined as the "*Area Below the Summit Area Cinder Cones*" beginning at the base of the summit cinder cones, at about elevation 4,084 m (13,400 ft) and extending down to about elevation 3,566 m (11,700 ft) the lower known limit of Wēkiu bug habitat (Englund and Others 2002).
- Below this area is the "*Silversword/Alpine Shrub Zone*", extending from about elevation 3,566 m (11,700 ft) down to about 2,804 m (9,200 ft).
- The lowest area of the mountain for the purposes of this discussion is the "*Māmane Subalpine Forest Zone*", extending from about elevation 2,804 m (9,200 ft) to Saddle Road at about elevation 2,005 m (6,578 ft).

3.1.3.1 Biological Resources of the Summit Area Cinder Cones

The summit of Mauna Kea reaches an altitude of 4,205 m (13,796 ft). The *Summit Area Cinder Cones* encompassing an area of approximately 184 ha (452 ac), consists of three cinder cones, Pu'u Hau'oki, Pu'u Wēkiu, and Pu'u Kea. This landscape feature is also known as Kūkahau'ula (Maly 1998; Maly 1999). The W.M. Keck Observatory site, the proposed location of the Outrigger Telescopes, is on Pu'u Hau'oki at an approximate elevation of 4,146 m (13,603 ft).

The summit area receives almost no rainfall. Most precipitation falls as snow that sometimes accumulates on the *Summit Area Cinder Cones*. Temperatures often drop below freezing at night and reach up to 10º Celsius (C) (50º Fahrenheit (F)) during the day. Solar radiation is extreme, and evaporation rates are high. The *Summit Area Cinder Cones* are characterized by harsh environmental conditions that limit the composition of the resident floral and faunal communities found there.

No floral species have been found within the area defined as *Summit Area Cinder Cones*. Plants have been found only below this area of the mountain. The extreme temperatures and very dry conditions of the cinder cones, including limited precipitation, porous cinder substrates, and high winds, have apparently prevented establishment of even very hardy plants. Lichens occur in low abundance on the *Summit Area Cinder Cones*, and only the most common lichen species occur there (Smith and Others 1982). The principal lichen habitats are in the blocky *ʻaʻa* flows in the area defined as *Below the Summit Area Cinder Cones* (Smith and Others 1982; Char 1990).

The only resident animal species found on the *Summit Area Cinder Cones* are arthropods. The loose packing of the cinder makes numerous spaces that provide shelter for resident arthropods from adverse weather conditions, intense solar radiation, freezing temperatures, and predators. Daily upslope winds carry insects, spores, seeds, and organic debris to the summit from surrounding forests. This aeolian (windborne) debris collects in the lee of summit cones and is a major food source of the resident arthropods. The resident arthropods have evolved distinctive adaptations in order to exploit the resources and live in this habitat (Howarth and Montgomery 1980).

Eleven species indigenous to Hawaiʻi are thought to be residents within the *Summit Area Cinder Cones*: Wēkiu bugs (*Nysius wekiuicola*), lycosid spiders (*Lycosa* sp.), sheetweb spiders (*Erigone* sp. A1 and B1), another sheetweb spider (Family Linyphiidae: species unknown), a mite (Family Anystidae: species unknown), another mite (Family Eupodidae: species unknown), springtails (Family Entomobryidae: 2 unknown species), another springtail (Class Collembola, family and species unknown), and a centipede (*Lithobius* sp.). An additional five species not indigenous to Hawaiʻi are thought to be residents of the *Summit Area Cinder Cones* (Howarth and Stone 1982; Howarth and Others 1999).

One of the arthropods found on Mauna Kea above 3,566 m (11,700 ft), the Wēkiu bug (Nysius wekiuicola), is a candidate for listing under the Endangered Species Act (see Figure 3-2). First collected in 1923, almost 60 years passed before it was recognized as a unique species (Ashlock and Gagne 1983). The Wēkiu bug is a "true bug" of the order Heteroptera. Wēkiu is the Hawaiian word for top or summit (Pukui and Elbert 1971).

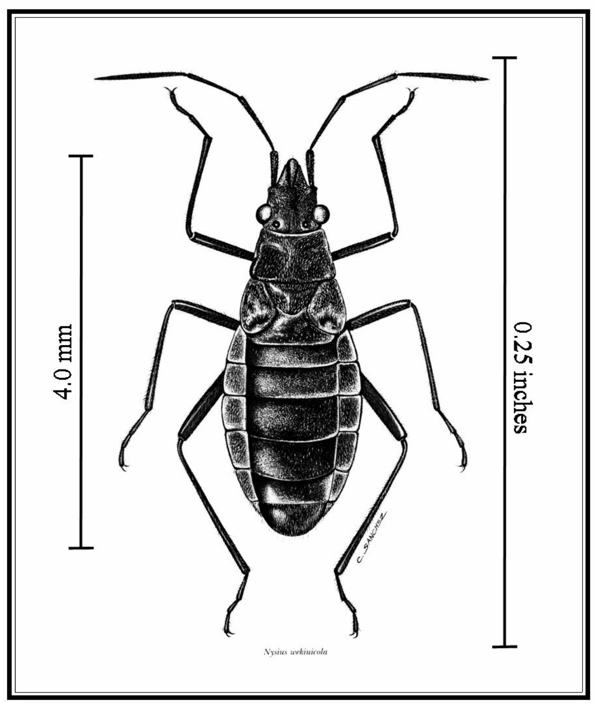


FIGURE 3-2. WĒKIU BUG
Source: Wēkiu bug drawn by Mr. C. Sanchez of the University of the Philippines College of Science and Humanities.

This small insect, 3.5 to 5 millimeters (mm) (0.14 to 0.20 in) long, has made a remarkable adaptation in feeding behavior. Many true bugs, including most of those found elsewhere in Hawaiʻi, are herbivores and feed on seeds and plant juices. The Wēkiu bug is a scavenger. It has presumably made this evolutionary adaptation because of the lack of suitable plants at the summit. Wēkiu bugs use their straw-like mouthparts to feed on wind-carried insects blown up the mountain from the surrounding lowlands. These aeolian insects accumulate in protected pockets on the high-elevation cinder cones, and unlike Wēkiu bugs, are not adapted to the cold temperatures at the summit. Aeolian insects quickly become moribund in the cold and are thus easy prey for foraging Wēkiu bugs.

Wēkiu bugs have been assessed twice, first in 1982 and again in 1997/98. Both of these assessments used pitfall traps for sampling. Pitfall traps measure activity of insects, not the size or density of their populations. For many insect species, the percentage of the population that is active under similar environmental conditions is roughly constant over time, and therefore changes in trap capture rates reflect changes in population size or density (Southwood 1978). More precise measures of the Wēkiu bug population size or density would require destructive sampling of the habitat and have not yet been attempted because of concerns that destructive habitat sampling may disturb remaining populations.

The 1982 assessment employed traps that resulted in the mortality of collected Wēkiu bugs (Howarth and Stone 1982). In 1997, three live trap designs were evaluated for survivability of captured Wēkiu bugs, effectiveness in capturing, and comparability to traps used in 1982. A modified trap that included shrimp bait, cinder habitat, and a small water reservoir was selected for the 1997/98 assessment. While different trapping methods were used during the two assessments, the results may be compared (Howarth and Others 1999).

In the 1982 assessment, Wēkiu bugs were found to be abundant on the summit cones and lava flows to the north down to an elevation of about 3,900-m (12,800-ft) below the *Summit Area Cinder Cones* (Howarth and Stone 1982). In the 1997/98 assessment, Wēkiu bugs were found in low abundance on summit cinder cones and only rarely outside of the *Summit Area Cinder Cones* on Puʻu Māhoe and Puʻu Mākanaka (Howarth and Others 1999). Although the lower elevations of the 1982 range were sampled, no Wēkiu bugs were found below the 4,084 m (13,400 ft) elevation of the summit area in 1997/98 (Howarth and Others 1999).

In 1982, Howarth and Stone mapped about 232 ha (573 ac) of Wēkiu bug habitat above 3,900 m (12,800 ft) elevation including some habitat below the *Summit Area Cinder Cones*. It is very likely that Wēkiu bugs occurred elsewhere above 3,900 m (12,800 ft) elevation in unsampled areas. The 1997/98 total habitat is estimated to have been about 120 ha (300 ac), the area of the MKSR above about 4,084 m (13,400 ft). After sampling in 1997/98, the scientists conducting the assessment concluded that Wēkiu bug activity apparently experienced a 99.7 percent decline in comparable areas surveyed in both 1982 and 1997/98 (Howarth and Others 1999). The decline was evident in both (1) habitat disturbed by observatory construction, (2) areas some distance from astronomy development, and (3) areas relatively undisturbed by construction. The 1997/98 trapping data indicated that Wēkiu bugs occurred in greater numbers in previously disturbed areas where habitat appears to have recovered. No Wēkiu bugs were found on roads or graded areas near observatory buildings. The apparent causes of the Wēkiu bug decline between 1982 and 1997/98 are not known. Hypotheses include climate change, a possible long-term downward trend in winter snowpack depth and persistence, destructive population sampling, introduction of predatory alien arthropods, mechanical habitat disturbance from observatory construction, recreational impacts, vehicle impacts, long-term population cycles, and the possible presence of environmental contaminants from human activities. The most likely cause would probably be a combination of some or all of the above factors.

More recent, limited studies have found Wēkiu bug activity returning to higher levels on some summit cinder cones (Polhemus 2001; Pacific Analytics, LLC 2002a - 2003d). A survey on Puʻu Haukea (Polhemus 2001), recorded an average Wēkiu bug trap capture rate of 47.3 bugs/trap/3-days (a standard measurement established by Howarth and Others 1999). In February 2002, Wēkiu bug monitoring began quarterly on Puʻu Hauʻoki and Puʻu Wēkiu. During the 2nd quarter 2003 monitoring session, Wēkiu bug trap capture rates averaged 90.6 bugs/trap/3-days on Puʻu Hauʻoki (Pacific Analytics, LLC 2003b). This is generally equivalent to the 105.6 bugs/trap/3-days recorded in 1982 on Puʻu Hauʻoki (Howarth and Stone 1982) and much greater than the 0.2 bugs/trap/3-days recorded during a comparable period in 1997. On Puʻu Wēkiu the 2nd quarter 2003 average trap capture rate was 11.5 bugs/trap/3-days, about a fourth of the 1982 average trap capture rate of 40.77 bugs/trap/3-days. No Wēkiu bugs were captured on Puʻu Wēkiu in a comparable sampling period during 1997/98 study. Increasing trap capture rates measured during quarterly Baseline Monitoring indicate that Wēkiu bug populations appear to have increased in sampled areas since 1998 (Pacific Analytics, LLC 2002a - 2003b).

The known range of the Wēkiu bug has expanded since 1982. During a 2002 study (Englund and Others 2002) designed to reevaluate the range of Wēkiu bug habitat, Wēkiu bugs were found on several cinder cones outside the *Summit Area Cinder Cones* (see Figure 3-3). Wēkiu bugs were found on Puʻu Mākanaka, Puʻu Poepoe, Puʻu Haukea, Puʻu Ala, and near the VLBA observatory at 3,572 m (11,715 ft), the lowest elevation Wēkiu bugs have ever been collected. The scientists in that study concluded that the "elevational distribution on Mauna Kea is considerably wider than previously reported" (Englund and Others 2002). Wēkiu bug trap capture rates near the lower extent of the habitat range are low, and evidence suggests that Wēkiu bugs prefer habitat on the *Summit Area Cinder Cones*.

Entomologists have speculated about whether Wēkiu bug populations have increased, decreased, or remained stable. However, all have agreed that habitat protection and minimizing disturbance is a desirable goal (Howarth and Stone 1982; Howarth and Others 1999; Polhemus 2001; Englund and Others 2002).

3.1.3.2 Biological Resources of the Area Below the Summit Area Cinder Cones

The *Area Below the Summit Area Cinder Cones* is surrounded by glacial till and blocky *ʻaʻa* flows eroded by ancient glaciers (Wolfe and Others 1997). Several cinder cones are located in this area including Puʻu Haukea, Puʻu Waiau, Puʻu Līlīnoe, Puʻu Poliʻahu, Puʻu Pōhaku, Puʻu Māhoe, Puʻu Ala, Puʻu Poepoe, Puʻu Mākanaka, and Puʻu Hoaka. Lake Waiau is also located in this

Kilauea crater, and colonies are suspected along the Mauna Loa summit trail, and on Mauna Kea above 3,002 m (9,850 ft) near Pu*ʻ*u Kanakaleonui (Harrison 1990; Day and Others 2003). Skeletal material indicates that *ʻUaʻu* may have been present at elevations up to 3,780 m (12,400 ft) on Mauna Kea (Kjargaard 1988). No *ʻuaʻu* were found above the 3,719 m (12,200 ft) elevation of MKSR during a May 1988 field survey conducted in conjunction with site surveys for locating the VLBA Antenna Facility. The Petrel survey was performed at night, during the height of the breeding season, at a period of the lunar cycle when calling is maximized (Kjargaard 1988). No evidence of petrel burrows has been found above 3,780 m (12,400 ft) on Mauna Kea (Kjargaard 1988).

The only fauna currently found in the *Area Below the Summit Area Cinder Cones* between 4,084 m (13,400 ft) and 3,566 m (11,700 ft) are arthropods. Of the eleven indigenous Hawaiian resident species found within the summit area of Mauna Kea, six of them have been found in the *Area Below the Summit Area Cinder Cones* (Howarth and Others 1999). The exceptions are two species of mites and two species of sheetweb spiders, found only on the *Summit Area Cinder Cones* (Howarth and Stone 1982; Howarth and Others 1999). Wēkiu bugs have been found as low as 3,572 m (11,715 ft) near the VLBA observatory (Englund and Others 2002). Wēkiu bugs have also been found on several cinder cones below the 4,084 m (13,400 ft) including Puʻu Māhoe, Puʻu Ala, Puʻu Poepoe, and Puʻu Mākanaka (Englund and Others 2002).

One other indigenous Hawaiian resident arthropod was found in this lower elevation area, but was not observed on the *Summit Area Cinder Cones* during the 1997/98 assessment. This is the summit moth (*Agrotis* sp.). It is not known whether other indigenous arthropods are resident in the *Area Below the Summit Cinder Cones*.

3.1.3.3 Biological Resources of the Silversword/Alpine Shrub Zone

The *Silversword/Alpine Shrub Zone*, 2,804 m to 3,566 m (9,200 to 11,700 ft) is predominantly *ʻaʻa* lava flows, cinder cones, and air-fall deposits of lapilli and ash (Wolfe and Others 1997). The upper reaches of the *Silversword/Alpine Shrub Zone* are home to the unique Hawaiian silverswords, *ʻahinahina*, (*Argyroxiphium sandwicense*). The Mauna Kea silversword is a Federally listed endangered species. An enclosure was built around the largest known population, about 30 plants near 2,850 m (9,350 ft) elevation above the Wailuku river basin. A single plant near the summit access road was recently enclosed with protective fencing. Silverswords are famous for their spectacular foliage and flowering spikes. Once so abundant that they were uprooted and rolled down cinder cones for sport, human vandalism and ungulate grazing have reduced silversword populations to dangerously low levels (Kimura and Nagata 1980).

Some vascular plants from lower elevations occur well above tree line, becoming sparser with increasing elevation (Cuddihy 1989). *Pūkiawe* (*Styphelia tameiameiae*)*, nohoanu* (*Geranium cuneatum ssp. hololeucum*)*,* and *ʻohelo* (*Vaccinium reticulatum*) are the most abundant plants above tree line, but various other shrubs, grasses, sedges, and ferns occur frequently (Ibid). Many of the shrubs have small, silvery leaves, or are covered with fine hairs as adaptations to the dry conditions, intense UV radiation, and low nighttime temperatures. The alpine plant community is almost entirely comprised of native species (Wagner and Others 1990).

Lichens and bryophytes may also occur in this zone, but systematic surveys have not been conducted. These species may occur in partially shaded small caves, crevices, or under large rock overhangs.

The fauna of the *Silversword/Alpine Shrub Zone* has not been well studied. Many species of birds have been observed flying in this zone, but because the principal food resources do not occur here, they are presumably just passing through. There may be resident arthropod species in this zone, but no systematic survey has been conducted.

3.1.3.4 Biological Resources of the Māmane Subalpine Forest Zone

The *Māmane Subalpine Forest Zone* extends from Saddle Road to about 2,804 m (9,200 ft). The soil is similar to that of the *Silversword/Alpine Shrub Zone*, consisting predominantly of *ʻaʻa* lava flows, cinder cones, and air-fall deposits of lapilli and ash (Wolfe and Others 1997). There are also postglacial stream sediments, largely gravelly sand with a variable composition that reflects local bedrock (UH 1983a). There are no permanent streams within the area, although gulches do fill with water during periods of heavy rainfall (UH 1983a).

A subalpine dry forest is found below the lower boundary of MKSR (Char 1999). The open-canopied forest comprises predominantly *māmane* trees (*Sophora chrysophylla*), and is home to the endangered bird, *palila* (*Loxiodes bailleui*) (Pratt and Others 1987; Scott and Others 1986). *Māmane* trees also act to intercept fog that provides them and other species nearby with the small amounts of moisture they need to survive (Gerrish 1979) (see Figure 3-4). *Māmane* wood is hard and heavy, and was used by early Hawaiians for *oʻo* (digging sticks) and posts in their houses (Kepler 1984). Below 2,377 m (7,800 ft), *naio* (*Myoporum sandwicense*) is co-dominant with *māmane*, with occasional scattered stands of *akoko* (*Euphorbia olowaluana*) and individual *ʻiliahi* (*Santalum paniculatum*) trees in very low abundance (Van Riper 1975; Wagner and Others 1990). *Naio* was also used for house framing (Krauss 1993), and its fruits are eaten by *palila* (Scott and Others 1986). *ʻIliahi* (sandalwood) was traditionally used to scent tapa cloth and coconut oil (Kepler 1984; Krauss 1993).

Photo courtesy of Pacific Analytics, LLC, 2004.

FIGURE 3-4. MĀMANE TREE

The understory of the *Māmane Subalpine Forest Zone* comprises largely native shrubs. *ʻAweoweo,* also called *ʻaheahea,* (*Chenopodium oahuense*) is found occasionally among the more abundant *pūkiawe* (*Styphelia tameiameiae*), a plant used in native Hawaiian ceremonies and in *lei*s (Krauss 1993), and *ʻaʻaliʻi* (*Dodonaea viscose*), a host plant of the colorful koa bug (*Coleotrichus blackburniae*). Less abundant are *naʻenaʻe* (*Dubautia ciliolata*) and an attractive woody geranium, *nohoanu* (*Gernium cuneatum*), found in more rocky areas of the forest. Two native mints, *Stenogyne microphylla* and *maʻohiʻohi* (*Stenogyne rugosa*), are fairly common, growing in dense tangles in *māmane* trees (Wagner and Others 1990).

Clumps of the native grasses *pili uka* (*Trisetum glomeratum*) and hairgrass (*Deschampsia nubigena*) are the most abundant ground cover. Early Hawaiians used *pili* for thatching their houses (Krauss 1993). Several introduced grasses and herbs have become established at low densities (Char 1999).

The *māmane* forest is made up of only about 20 plant species. The paucity of species is due to the harsh conditions found there (Char 1999). Annual rainfall averages 76 to 102 centimeter (cm) (30 to 40 in) and most precipitation falls during the winter. The thin soils are composed primarily of weathered lava and ash, and hold little moisture. Plants must collect water from low-lying clouds and fog to survive the hot, dry summers. The average annual temperature is 4.4° to 10° C (40° to 50° F), and frost is common at night.

At least three botanical surveys have been conducted at the Hale Pōhaku facilities at 2,804 m (9,200 ft) (Char 1985; Char 1999; Gerrish 1979). Except in a special area enclosing endangered silverswords, no threatened and endangered plant species or USFWS species of concern were found (Char 1999; USFWS 2002). Much of the *māmane* forest has been damaged by cattle grazing, feral animals, fire, alien species, and increased visitor traffic (Stone and Pratt 1994; Hess and Others 1999).

Cattle grazing has degraded much of the forest along the Mauna Kea Access Road. The vegetation of the open pastures is largely introduced grasses and forbs including orchid grass (*Dactylis glomerata*), Kentucky bluegrass (*Poa pratensis*), kikiyu (*Pennistum clandestinum*), mullein (*Verbascum thapsus*), sweet vernal (*Anthoxanthum odoratum*), wallaby grass (*Danthonia semiannularis*), velvet grass (*Holcus lanatus*), sheep sorrel (*Rumex acetosella*), and gosmore (*Hypochaeris radicata*) (Char 1985).

Several species of birds native to Hawai‘i are found in the *māmane* forest. Much of the forest below MKSR is designated critical habitat of the endangered finch, *palila* (*Loxiodes bailleui*). These Federally listed birds feed primarily on the green seeds and flowers of *māmane* trees, but also consume *Cydia* caterpillars that inhabit *māmane* seed pods (Hess and Others 1999). *Palila* occurred historically on west and southeast slopes of Mauna Loa, and on Mauna Kea. They presently occur only on the upper western slopes of Mauna Kea to 3,002 m (9,850 ft).

Other native birds that inhabit the *māmane* forest include the endangered *akiapola‘au* (*Hemignathus munroi*), and *i‘iwi* (*Vestiaria coccinea*). *Akiapola‘au* are rarely seen, and a small population survives in the Hakalau wildlife refuge above Hilo. *I‘iwi* were once one of the most abundant and widespread birds in Hawai‘i, but populations have declined since the 1940s (Scott and Others 1986).

The introduced Japanese white-eye (*Zosterops japonicus*) is the most abundant bird in the *māmane* forest, feeding on fruit, nectar, and insects (Scott and Others 1986). Several game birds have also been introduced to the forest, and are hunted seasonally.

The major threat to *palila* is the decline of the *māmane* forest, due primarily to grazing by ungulates. Since their introduction in 1793, sheep, mouflon, goats, and cattle have limited *māmane* regeneration (Hess and Others 1999). Federal court rulings in 1979 and 1986 mandated removal of feral ungulates to protect habitat and allow regeneration of the *māmane* forest. Most ungulates are now gone from the upper elevations (Stone 1989). Hunting was a popular sport, and the elimination of sheep from Mauna Kea is still the subject of local debate. After efforts to reduce sheep and mouflon populations the *māmane* forest is apparently recovering (Environmental Review 2002). *Palila* are further threatened by fire, predators (cats, rats and mongoose), disease, and depletion of native insect food by alien wasps and other insects.

At least 19 species of mammals can be found in Hawaiʻi. Polynesians brought domesticated pigs and dogs, and may have accidentally introduced rats to the islands. After initial contact by Europeans in 1778, other mammals were introduced to Hawaiʻi, including cattle, goats, European pigs, sheep, horses, and donkeys. Several of these species were botanically destructive; Hawaiian flora evolved in the absence of grazing pressure, and developed few protective chemical or physical structures. Other species, such as the black rat, have reduced populations of native birds and insects, as well as preying on seeds, seedlings, and shoots of native plants.

The endangered Hawaiian bat, *ʻōpeʻapeʻa* (*Lasiurus cinereus*) is the only native land mammal living in Hawaiʻi today. This federally listed bat roosts in trees, and feeds on a broad range of insects. *ʻŌpeʻapeʻa* are most abundant near water and in the lowlands, but have been recorded as high as 3,048 m (10,000 ft) flying over vegetation foraging for food. This endangered species has been seen in the *māmane* forest below MKSR, but is not thought to live above tree line, 2,804 m (9,200 ft), on Mauna Kea.

There are more than 6,000 native arthropod species in Hawaiʻi (Eldredge and Miller 1995). Many elements of this fauna are restricted to narrow geographical or ecological limits. For instance, forty percent of the canopy-associated arthropod species found in dry *ʻōhiʻa* forests on Mauna Loa occur only in dry forests (Gagne 1979).

More than 3000 species of invertebrates have been introduced into Hawaiʻi, largely over the last 200 years. These species have replaced native insects in low elevations, but native insects still make up a large proportion of the arthropod fauna above 1,829 m (6,000 ft). For example, sixty percent of the species collected from the crater region of Haleakala are endemic to Hawaiʻi (Beardsley 1980).

The *māmane* forest on Mauna Kea has a very diverse arthropod fauna. More than 200 arthropod species have been collected there, and more are found with every new study. The arthropod fauna includes several species of *Plagithmysus*, an endemic Hawaiian genus of wood-boring beetles that occurs only on native plants. Seven species of small native caterpillars (*Cydia* spp.) that live in *māmane* pods are important prey of the endangered *palila*. The beautiful Kamehameha butterfly (*Vanessa tameamea*), the proposed state insect of Hawaiʻi, can often be spotted flying over the canopy, and showy koa bugs (*Coleotichus blackburniae*) feed on seeds of the *ʻaʻaliʻi* (*Dodonaea viscose*). Most of these species can be found in *māmane* forest near Hale Pōhaku.

There are several threats to the survival of the native arthropod species found in the *māmane* forest on Mauna Kea. Grazing by ungulates has reduced the host-plant populations of many of these species to very low levels. Parasitoids, introduced to biologically control pests in agricultural areas have migrated up to this forest and have been implicated in the decline of the *Cydia* caterpillars (Brenner and Others 2002). Competition from alien species has pushed many native arthropod species to the brink of extinction (Gagne and Christensen 1985).

3.1.4 Hydrology, Water Quality, and Wastewater

3.1.4.1 Occurrence and Movement of Ephemeral Surface Water

Due to the low precipitation rates, the occurrence of ephemeral (short term or transitory) surface water at the summit is limited to winter storms and/or rapid snowmelts. These infrequent runoff occurrences have cut small channels and gullies that connect with larger gulches further down the mountain slope. On the north side of the summit, Puʻu Hauʻoki is nominally at the upper end of a drainage basin, which ultimately empties into Kuʻupahaʻa Gulch. However, based on the fact that there is no rill (small eroded pathway of water) erosion or other evidence of surface runoff down the slope of Puʻu Hauʻoki, it does not appear that any surface runoff from the W.M. Keck Observatory facility moves down the north side of the *puʻu.*

On the south side, Puʻu Hauʻoki is at the upper end of a drainage basin that empties into Pōhakuloa Gulch. Identifiable surface runoff pathways are depicted on Figure 3-5. None extend up the slope of Puʻu Hauʻoki or any of the other cinder cones at the summit. The permeability of the gravel and sand-sized particles, which cover these cinder cones, has prevented the movement of surface water across the areas cleared for the observatories or down the undisturbed slopes. The highest identifiable evidence of surface runoff begins in Submillimeter Valley directly to the south of Puʻu Hauʻoki.

3.1.4.2 Perennial Surface Water in Lake Waiau

Lake Waiau is a perennial body of perched water (groundwater that sits atop impermeable layer) in the crater of Puʻu Waiau, a cinder cone at 3,970 m (13,020 ft) elevation and 1.7 kilometers (km) (1.08 miles (mi)) south of W.M. Keck Observatory on Puʻu Hauʻoki. The topography of the crater limits the watershed contributing runoff to the lake to about 14.2 ha (35 ac). Some of the lake's more significant physical attributes are as follows:

- The lake's margin freezes at night and thaws during the day for most of the year.
- Depending on the time of year and prior weather, the lake often has a very high algae content. One of the earliest known observations recorded Lake Waiau to be green and slimy (Jarves 1840). One of the first published observations of its high standing crop of algae is in Gregory and Wentworth (1937).
- The lake is underlain by numerous sediment layers, which are more than 10-m (33-ft) thick at the center of the lake and taper to its sides.
- Carbon-14 dating of these sediments in Woodcock, Rubin, and Duce (1966) puts the age of the upper several meters in the thousands of years. By extrapolation, the bottom sediments may be more than 30,000 years old (see Table 3-3).
- Woodcock, Rubin, and Duce (1966) also found cyclical layering of algae in the sediments. In other words, the high standing crop of algae in the lake's water column today appears to be a continuation of processes that have been going on for thousands of years.
- Modeling in Ebel (2001) and Johnson (2001), as well as isotope analyses described in Arvidson 2002, indicate that the lake's source of water is limited to precipitation on its 14.2-ha (35-ac) watershed, that seepage loss

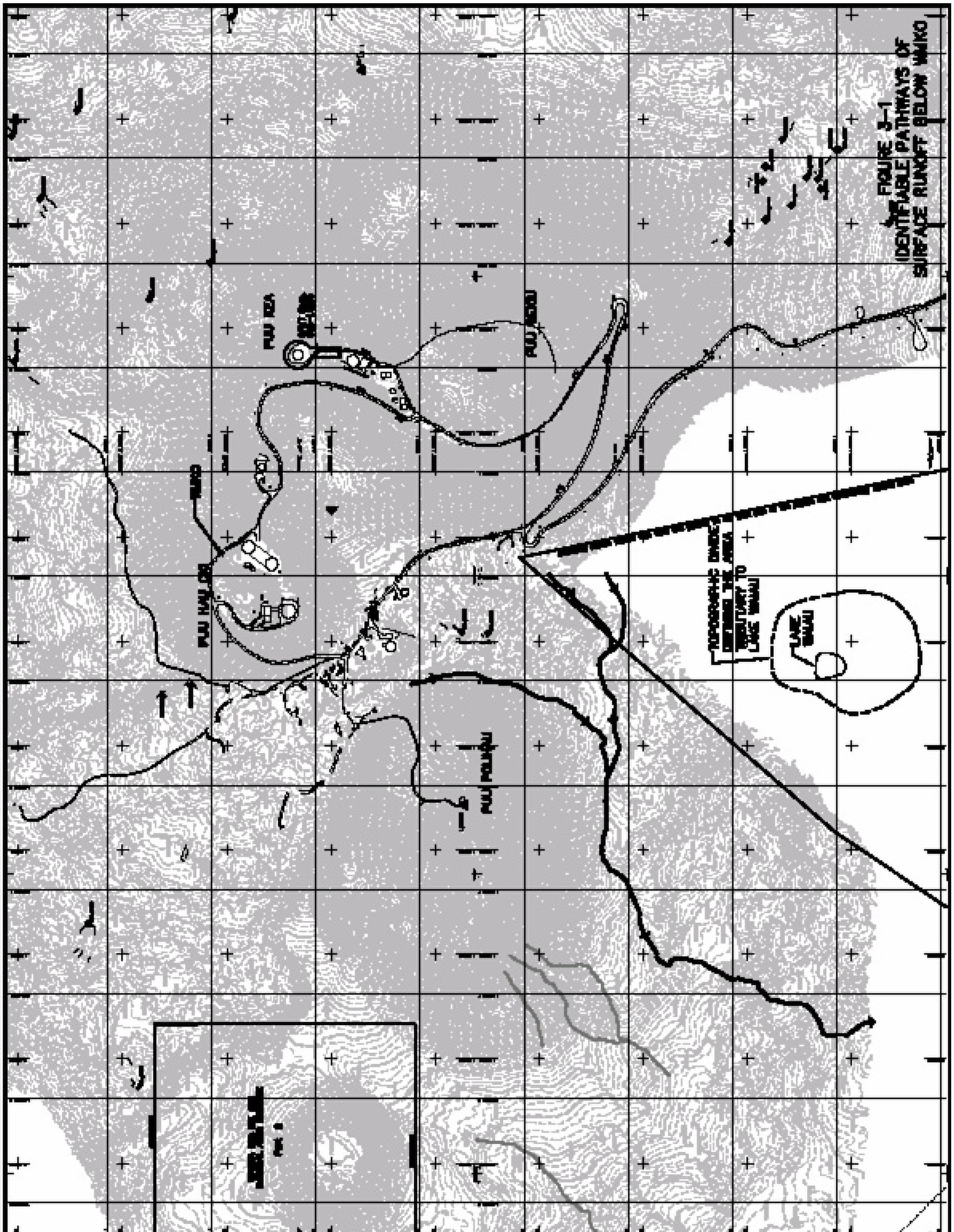


FIGURE 3-5. SURFACE RUNOFF PATHWAYS

TABLE 3-3. AGE AND DEPTH OF SEDIMENTS IN LAKE WAIAU

Depth		Age (Years)
Meters	Feet	
1.0	3.3	2,270 ± 500
1.5	4.9	4,500 ± 500
2.0	6.6	7,160 ± 500

through the bottom sediments is minimal, and that the dominant water loss is through evaporation. Periodically when the lake is full at a maximum water depth of about 2.5 m (8.2 ft), it does overflow the northwest crater rim into Pōhakuloa Gulch.

- The limited and strongly seasonal supply of water to the lake leads to substantial changes in its depth (it has been measured between 0.5 to 2.5 m (1.6 to 8.2 ft) in the middle of the lake), its surface area (from 0.4 to 0.7 ha (1.0 to 1.7 ac)), and its volume (from 1,900 to 11,400 cubic meters (2,485 to 14,911 cubic yards)).
- The cycles of algal blooms and die offs which have been going on for thousands of years are attributed to these substantial fluctuations of the lake’s depth and volume (Laws and Woodcock 1981).
- The lake's water chemistry, from a series of sampling done in the 1976 to 1977 period, is presented in Table 3-4. Data of two other samples taken in January 2003 are listed in Table 3-5. As would be expected at this elevation, dissolved constituent levels are quite low. Variations are largely driven by prior precipitation and evaporation, with higher levels occurring when lake levels are low at the end of prolonged dry periods.

3.1.4.3 Shallow Groundwater in the Summit Area

As evidenced by modest springs and seeps, shallow groundwater does exist in the mountain’s flanks below the summit area. The most prominent of these are the series of springs on the west side of Pōhakuloa Gulch on the mountain’s south flank (refer to Table 3-6). These springs are perched on glacial drift deposits which run parallel to the mountain’s slope and are interbedded with its lava flows (Wentworth and Powers 1943). Tritium dating of the springs’ water indicates that it is recent, meaning that it is not from the melting of ancient subsurface ice or permafrost (Arvidson 2002). Further, isotope analysis shows the water to be identical to rainfall at the summit. Water discharged at the springs originates as rainfall on and near the summit. It percolates downward to a perching layer and then moves conformably downslope on this relatively impermeable layer to ultimately discharge at the ground surface as a spring or seep (Arvidson 2002) (see Table 3-6).

Laboratory analyses of December 2002 samples from the two upper Hopukani Springs are presented in Table 3-5. As with Lake Waiau water, dissolved constituent levels are very low.

3.1.4.4 Deep Groundwater Beneath the Summit

Information on the nearest wells in all directions from the Mauna Kea summit is listed in Table 3-7. None of these wells are

TABLE 3-4. LAKE WAIAU WATER QUALITY DATA FOR 1976-1977

Constituent	Units	Month of Sampling					
		August 1976	**May 1977**	**June 1977**	**July 1977**	**August 1977**	**September 1977**
Temperature	°F	--	42.6	44.4	51.6	43.9	47.3
Conductivity	µS/cm @ 25° C	--	109	--	118	114	121
pH	pH Units	--	8.6	8.8	9.1	9.2	9.8
Silicon (Si)	mg/l as SiO_2	10.7	1.39	1.00	0.74	1.35	2.37
Nitrate (NO_3)	mg/l as N	0.007	0.006	0.001	0.003	0.016	0.006
Ammonium (NH_4)	mg/l as N	--	0.023	0.018	0.015	0.033	0.023
Phosphate (PO_4)	mg/l as P	0.003	0.021	0.014	0.004	0.012	0.009
Aluminum	mg/l	0.10	--	--	--	--	--
Calcium	mg/l	3.0	5.03	5.76	6.25	5.86	5.72
Copper	mg/l	0.008	0.017	0.011	0.016	0.041	0.011
Iron	mg/l	0.65	0.64	0.75	0.74	1.09	1.89
Lead	mg/l	< 0.01	--	--	--	--	--
Magnesium	mg/l	2.0	3.79	3.96	4.13	3.96	4.35
Nickel	mg/l	0.03	0.032	0.047	0.031	0.052	0.039
Sodium	mg/l	4.1	5.98	6.30	6.39	6.48	6.20
Potassium	mg/l	2.3	3.30	3.85	3.78	3.75	4.20
Zinc	mg/l	0.095	0.043	0.075	0.061	0.024	0.040
Mercury	mg/l	ND	--	--	--	--	--

Source: Massey 1978

Note: The monthly values in 1977 are the averages of a series of samples in each month.

mg/l = milligrams per liter

µS/cm = microSiemens per centimeter

SiO_2 = silicon dioxide

N = nitrogen

P = phosphorus

ND = not detected

-- = not measured

TABLE 3-5. WATER QUALITY SAMPLES FROM HOPUKANI SPRINGS, LAKE WAIAU, AND WAIKI'I WELL NO. 2

Constituent		Units	Hopukani Springs		Lake Waiau			Waiki'i Well No. 2
			East	West	East Side	West Side	Sediments on East Side	
Field Measured	Temperature	°F	57.2	58.0	39.5	39.5	33.7	82.4
	Conductivity	µS/cm @ 25° C	45.5	48.7	107.8	91.8	65.8	450
	pH	pH Units	7.60	7.96	10.2	--	--	--
Laboratory Analyses	Salinity	PPT	0.081	0.077	0.116	0.098	0.081	0.305
	Si	mg/l as SiO_2	31.2	32.9	43.1	41.2	21.1	64.0
	NO_3	mg/l as N	0.26	0.21	0.012	0.008	0.478	1.69
	NH_4	mg/l as N	0.002	0.000	0.051	0.005	0.238	7×10^{-4}
	TON	mg/l as N	0.221	0.256	1.30	1.87	1.19	0.259
	TN	mg/l as N	0.49	0.47	1.36	1.88	1.90	1.95
	PO_4	mg/l as P	0.218	0.197	0.158	0.161	1.09	0.074
	TOP	mg/l as P	0.129	0.088	0.065	0.133	0.204	0.170
	TP	mg/l as P	0.347	0.285	0.223	0.294	1.295	0.245
	pH	pH Units	--	--	9.761	9.814	7.849	--
	Aluminum	mg/l	< 0.05	< 0.05	0.094	0.19	5.7	< 0.05
	Arsenic	mg/l	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Barium	mg/l	< 0.01	< 0.01	0.32	0.33	0.46	< 0.01
	Cadmium	mg/l	< 0.01	< 0.01	0.033	< 0.01	< 0.01	< 0.01
	Calcium	mg/l	3.1	3.2	9.7	9.5	14	15
	Chromium	mg/l	< 0.01	< 0.01	0.041	< 0.01	< 0.01	< 0.01
	Copper	mg/l	< 0.01	< 0.01	0.018	< 0.01	< 0.01	< 0.01
	Iron	mg/l	< 0.2	< 0.2	0.76	0.55	3.4	< 0.2
	Lead	mg/l	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Magnesium	mg/l	1.3	1.4	5.3	3.9	5.2	26
	Manganese	mg/l	< 0.1	< 0.1	< 0.1	< 0.1	0.64	< 0.1
	Sodium	mg/l	4.9	5.0	24	11	8.6	49
	Potassium	mg/l	< 5	< 5	7.7	3.4	7.3	9.5

TABLE 3-5. WATER QUALITY SAMPLES FROM HOPUKANI SPRINGS, LAKE WAIAU, AND WAIKI'I WELL NO. 2 (CONTINUED)

Constituent		Units	Hopukani Springs		Lake Waiau			Waiki'i Well No. 2
			East	West	East Side	West Side	Sediments on East Side	
	Selenium	mg/l	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Silver	mg/l	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Vanadium	mg/l	< 0.015	< 0.015	< 0.01	< 0.01	0.037	< 0.01
	Zinc	mg/l	< 0.05	0.070	0.38	0.088	0.29	< 0.05
	Mercury	mg/l	< 0.001	< 0.001	0.0012	0.0012	0.0012	< 0.001
	Fecal Coliform	mg/l	< 1	< 1	< 4	< 4	< 10	< 1
	Enterococcus (bacteria)	mg/l	< 1	Not Enterococcus	< 4	< 4	Not Enterococcus	< 1

Notes:

1. All samples were collected by Tom Nance and Dr. Steve Dollar. The spring and well samples were collected on December 18, 2002. The Lake Waiau samples were collected on January 3, 2003.
2. Laboratory analyses of salinity, pH, and nutrients were done by Marine Analytical Specialists in Honolulu, Hawai'i.
3. Coliform analyses were done by Food Quality Lab in Honolulu, Hawai'i.
4. Laboratory analyses of the metals were done by Positive Lab Service in Los Angeles, California.

mg/l = milligrams per liter

µS/cm = microSiemens per centimeter

SiO_2 = silicon dioxide

N = nitrogen

P = phosphorus

MPN = most probable number

TON = total organic nitrogen

TN = total nitrogen

TOP = total organic phosphates

TP = total phosphates

PPT = parts per trillion

-- = not sampled

TABLE 3-6. SPRINGS ON THE WEST SIDE OF PŌHAKULOA GULCH

	Elevation		Distance From W.M. Keck Observatory	
Name	**Meters**	**Feet**	**Kilometers**	**Miles**
Hopukani	3,170	10,400	5.55	3.45
Waihu	3,005	9,860	6.19	3.84
Liloe	2,720	8,920	7.01	4.36
Unnamed	2,635	8,640	7.27	4.52

Source: Information from the Ahumoa and Mauna Kea USGS Quadrangle maps.

actually very close to the summit. The closest that reach groundwater are 20.3 km (12.6 mi) to the west of the summit in Waiki‘i (State Well Nos. 5239-01 and 02). Despite these distances, information on the groundwater occurrence tapped by these wells demonstrates that groundwater beneath the summit is what is referred to in Hawai‘i as “high level”. This distinguishes it from basal groundwater, which is typically found closer to the shoreline. Basal groundwater floats on saline water at depth and discharges to the ocean at and beneath the shoreline. Tidal signals can be measured in basal groundwater for miles inland. In contrast, the occurrence of "high level" groundwater is controlled by geologic structures. This water is not in dynamic equilibrium with saltwater at depth or at the shoreline, and its daily water level fluctuations are in response to semi-diurnal barometric pressure variations rather than the ocean tide.

By inference from the locations of the mountain’s vents, cones, and rift zones, geologic control of deep groundwater beneath the summit is exerted by nearly vertical intrusive structures called dikes. The permeabilities of the dikes are orders of magnitude less than the parent rock they have intruded through. Directly beneath the summit, the density of dikes is undoubtedly very high and their mass is a significant percentage of the entire rock mass. As a result, the overall effective permeability of the rock mass is significantly reduced. Groundwater compartments formed by intersecting dikes are very small and the wells generally cannot be successfully developed in them.

The density of the dikes decreases with distance from the summit. This enables far larger compartments to be created by the dike intersections at lower elevations. These larger compartments can be utilized to develop significant quantities of very high quality groundwater. Water can leak slowly through, overtop, or possibly flow around these dikes. This typically results in a series of distinctly different, stepping-down water levels associated with each compartment enroute. At Mauna Kea, the depths to the mountain’s highest groundwater compartments are not known. The deepest boring done at the Keck site for its foundation design, 40 m (131 ft), did not encounter groundwater (or permafrost). Test well T-20 (State No. 4532-01), which was drilled 10.9 km (6.8 mi) southwest of the summit near the Saddle Road, did not encounter groundwater to its full depth drilled. The bottom of this boring was 305 m (1,000 ft) below ground at elevation 1,638 m (5,374 ft). From resistivity surveys in the saddle area between Mauna Kea and Mauna Loa it has been inferred that the groundwater there may be more than 600-m (1,970-ft) below ground or about 1,372-m

TABLE 3-7. INFORMATION ON EXISTING DRILLED WELLS NEAREST TO MAUNA KEA SUMMIT

State Well No.	Well Name	Ground Elevation (feet MSL)	Well Depth (feet)	Elevation at Bottom (feet MSL)	Static Water Level feet	Distance From Summit km	Azimuth From Summit (Degrees from North)	Classification of Groundwater Occurrence
6223-01	DWS Paauilo	1,055	1,148	-93	11.6	15.7	22°	Basal
6017-05	DWS Ookala	640	700	-60	7.7	17.9	44°	Basal
5006-01	DWS Kulaimano	378	492	-114	12.3	24.5	88°	Basal
4708-03	DWS Kaieie Mauka	1,130	1,300	-170	27	22.5	96°	High Level
4110-01	DWS Saddle Road “A”	1,908	1,400	+508	950	21.4	117°	High Level
4010-01	USGS Kaumana	1,796	1,397	+399	997	21.8	118°	High Level
4532-01	Pōhakuloa T-20	6,375	1,000	+5,374	Water Not Reached	6.8	218°	Not Encountered
4650-01	Pu‘u Waawaa	2,550	5,599	-3,049	232	24.2	262°	High Level
4850-01	Pu‘u Anahulu	2,314	6,800	-4,486	19	23.7	268°	High Level
5239-01	Waiki‘i 1	4,260	4,350	-90	1,510	12.6	284°	High Level
5239-02	Waiki‘i 2	4,260	3,300	+960	1,510	12.6	284°	High Level
6141-01	Waiaka Tank	2,506	1,507	+999	1,243	19.7	313°	High Level
6240-01	Waimea Exploratory	2,969	2,000	+969	1,263	19.1	319°	High Level
6239-02	Parker Ranch 1	2,822	1,679	+1143	1,265	18.5	320°	High Level
6235-01	Waimea C.C.	2,814	1,415	+1399	1,657	17.0	333°	High Level

1. Data on well depths and water level obtained from the individual well file folders maintained in the office of the State Commission on Water Resource Management (CWRM).
2. Azimuth and distance of wells from the Mauna Kea summit measured on the well location maps maintained in the office of the State CWRM.
3. 1 ft = 0.3048 meter (m); 1 mi = 1.6093 kilometers (km).

(4,500-ft) above sea level (Zhody and Jackson 1969). This is about 305 m (1,000 ft) below the drilled depth of the exploratory T-20 well.

Actual groundwater elevations nearest to the summit, as measured in existing wells and compiled in Table 3-7, are: 460 m (1,510 ft) (20.3 km (12.6 mi)) to the west at Waiki‘i (Well Nos. 5239-01 and 02); 378 to 384 m (1,240 to 1,260 ft) (31.7 km (19.7 mi), 30.7 km (19.1 mi), and 29.8 km (18.5 mi) respectively) to the northwest in Waimea (Well Nos. 6141-01, 6240-01, and 6239-02); 505 m (1,657 ft) (27.4 km (17.0 mi)) north-northwest outside of Waimea (Well No. 6235-01); and 290 to 305 m (950 to 1,000 ft) (34.4 km (21.4 mi) and 35.1 km (21.8 mi)) to the east toward Hilo (Well Nos. 4110-01 and 4010-01). Based on documented occurrences elsewhere in Hawai‘i, it is almost certain that groundwater levels in the areas between these wells and the summit step up incrementally toward the summit. However, until actual deep borings are undertaken, the groundwater levels directly beneath the summit and its immediate flanks will remain unknown.

3.1.4.5 Domestic Wastewater Collection, Treatment, and Disposal

Each observatory largely operates its own system to collect and treat domestic wastewater, which is ultimately disposed of into the subsurface cinder. No plan exists to replace these individual systems with a common sanitary sewer (UH 1999).

Prior to 1993, the W.M. Keck Observatory handled its domestic wastewater with a 2.7-m (9-ft) diameter, 3.7-m (12-ft) deep cesspool located in the leveled area on the southeast side of the observatory. In 1993, as part of the Keck II construction, the observatory upgraded its wastewater-handling capability by installing a 3,785-l (1,000-gal) septic tank and retaining the cesspool for use as a seepage pit. The observatory continues to use this septic tank/seepage pit configuration and it remains today a standard, accepted wastewater handling method in the State of Hawai‘i (HAR 11-62). The Hawai‘i Department of Health approved and issued a permit for this system in 1994 (CARA 2001b). UH and CARA hold all permits for the W.M. Keck Observatory facility, and the observatory is in compliance with permitting requirements.

Human waste and refuse liquids from the two lounges and the rest rooms are the primary sources of raw domestic wastewater (CARA 2004b). The restrooms at the W.M. Keck Observatory are the only ones on the summit open to the general public. Raw wastewater drains to the two-stage septic tank, which captures floatable and settleable bio-solids. Bacteria digest the bio-solids that migrate to the bottom of the tank. The clarified liquid effluent flows from the septic tank into the seepage pit, which is lined with perforated concrete rings. Effluent entering the seepage pit percolates through these rings and into the surrounding cinder. The seepage pit is capped by a reinforced concrete lid with a 31-cm (12-in) plug (CARA 2001b).

Wash water from mirror cleaning is also a source of raw wastewater (CARA 2004o). Approximately once every two years, the secondary and tertiary mirrors are cleaned with mild soap (even milder than common floor soap) and water to wash away (primarily) accumulations of cinder dust on the telescope mirrors (CARA 2004o). Mirror cleaning produces approximately 20 l (5 gal) of wash water for each mirror (CARA 2004f). Each of the two Keck Telescopes has two secondary and one tertiary mirror.

In response to community concerns the facility no longer releases process wastewater from mirror coating removal to the septic system (CARA 2001e). See Section 3.1.5.2 for a description of the mirror coating removal process.

W.M. Keck Observatory visually inspects the septic system each year (CARA 2001c) and retains a licensed septic waste hauler to pump out the digested bio-solids sludge every six months for disposal off site at an approved treatment facility (CARA 2004b).

3.1.5 Solid Waste and Hazardous Materials Management

3.1.5.1 Solid Waste Management

Solid waste generated at W.M. Keck Observatory consists of municipal solid waste— also known as trash—and process wastes from maintenance activities that do not contain hazardous materials.

Trash Handling. Trash includes waste paper products, spent containers and very limited amounts of waste food (CARA 2004g). W.M. Keck Observatory stores trash in a 2.3 m^3 (3 yd^3) dumpster in the observatory's Receiving Room. CARA trucks the waste to headquarters, as necessary (on average one or two times per week). Pacific Waste, Inc. transports it to the local landfill in Waikoloa (CARA 2001b).

3.1.5.2 Hazardous Materials

W.M. Keck Observatory uses a variety of products to operate and maintain the telescopes, scientific instruments, equipment and the facilities. In some instances these products contain or are themselves hazardous materials. A hazardous material can be described generally as a substance that, under certain circumstances, poses a risk to the public or the environment.

CARA Safety Program. CARA has a written, active safety program that has been in place at the observatory since 1994. One key component of this program is the CARA Safety Manual. It presents information on general safety practices and emergency response procedures related to hazardous materials. It is issued to all new employees who are then trained on its guidelines and procedures (CARA 2004g). CARA reinforces this initial orientation with refresher safety training periodically throughout the year (CARA 2001b).

Additional staff training is based upon the levels of work employees do with hazardous substances. The training is specific to the product involved and is in accordance with the requirements in Occupational Safety and Health Administration Title 29, Code of Federal Regulations, Section 1910.120, Hazardous Waste Operations and Emergency Response and Hawaiʻi Occupational Safety and Health Title 12, Chapter 74.1, Hazardous Materials (CARA 2004k).

Use, Handling, and Storage. Hazardous materials used at the observatory include elemental mercury, acids, lubricants, coolant, oils and paint (CARA 2002b). The observatory does not use or store pesticides, insecticides or herbicides at the observatory (CARA 2004b). Table 3-8 lists the types of hazardous materials used at the observatory.

W.M. Keck Observatory adheres to the handling and storage guidelines in the MSDS for each product and other information as provided in the CARA Safety Manual (CARA 2004d; CARA 2004e). The observatory stores hazardous materials in appropriate storage cabinets, racks (for compressed gases), or floor space and away from any receptacle that might lead to the septic system (CARA 2004c).

TABLE 3-8. HAZARDOUS MATERIALS USED AT THE W.M. KECK OBSERVATORY

Material Class	Amounts Used and Stored at Observatory	Purpose of Material
Cooling	1.1 kiloliters (kl) (300 gallons (gal)) propylene glycol in Keck I; 1.1 kl (300 gal) ethylene glycol in Keck II; 2.3 kl (600 gal) glycols in storage	Used as cooling agent for instruments
Fuel	Diesel, 9.5 kl (2,500 gal) in underground storage tank	Emergency generator
Hydraulic Fluid	Each Keck Telescope uses 2.3 kl (600 gal) synthetic hydraulic fluid; 210 liters (l) (55 gal) in storage	Telescope hydraulic systems
Laser Dye	Comprised of R2 perchlorate and ethanol	Used as lasing medium for the laser guide star on Keck II
Lubricants	Grease used, several 19-1 (5-gal) pails in storage Each Keck Telescope uses 1.9 kl (502 gal) oil; 0.4 kl (100 gal) in storage	Grease used for ball bearings and various gear box drives Oil used in the machinery
Mercury	2.9 kilograms (kg) (6.5 pounds (lb)) in each Keck; 7.7 kg (17 lb) in storage	Used in ring girdle support for f/15 secondary mirrors
Mirror De-coating, Re-coating, Maintenance	In storage, 20 l (5 gal) hydrochloric acid, 2 kg (4 lb) potassium hydroxide pellets, 1.4 kg (3 lb) copper sulfate crystals; several centiliters (ounce-level) hydrofluoric acid in storage	Up to four mirrors de-coated each month with these chemicals; hydrofluoric acid used
Other Compressed Gases	Acetylene, argon, carbon dioxide, oxygen, propane in use and storage; two 8.6 kl (300 cubic feet) bottles of carbon dioxide used monthly	Compressed gases used for variety of tasks such as cutting and welding. Carbon dioxide used for monthly snow cleaning
Paints & Related Solvents	Various amounts stored on site	Used as needed around facility

The following describes briefly observatory activities that involve hazardous materials.

Mirror Ring Girdle. W.M. Keck Observatory uses elemental mercury in the ring girdles for the f/15 secondary mirrors on the Keck I and Keck II Telescopes (CARA 2001b). The f/15 secondary mirrors are 1.4 m (4.6 ft) in diameter. The mirror ring girdle, which is a common support technique used at many other observatories (CARA 2001a), features a rubber bladder that centers the mirror as the telescope moves from zenith (pointing up) to the horizon. It sits between the outer edge of the mirror and the mirror holding cell (CARA 2000e). When disassembling the secondary mirrors for recoating, the ring girdle is carefully removed with the mirror in place. Prior to removing the mirror, technicians create a safety reservoir with plastic laid out and rolled up at the perimeter to form a dam. Three staff members are required to carefully remove the ring girdle and store it within the safety reservoir (CARA 2001b).

The mercury is inside the mirror ring girdle. Tracking over time of mercury quantities used to support the f/15 secondary mirrors has disclosed no bladder leaks (CARA 2001b).

W.M. Keck Observatory uses and stores a total of 13.6 kilograms (kg) (30 pounds (lb)) of elemental mercury on site. The observatory uses 2.9 kg (6.5 lb) in each of the two mirror ring girdles and maintains a reserve of 7.7 kg (17 lb). The observatory stores its mercury supply in a blue plastic acids cabinet in the mirror cleaning area of the aluminizing area. The observatory receives mercury shipped by the supplier in an approved shipping container. W.M. Keck Observatory staff transfer the mercury from the shipping container to the bladder by gravity feed through a vinyl tube that is connected to the container and bladder with secure fittings (CARA 2004b).

CARA reports that three mercury spills have occurred at the observatory:

- August 10, 1995, while working on a f/15 secondary mirror, resulting in a 5-ml (1-teaspoon) spill (CARA 1995a)
- September 15, 1995, while working on a f/15 secondary mirror, resulting in a 100-ml (7-tablespoon) spill (CARA 1995b)
- November 6, 1995, while transferring mercury between containers, resulting in a spill of 5 to 10-ml (1 to 2-teaspoons) (CARA 1995c).

All three spills occurred in the mirror handling room (CARA 1995a-c). None of the spills resulted in any of the mercury seeping into the ground or the septic system (CARA 2001b).

As a result of the lessons learned during these episodes, the observatory's Emergency Response Plan for mercury spills was carefully reviewed, rewritten, and implemented in early 1996. It is mandatory that all personnel handling the secondary mirror during recoating tasks be orally briefed on safe-handling procedures contained in the revised plan, read them carefully, and follow the procedures to the letter (CARA 2001a). Mercury spill response kits are positioned strategically to minimize response time in the unlikely event of a spill (CARA 2004m). Since implementation of the revised procedures, there have been no other mercury spills.

<u>Mirror Coating (Aluminizing)</u>. The Keck I and Keck II Telescopes each consist of 36 separate hexagonal primary mirror segments, plus two secondary mirrors and one tertiary mirror (78 mirrors total for both telescopes) (CARA 2000d). The reflective side of these mirrors has a thin coat of aluminum. To maintain the optical performance of the mirrors, W.M. Keck Observatory periodically strips and re-applies this aluminum coating. The observatory de-coats and re-aluminizes the mirrors in the mirror handling room, a facility within the observatory specially designed for this purpose.

The first step in the recoating process is to use two solutions to remove the old coating. One contains a mixture of hydrochloric acid, copper sulfate and distilled water (approximately 0.3 l or 10 oz), and the second combines potassium hydroxide and distilled water (approximately 0.3 l or 10 oz). The solutions are rinsed off with about 150 l (40 gal) of potable water (Aqua/Waste 1992). The rinse water, which technicians neutralize with additional amounts of potassium hydroxide and calcium carbonate (CARA 2004d), contains small amounts of aluminum chloride, aluminum sulfate, copper chloride, copper sulfate, and potassium hydroxide (Aqua/Waste 1992).

Technicians capture the rinse water in a sump and pump it into containers for disposal off site. Prior to 2002, the rinse water was disposed of through the observatory's septic system (CARA 2004b). In 1992, a study by Aqua/Waste Engineers concluded that this non-domestic waste stream was acceptable for disposal into the planned septic system, with the level of copper less than the standard for drinking water (Aqua/Waste 1992). However, due to concerns from community groups, the observatory decided subsequently to retrofit the drains in the mirror handling room with a sump and pump to capture the mirror decoating rinse water. The containerized waste is now disposed of at the wastewater treatment plant in Waimea (CARA 2001h).

While amounts vary over time, W.M. Keck Observatory typically has on hand about 20 l (5 gal) of hydrochloric acid, 2 kg (4 lb) of potassium hydroxide pellets and 1.4 kg (3 lb) of copper sulfate crystals. The observatory stores these materials in a locked cabinet in the re-aluminizing room (CARA 2004f). The observatory does not store or use carbon disulfide in the mirror re-aluminizing process or in any other application (CARA 2004b).

Recoating takes place in the coating chamber. Workers place aluminum clips on the tungsten filaments in the bottom half of the coating chamber. Next, they position the mirror in the top of the chamber (face down) and create a vacuum. Technicians heat up the filaments to melt the aluminum initially and then increase power rapidly to evaporate the aluminum and coat the mirror (CARA 2000d). The observatory collects the extra aluminum from the inside walls of the chamber for transport off site and disposal (CARA 2004b).

W.M. Keck Observatory processes up to four segments per month with a goal of re-aluminizing all the mirrors in each of the two telescopes every two to three years (CARA 2000d).

<u>Instrument Cooling</u>. The W.M. Keck Observatory uses propylene glycol in Keck I as a cooling agent for its instruments. Ethylene glycol is used in the Keck II for the same purpose. The observatory uses 1.1 kl (300 gal) of glycol in each Keck Telescope and stores 2.3 kl (600 gal) in 210-l (55-gal) drums on the dome floors on fluid containment pallets (CARA 2000b; CARA 2004b; CARA 2004e).

On March 30, 2004 the observatory experienced a spill of propylene glycol. The spill occurred during testing of an auxiliary glycol cooler when one of the hoses became dislodged accidentally from its barbed fittings. The spill was estimated to be between 76 and 114 l (20 and 30 gal), with approximately two-thirds of it escaping outside the facility under an exterior door. The CARA Safety Officer handled the spill response during which the affected cinder was contained, removed, and disposed of properly. The spill was reported to OMKM which advised on how to handle the cinder.

<u>Lubrication of Ball Bearings</u>. Periodically, W.M. Keck Observatory lubricates ball bearings throughout the facility. During lubrication, technicians collect and remove any excess lubricant to an appropriate waste container (CARA 2002a). Any lubricant that might be spilled accidentally during the lubrication procedure is cleaned up immediately.

W.M. Keck Observatory stores 20-l (5-gal) pails of lubricant in the generator room and mechanical room (CARA 2000b).

<u>Laser Dye</u>. R2 perchlorate is used as a main lasing medium and exists in closed, pumped loops and in appropriately marked storage containers (CARA 2004g). The R2 perchlorate powder is pre-mixed by the supplier and shipped to Keck for additional

mixing with ethyl alcohol for use in the lasing process. The R2 perchlorate product is stored at Keck Headquarters in a UL-approved cabinet. It is transported to the summit by CARA vehicles in approximately 20-l (5-gal) containers secured in an additional container capable of retaining the product in the event of a spill in route. The container is secured during transport to the summit. The R2 perchlorate product is further combined with ethyl alcohol in the Keck Observatory aluminizing room. There are spill containment safeguards in place in the mixing area. There have been no spills or releases of R2 perchlorate on the summit (CARA 2004m).

Compressed Gases. W.M. Keck Observatory uses compressed gases, such as oxygen, acetylene, propane and argon, for several purposes at the summit. Carbon dioxide gas is used monthly to spray-clean the Keck I and Keck II mirrors (CARA 2000d). The observatory uses two bottles per month, and each bottle contains 8.6 kl (305 ft^3) of carbon dioxide. Carts are used to handle compressed gases whenever possible. When not in use, cylinders are stored in racks and chained.

Other Operations and Maintenance. Each of the Keck Telescopes uses 2.3 kl (600 gal) of synthetic hydraulic fluid. Unused hydraulic fluid (one 210-l or 55-gallon drum) is stored in the lower mechanical room (CARA 2000b; CARA 2001b).

The observatory uses approximately 1.9 kl (500 gal) of oil in the machinery for each of the Keck Telescopes and stores an additional 0.4 kl (100 gal) in 210-l (55-gal) drums in the lower mechanical room (CARA 2000b; CARA 2004b).

The observatory uses hydrofluoric acid to fuse cracks or voids in the optics to prevent further migration. WMKO stores only centiliter-levels (ounce-levels) of hydrofluoric acid in a locked cabinet in the mirror handling room (CARA 2000b; CARA 2004b).

The observatory uses grease in various gearbox drives (CARA 2004b). Twenty-liter (5-gal) pails of grease are stored in the generator room and mechanical room (CARA 2000b).

The observatory performs painting on site as required (CARA 2004d). Paint-related equipment is cleaned in the Shipping and Receiving area where the effluent is collected and containerized for disposal off site (CARA 2004e). Paints and related solvents are stored in paint cabinets throughout the observatory (CARA 2004e). Left over paint is disposed of properly (CARA 2000b).

The observatory stores diesel fuel for the standby power generator in a 9.5-kl (2,500-gal) underground storage tank. The storage tank is double-walled fiberglass with a leak detection system on the tank and fuel lines. The tank meets USEPA standards and is inspected regularly (UH IfA 2001a). There have been no spills or leaks of diesel fuel (CARA 2004m).

Hazardous Waste. The CARA Safety Manual sets forth proper procedures for handling hazardous waste. The W.M. Keck Observatory containerizes all hazardous wastes for disposal offsite and disposes of no such material through the onsite septic system (CARA 2004b).

Two to three times per year the observatory transports the containerized waste to its headquarters whereupon a licensed contractor collects the material for proper disposal.

Emergency Response Procedures. To minimize the likelihood and potential environmental impact of an accident, the W.M. Keck Observatory has three sources, in writing, of emergency procedures to respond to a hazardous materials incident on the summit (CARA 2004e). These are:

- The emergency response procedures and instructions provided in the product MSDS.
- Emergency response procedures provided in the CARA Safety Manual, which are specific to a class of product (*e.g.*, cryogens, mercury, and glycols).
- Emergency response procedures as provided in the preliminary draft "Summit Emergency Response Plan." This plan is currently under review by the CARA Safety Committee but is in full effect (CARA 2004d; CARA 2004m). These procedures instruct the Summit Lead and all other summit personnel in their respective roles and functions when there is an emergency requiring the use of emergency equipment on the summit.

W.M. Keck Observatory reports chemical spills requiring emergency response at the observatory site to the Hawai‘i County Fire Department, the State Health Department and the Pōhakuloa Training Area (PTA). The PTA can offer assistance and has emergency equipment available, if needed. Observatory spill response procedures include the notification of OMKM for any release or spill of any hazardous material making contact with cinder (CARA 2004m). W.M. Keck Observatory assumes clean-up responsibility should a vehicle transporting products or wastes to or from the observatory get into an accident on the roadway. W.M. Keck Observatory has policies and procedures in place to handle such an event (CARA 2004b).

CARA has in place an established incident reporting protocol for employees to follow in the unlikely event of a chemical spill. Incident reports are prepared by individual(s) most knowledgeable about the incident. Reports are reviewed by management, and the Safety Committee discusses corrective action and develops implementation plans (CARA 2000b).

In addition to State and local reporting procedures, W.M. Keck Observatory has Federal reporting requirements for chemical spills that exceed federal standards.

Table 3-9 lists chemicals used at W.M. Keck Observatory subject to reporting requirements under the Emergency Planning and Community Right-to-Know Act (EPCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) (USEPA 2001; CARA 2002b).

The presence of EPCRA Section 302 extremely hazardous substances (EHSs) in quantities at or above the Threshold Planning Quantity (TPQ) requires certain emergency planning activities to be conducted. The EHSs and their TPQs are listed in Title 40, Code of Federal Regulations, Part 355, Appendices A and B. For Section 302 EHSs, Local Emergency Planning Committees must develop emergency response plans. Facilities must notify the State and local emergency response commissions if they receive the substance on site at or above the EHS's TPQ. Releases of reportable quantities (RQ) of EHSs are subject to State and local reporting under Section 304 of EPCRA (USEPA 2001).

Releases of CERCLA hazardous substances, in quantities equal to or greater than their RQ, are subject to reporting to the National Response Center under CERCLA. Such releases are also subject to state and local reporting under Section 304 of EPCRA. CERCLA hazardous substances, and their reportable quantities, are listed in Title 40,

TABLE 3-9. FEDERAL HAZARDOUS MATERIAL SPILL REPORTING STANDARDS FOR COMPOUNDS USED AT THE W.M. KECK OBSERVATORY

Compound (CAS No.)	Product or Process	EPCRA TPQ[1] Sec. 302	CERCLA RQ[1] Sec. 103
Aluminum Chloride	Mirror decoating	NA	NA
Aluminum Sulfate	Mirror decoating	NA	5,000
Copper Chloride	Mirror decoating	NA	10
Copper Sulfate	Mirror decoating	NA	10
Hydrochloric Acid	Mirror decoating	NA	5,000
Potassium Hydroxide	Mirror decoating	NA	1,000
Ethylene Glycol	Instrument cooling	NA	5,000
Propylene Glycol	Instrument cooling	NA	NA
Hydrofluoric Acid	Mirror etching	100	100
Mercury	Mirror ring girdle	NA	1
Methylene Chloride	Paint Stripping	NA	1,000
Acetone	solvent	NA	5,000
Methyl Ethyl Ketone	solvent	NA	5,000
Toluene	solvent	NA	1,000
1,1,1-Trichloroethane	solvent	NA	1,000
Trichloroethylene	solvent	NA	100

Sources: Aqua/Waste 1992; USEPA 2001; CARA 2002

1. TPQ and RQ values in lbs; 1 lb = 0.454 kg.
2. NA = Not applicable, no threshold amount established.

Code of Federal Regulations, Part 302, Table 302.4 (USEPA 2001).

3.1.6 Geology, Soils, and Slope Stability

Mauna Kea, the tallest mountain within the Pacific basin, is a dormant volcano that first rose above the Pacific Ocean about 400,000 years ago (Moore and Clague 1992). The volcano grew rapidly to heights that allowed the accumulation of snow and ice, so that Mauna Kea has been repeatedly glaciated during the past 250,000 years (Porter 1987). Eruptive activity at Mauna Kea's summit took place when snow and ice covered the volcano above about 3,353-m (11,000-ft) elevation (Porter 1979), and the eruptions that formed the cinder cones on which the astronomical observatories are situated all took place in association with water.

The interactions of molten lava with snow and ice formed different sorts of volcanic rocks at Mauna Kea's summit than those formed lower on the volcano's slopes, or on other volcanoes in Hawai‘i. Many of the features formed in this environment are unique and well preserved, and are among the best examples of lava/ice interaction structures in the world. More information about these unique features is provided by Lockwood (2000).

Influence of lava/ice interactions on the summit cinder cones of Mauna Kea:

Each of the summit cinder cones (Puʻu Wēkiu, Puʻu Kea, Puʻu Hauʻoki, and Puʻu Poliahu) was formed by eruptions that took place beneath snow and ice – in contact with meltwater. During the initial phases of each of these eruptions lava/water interactions caused a great deal of explosive fragmentation of lava and water-quenching of lava. These early formed deposits were extensively altered by prolonged contact with hot water (hydrothermal alteration), and are typically fine-grained and yellow to orange-red in color. In later phases of the eruptions as ice and snow were melted and boiled away, molten rocks could be ejected directly into the atmosphere, where they were air-quenched and not subject to hot-water alteration. These later deposits differ greatly from the hydrothermally altered deposits that underlie them. They are brown to black in color, and consist of much coarser-grained cinders and volcanic bomb fragments Figure 3-6. The surface of Puʻu Wēkiu is almost entirely covered by these dark-colored, loose fragments, commonly mixed with finer material a few inches below the surface. The seismic velocity studies of Furamoto and Adams on Puʻu Wēkiu (1968) inferred that finer-grained, altered deposits exist at depth, buried by as much as 152 m (500 ft) of air-quenched ejecta. The flanks of Puʻu Kea, north of Puʻu Wēkiu are also covered by these coarse-grained, loose spatter deposits.

Puʻu Hauʻoki and the unnamed cone to the west that underlies the Keck Observatories were apparently formed almost entirely in the presence of glacial meltwater, and their character is different from Puʻu Wēkiu and Puʻu Haukea. The deposits underlying the W.M. Keck Observatory, the NASA Infrared Telescope and the Subaru Telescope consist in large part of water-quenched cinders and hydrothermally altered material that is in general finer grained than are the deposits of Pu'u Wēkiu and Puʻu Kea. These deposits are characterized by a high proportion (25 to 40 percent) of fine-grained, sand-sized, red fragmental material that forms the close-packed matrix for altered breccia fragments (see Figure 3-7).

Because of the potential biological significance of tephra size differences, an attempt was made to quantify the grain size differences between Puʻu Wēkiu, Puʻu Haukea and the Puʻu Hauʻoki cones by sieving techniques. With permission of the Office of Mauna Kea Management, representative samples of tephra from slopes of these cones were obtained adjacent to existing roadcuts, where surfaces were undisturbed by prior construction debris. Bulk samples were obtained from areas about 20 x 20 cm (8 x 8 in) in size, excavated to about 8 cm (3 in) depth. These samples, which weighed 2 to 3 kg (5 to 6 lb) each, were then sieved through a series of sieves with the following opening dimensions: 1, 2, 4, 8, and 16 mm (0.04, 0.08, 0.16, 0.31, 0.63 in). Results of the sieving showed a high degree of grain size variability within each puʻu and that overall differences between Puʻu Wēkiu/Kea and Puʻu Hauʻoki were slight, but that the former were characterized by somewhat more coarse grain size than the latter (see Figure 3-8). The number of samples sieved was very small, however, and a much larger sampling program would be required to confirm these differences.

Tephra grain size is affected by two other factors that can greatly influence grain size distribution on the slopes of the Mauna Kea summit cones. Coarser fragments tend to rise to the surface relative to finer material, so that the grain size becomes finer with depth, and the depth of sampling can thus impact results. Another factor is that large fragments tend to roll downslope from steep areas and accumulate on lower, more gentle

FIGURE 3-6. LARGE FUSIFORM BOMB ON STEEP SLOPE OF PU‘U WĒKIU

Note the coarse nature of the cinders, which mostly represent air-quenched ejecta.

FIGURE 3-7. INTERNAL STRUCTURE OF TEPHRA DEPOSITS NORTHWEST OF THE KECK TELESCOPES, ALONG THE "DETOUR ROAD" BELOW THE SUBARU TELESCOPE

Note the abundance of fine-grained, altered fragmental material enclosing hydrothermally altered blocks.

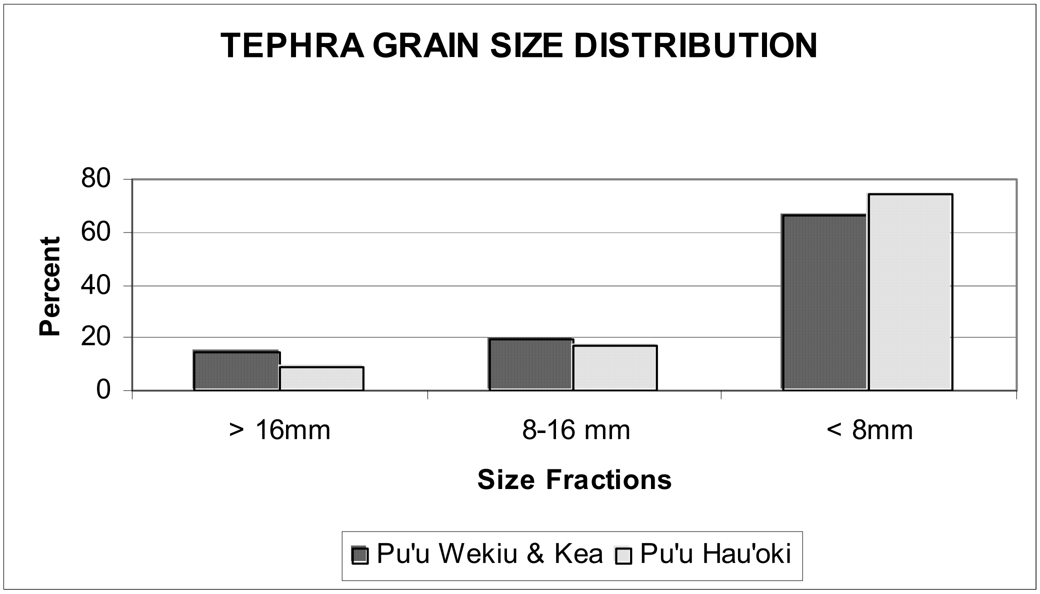


FIGURE 3-8. DISTRIBUTION OF AVERAGE TEPHRA GRAIN SIZE IN SAMPLES FROM THE FLANKS OF PU'U WĒKIU, PU'U KEA, AND PU'U HAU'OKI

slopes. This effect is demonstrated by plotting grain size distribution against cone slope angles (see Figure 3-9). All else being equal, cinder sizes will thus be greater on the lower flanks of cones. These factors imply that interstitial void space between tephra clasts (which affects the populations of arthropods— see Section 4.1.2) will be greater near the surface than at depth, and will be greater on less steep slopes where coarse tephra clasts accumulate.

3.1.7 Geologic Hazards

Volcanic Hazards. Mauna Kea has not erupted within the period of Hawai'i's human occupancy (the last eruption occurred about 4,400 years ago), and the volcano is considered to be "dormant" by volcanologists. It is almost certain that Mauna Kea will erupt again, although it appears that such eruptions will be very infrequent, and will take place on the lower flanks of the volcano.

Wolfe and Others (1997) mapped a total of 12 post-glacial eruptive vents on Mauna Kea; the youngest on the south flank erupted about 4,000 years ago. None of these younger vents are found near the summit, however, and most are below 2,743-m (9,000-ft) elevation. The eruptions that formed the cinder cones and lava flows underlying the astronomical observatories at the summit of Mauna Kea all occurred more than 40,000 years ago (Wolfe and Others 1997), and the chance for future eruptions in the summit area appear to be quite slight. Future eruptions will be similar to those of Mauna Kea's recent past (last 10,000 years), and will be marked by the formation of high cinder cones and sluggish lava flows that will mostly impact the lower flanks of the volcano. Eruptions of this type will almost certainly be preceded by substantial premonitory activity, which will likely give years of advance warning. No "volcanic earthquakes" of the sort that will precede Mauna Kea's next eruption have ever been detected beneath the volcano, and it can be

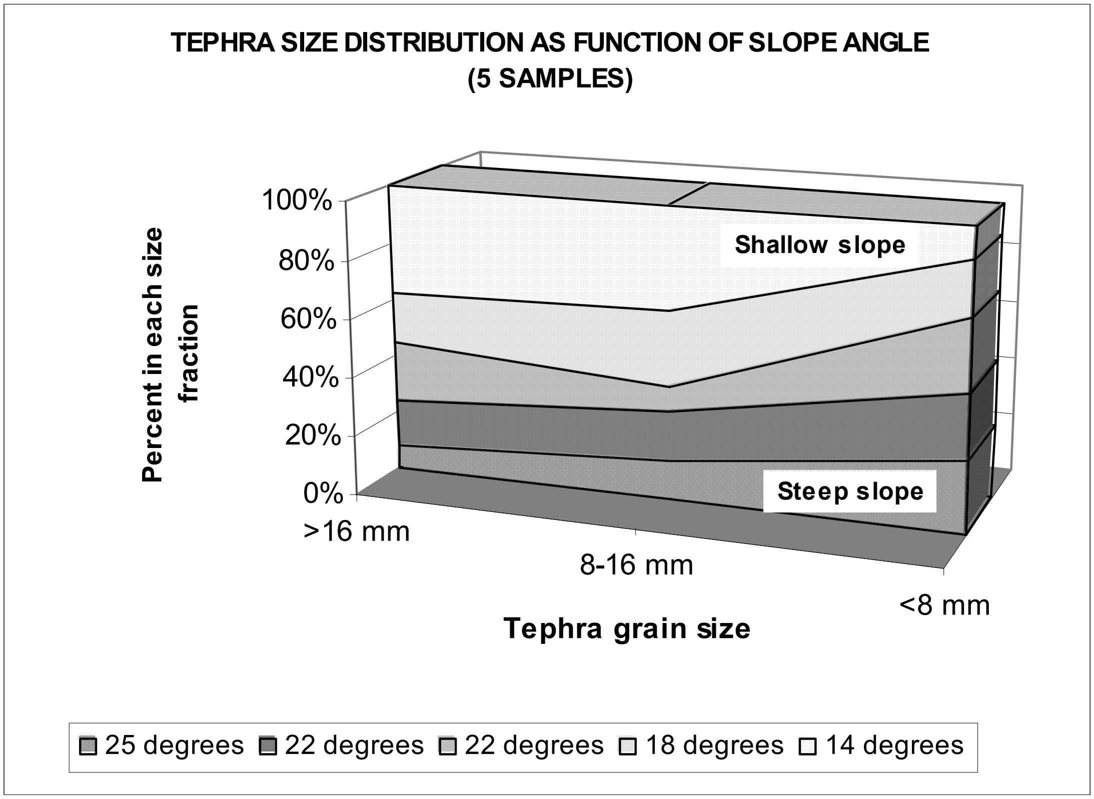


FIGURE 3-9. EFFECT OF SLOPE ANGLE ON TEPHRA GRAIN SIZE DISTRIBUTION

Note that steep slopes tend to be covered with finer-grained material than are gentle slopes, where coarse tephra accumulates by rolling downhill.

safely assumed that no eruption is likely in the humanly near future. The earthquakes that will accompany any future eruption of Mauna Kea will doubtless cause significant ground-shaking on all parts of Mauna Kea, however, and might be expected to cause substantial damage to astronomical facilities at the summit, and also to eject substantial ash and dust that could reach the summit and severely impact telescope operations. Mullineaux and Others (1987) discussed volcanic hazards throughout Hawai‘i and considered hazards for lava flows, ash falls, ground fractures and volcanic gas emissions on Mauna Kea, and considered them very low – lower than anywhere else on the island of Hawai‘i except for the Kohala region.

Earthquake Hazards. The island of Hawai‘i is one of the most seismically active areas in the world, with more destructive earthquakes occurring here than in any other comparably sized area in the United States (Wyss and Koyanagi 1992). Large, damaging earthquakes will definitely occur in the future on Hawai'i, and the summit area of Mauna Kea will be impacted. Although the frequency and magnitudes of earthquakes are greatest on the southeastern margin of Hawai‘i, many earthquakes also occur within and beneath Mauna Kea. The locations of all earthquakes beneath Mauna Kea with magnitudes greater or equal to 3.0 for the 30-year period 1973 to 2003 are shown in Figure 3-10. Most of these earthquakes were large enough to be felt,

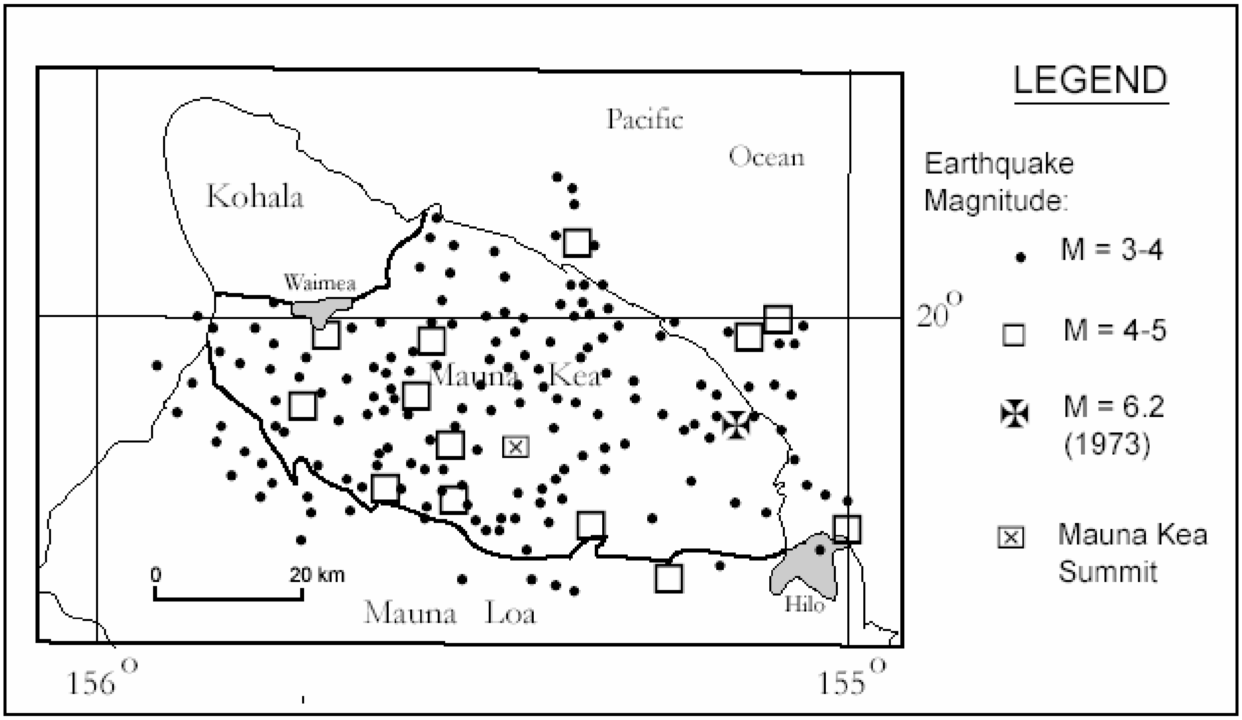


FIGURE 3-10. EARTHQUAKE MAGNITUDES

and the 1973 M=6.2 earthquake caused extensive property damage on Hawaiʻi, and was felt as far away as Kauai (Wyss and Koyanagi 1992).

Earthquake Categories. Earthquakes on the island of Hawaiʻi fall into three distinct classes (Johnson and Koyanagi 1988; Klein 1994): (1) "volcanic earthquakes," (2) "tectonic crustal earthquakes," and (3) "deep, lower crustal, and subcrustal earthquakes" (Klein 1994).

Volcanic earthquakes occur beneath the summit calderas of Mauna Loa and Kilauea and the rift zones of these two active volcanoes. They are directly related to the movement of magma within conduit systems of these volcanoes and are caused by deformation of the volcanic rocks surrounding magma chambers and dikes. Many coincide with the intrusion of magma prior to eruptions. These earthquakes account for perhaps 95 percent of the total number of earthquakes recorded on Hawai'i (Furumoto and Others 1990), but they are generally less than magnitude 4 and thus pose no great hazard to the astronomical facilities on Mauna Kea, although they may temporarily disrupt operations.

Tectonic crustal earthquakes occur mostly within the lower crust below volcano flanks, typically 3 to 19 km (2 to 12 mi) from active rift zones. The most active sources of these earthquakes are the southern flanks of Mauna Loa and Kilauea. These earthquakes generally occur at depths of 5 to 13 km (3 to 8 mi) depth and include the largest and most destructive earthquakes in Hawai'i's history (1868 and 1975). They most likely occur in response to stored stresses within volcano flanks caused by the long-term injection of magma into adjacent rift zones, and are not directly caused by volcanic activity.

The third class of earthquakes occurs 19 to 59 km (12 to 37 mi) deep in the crust beneath Mauna Kea and Kohala volcanoes and in the upper mantle beneath the entire island of Hawai‘i, including offshore flanks. These deep earthquakes show no relationship to active volcanism, but are likely the result of the bending and deformation of the Pacific tectonic plate, owing to the accumulated mass of the islands. These earthquakes can occur throughout the Hawaiian Island chain and have caused damaging earthquakes near Maui and O‘ahu as well as the Big Island. Because of their depth, these earthquakes are often felt over large areas of the State. The April 26, 1973 M=6.2 Honomu earthquake occurred 40 km (25 mi) beneath the eastern flank of Mauna Kea (Unger and Ward 1979), and was felt as far away as Kauai.

Expected Earthquake Intensities at the Mauna Kea Summit. The record of earthquake intensities (what people have observed) on the island of Hawai‘i is fairly complete for the past 166 years. Wyss and Koyanagi (1992) compiled available instrumental and intensity data for felt earthquakes from the U.S. Geological Survey’s Hawaiian Volcano Observatory records and reports, and have greatly expanded that data set with information from newspaper archives and personal accounts dating back to 1833. Their compilation of intensity reports for strong earthquakes in Hawai’i from 1833 to 1989 led to the preparation of a map showing maximum recorded earthquake intensities on the island of Hawai‘i during this period According to Wyss and Koyanagi (1992) the summit of Mauna Kea lies within the occurrence zone of maximum Intensity VII earthquakes (Modified Mercalli Intensity Scale).

Although no earthquakes of magnitudes greater than six have occurred on Hawai‘i Island since 1983, such earthquakes will occur in the future, and will temporarily impact observation activities on Mauna Kea’s summit. Klein (1994) estimated the recurrence intervals for “large” Hawaiian earthquakes with magnitudes greater than 5.5 at 3 to 4.5 years; for “major” earthquakes with magnitudes greater than 7 at 29 to 44 years, and for “great” earthquakes approaching magnitude 8 (such as that of April 2, 1868) at 120 to 180 years. Volcanic eruptions on Kilauea and Mauna Loa volcanoes generally do not cause earthquakes greater than M=5, but the rhythmic pulsation of moving subsurface lava during eruptions causes “harmonic tremor” that can affect Mauna Kea telescopes.

The best estimate of future seismic activity is based on past events. Most large earthquakes on the island of Hawai‘i occur along the island’s southern flank (Wyss and Koyanagi 1992), but several have occurred within or beneath Mauna Kea. The largest Mauna Kea earthquake in historic times happened on April 26, 1973 beneath the eastern flank of Mauna Kea, 32 km (20 mi) east of the summit, deep beneath the town of Honomu. This earthquake had a Richter magnitude M=6.2 (Unger and Ward 1979) and generated Mercalli intensities estimated at VII beneath the Mauna Kea summit (Wyss and Koyanagi 1992). The largest earthquake in Hawai‘i’s history (April 2, 1868) had an estimated M=7.8 (Wyss 1988), and occurred near the southwest coast of the Island, 48 km (30 mi) south-southwest of the Mauna Kea summit. It also resulted in estimated intensities of VII at the summit (Wyss and Koyanagi 1992). Earthquakes beyond the island of Hawai‘i can also cause large intensities ground shaking beneath Mauna Kea. The estimated M=6 earthquake of January 2, 1938 occurred just northeast of the island of Maui, 177 km (110 mi) northwest of Mauna Kea, but resulted in estimated intensities of VI at Mauna Kea's summit (Wyss and Koyanagi 1992).

3.1.8 Transportation

The drive from Hilo or Waimea to the upper elevations of Mauna Kea takes approximately 1 to 1.5 hours. Access to the summit is from Saddle Road (Route 200) to Puʻu Huluhulu, and from there along a 9.7-km (6-mi) long, 6-m (20-ft) wide paved portion of the Mauna Kea Access Road to Hale Pōhaku, located at an elevation of 2,804 m (9,200 ft). From Hale Pōhaku, the Mauna Kea Access Road continues unpaved for approximately 7.2 km (4.5 mi). The road is then paved again at an elevation of 3,597 m (11,800 ft) to the project site elevation of 4,146 m (13,603 ft) (see Figure 2-1).

Observatory personnel, commercial operators, cultural practitioners, recreational users, and other visitors currently use the Mauna Kea Access Road and Summit Road. Between January and December 2003, approximately 34,659 vehicles traveled to the summit (OMKM 2004). Commercial operators accounted for approximately 3,620 vehicles, an average of 302 vehicles per month. Observatory personnel accounted for approximately 20,545 vehicles, an average of 1,712 vehicles per month. Other visitors, including cultural practitioners, recreational users, tourists and local traffic, accounted for approximately 10,494, an average of 875 vehicles per month. Table 3-10 estimates the type of traffic and average number of monthly trips.

Although it is recommended that visitors use a four-wheel-drive vehicle to go beyond Hale Pōhaku, no measures are taken to prevent two-wheel-drive vehicles from using the summit road.

Hazards encountered during travel to and from the summit include brake failures on the steep summit road and weather-related accidents. On average, there are about three accidents each year that require a vehicle to be towed (MKSS 2004a). Drivers occasionally decide to take their vehicles off designated roadways. This results in increased personal risk as well as risk to archaeological sites, arthropod and flora habitat, and to the serenity of the natural landscape.

3.1.9 Utilities and Services

3.1.9.1 Water Supply

Water supply for Hale Pōhaku and the summit is trucked from Hilo in a 19-kiloliter (kl) (5,000-gal) capacity tanker truck. Two 152-kl (40,000-gal) water tanks are located at Hale Pōhaku. Currently, 95 kl (25,000 gal) of water are trucked to the Mid-Elevation Support Facilities each week (UH IfA 2001a). An additional 57 kl (15,000 gal) of water each week are trucked to the summit to supply all the various facilities. Each facility has its own on-site water storage and distribution system. Table 4-22 provides individual storage capacities of each of the observatories as well as Hale Pōhaku. At the W.M. Keck Observatory, the water is stored in two tanks; 15 kl (4,000 gal) and 30 kl (8,000 gal) (UH IfA 2001a).

Typical consumption at W.M. Keck Observatory is 11 kl (3,000 gal) per week for all purposes (UH IfA 2001a). Potable water is distributed through the W.M. Keck Observatory via its on-site system.

3.1.9.2 Electrical Power and Communications

The Mauna Kea summit is presently served by a 69-kilovolt (kV) overhead transmission line to the Hale Pōhaku substation (UH 1999). This substation consists of two 3,000-kilovolt-ampere (kVA) transformers with a total capacity of 6,000 kVA. From the substation, there is an underground 12.47-kV dual loop feed system that loops

TABLE 3-10. VEHICLE TRIPS TO THE MAUNA KEA SUMMIT

Traffic Type	Jan-03	Feb-03	Mar-03	Apr-03	May-03	Jun-03	Jul-03	Aug-03	Sep-03	Oct-03	Nov-03	Dec-03
Commercial Operators												
Total am	17	16	26	29	16	17	10	16	18	21	26	14
Total aftn	17	23	14	4	15	3	5	2	5	12	2	3
Total pm	251	230	244	197	223	237	298	332	378	351	303	245
Totals	285	269	284	230	254	257	313	350	401	384	331	262
Visitors 4 Wheel Drive												
Total am	130	153	147	140	127	123	117	130	131	202	120	238
Total aftn	242	300	293	204	253	236	197	241	261	237	229	298
Total pm	176	188	217	176	202	242	275	367	277	188	221	166
Totals	548	641	657	520	582	601	589	738	669	627	570	702
Visitors 2 Wheel Drive												
Total am	60	89	59	55	56	55	67	66	71	88	61	75
Total aftn	82	93	96	72	123	115	75	121	118	102	103	137
Total pm	61	57	49	56	89	98	102	128	112	66	109	84
Totals	203	239	204	183	268	268	244	315	301	256	273	296
Observatory Personnel												
Total am	480	559	646	670	702	621	656	684	688	793	537	490
Total aftn	595	605	746	686	703	685	679	789	659	800	560	531
Total pm	332	308	417	422	418	464	447	435	406	455	520	357
Totals	1,407	1,472	1,809	1,778	1,823	1,770	1,782	1,908	1,753	2,048	1,617	1,378
Month Totals	**2,443**	**2,621**	**2,954**	**2,711**	**2,927**	**2,896**	**2,928**	**3,311**	**3,124**	**3,315**	**2,791**	**2,638**

Source: OMKM 2004

around the Mauna Kea summit (UH 1999). The monthly average power consumption at the substation is 1,045,000 kW-hours. The existing peak demand load at the substation is approximately 2,230 kW. This peak is approximately half of the capacity at the substation (CARA 2004j). Table 4-22 provides the average annual electrical usage for each observatory.

The existing W.M. Keck Observatory electrical service provided by the Hawaii Electric Light Company (HELCO) has a 1,000-kW capacity (UH IfA 2001a). The existing peak demand load of the Keck Telescopes is approximately 525 kW (CARA 2004i), or 52.5 percent of capacity.

In addition, a 250-kW standby diesel-powered generator is located at Keck to provide minimal power needs such as dome closure in the event of a power outage (UH IfA 2001a). Diesel fuel for the generator is stored on site at the W.M. Keck Observatory site in a 9.5-kl (2,500-gal) double-walled storage tank with a leak detection system (UH IfA 2001a).

The communications system serving the observatories at the summit was upgraded between 1996 and 1998, including the installation of a fiber optic communications system (UH 1999). This system provides communications links to provide real-time data flow between the summit and base facilities in Waimea and Hilo. Remote observing from outside Hawaiʻi via the Internet is also possible with the improved communications link.

3.1.9.3 Emergency Services and Fire Suppression

Emergency Services. An emergency preparedness and medical evacuation plan has been prepared by MKSS. This plan covers and applies to all observatories on the summit of Mauna Kea. The plan is updated as required and distributed to all facilities (MKSS 2000).

Because Mauna Kea is an isolated work location, many miles from the nearest professional Emergency Medical Service (EMS), the responsibility and primary source of first aid assistance are the employees at each observatory facility. There are no emergency medical facilities on the summit or at Hale Pōhaku. The plan recommends that each facility maintain a stock of emergency first aid supplies and that all employees have current first aid training and experience using the equipment available to them. In addition, the plan recommends that some staff members undergo emergency medical technician training and that each facility should establish regular first aid drills, test emergency and safety equipment, and test drive the emergency evacuation vehicle. The emergency evacuation vehicle is available if facility vehicles are inadequate and an accident victim needs to be transported to an EMS location or must meet an EMS vehicle. This emergency vehicle is located at the Caltech Submillimeter Observatory (CSO) for use by all observatories. The purpose of this vehicle is to provide a means of transporting an injured person down the mountain to an ambulance or helicopter at Saddle Road or Hale Pōhaku. The vehicle is equipped with first aid supplies and a cellular phone. EMS is available from both the Hawaiʻi County Fire Department and Pōhakuloa Training Area. Pōhakuloa is closer to Mauna Kea and can respond more quickly than the Fire Department. EMS personnel from the County and PTA can be dispatched either by ambulance or helicopter. The nearest hospital is Hilo General Hospital.

Fire Suppression. The fire suppression equipment at W.M. Keck Observatory consists of widely available hand-held fire extinguishers. The hand-held fire extinguishers consist of carbon Dioxide (CO_2) and dry chemical (A-B-C) types. Personnel are trained in the use of hand-held fire extinguishers. Keck has a newly installed, modern fire alarm system consisting of pull stations, smoke, flame, and heat detectors in all areas of the observatory with a voice annunciation system and flashing lights. The fire alarm system also controls Halon/FM-200 agent release systems in key areas; Keck I and Keck II control and computer rooms, the interferometer control room, laser control room, and the two laser dye pump cabinets. There are also heat activated agent (FM-200) fire suppression systems in the dye pump cabinets and the laser table enclosure.

Fire drills are conducted three times per year. Two self-contained breathing apparatus (SCBA) units are also located at the W.M. Keck Observatory; and annual training is conducted on their use. There are currently five upgraded SCBA units maintained on the summit.

3.1.10 Socioeconomics

Introduction. Astronomy is an industry in Hawaiʻi and in particular on the island of Hawaiʻi because Mauna Kea offers exceptionally fine observing (viewing) conditions. The State and County have protected these conditions through the management of the summit of Mauna Kea and land use changes on the island of Hawaiʻi (*e.g.*, urban lighting) that could affect astronomical observations.

Astronomers and scientific organizations throughout the world have responded by investing in observatories on the summit. In addition, UH has developed an undergraduate program in astronomy at Hilo and a graduate program at Manoa with the ability to create scientific instruments for astronomical observations.

Demographics. Figure 3-11 shows the resident population for the State of Hawaiʻi determined in the decennial census of 2000 (USDOC 2000). The height of each bar in Figure 3-11 represents the population measured in thousands of persons. Percentages of the total population are shown above each bar. As indicated in the figure, over three-quarters of the population is composed of minority residents. Persons self-designated as Asian, Native Hawaiian or Other Pacific Islander, or multiracial (primarily Asian and Native Hawaiian) comprised approximately 67 percent of the total resident population.

Figure 3-12 shows similar information for the County of Hawaiʻi. Residents self-designated as Asian, Native Hawaiian or Other Pacific Islander, or multiracial comprised nearly 60 percent of the resident population of the County of Hawaiʻi.

The area surrounding MKSR is relatively unpopulated. Figure 3-13 shows the population residing within 50 km (31 mi) of the reserve. Moving outward from the reserve, resident populations show relatively large increases as one approaches population centers in Waimea and Hilo.

As shown in Table 3-11, population centers in Hilo and Waimea both experienced an overall increase in population during the decade between 1990 and 2000. During that decade, Waimea's population grew by approximately 18 percent, while Hilo's population grew by 8 percent.

Although the non-minority population in both areas declined, that decline was offset by growth in the minority populations. The enumeration conducted during Census 2000 showed that Waimea's population increased by approximately 1,000 to 7,028 residents.

The summit of Mauna Kea and the Astronomy Precinct has a transient population consisting of observatory staff

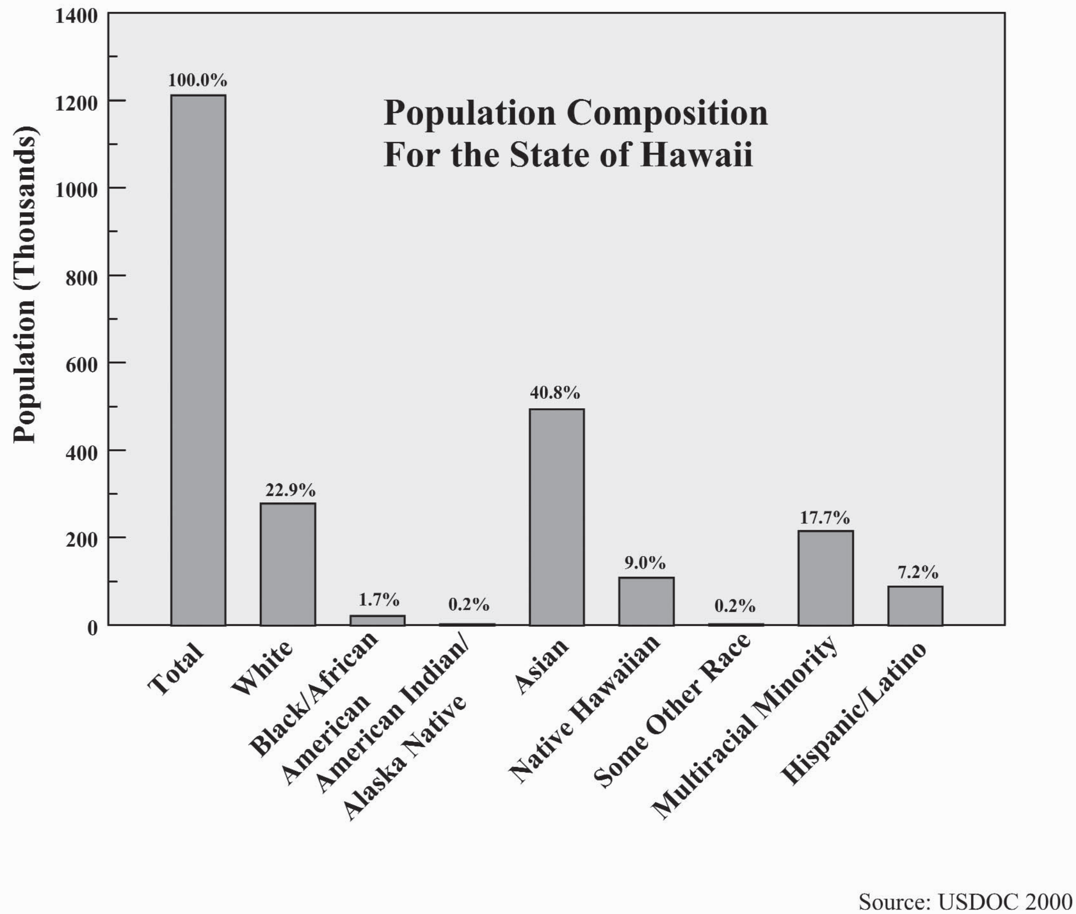
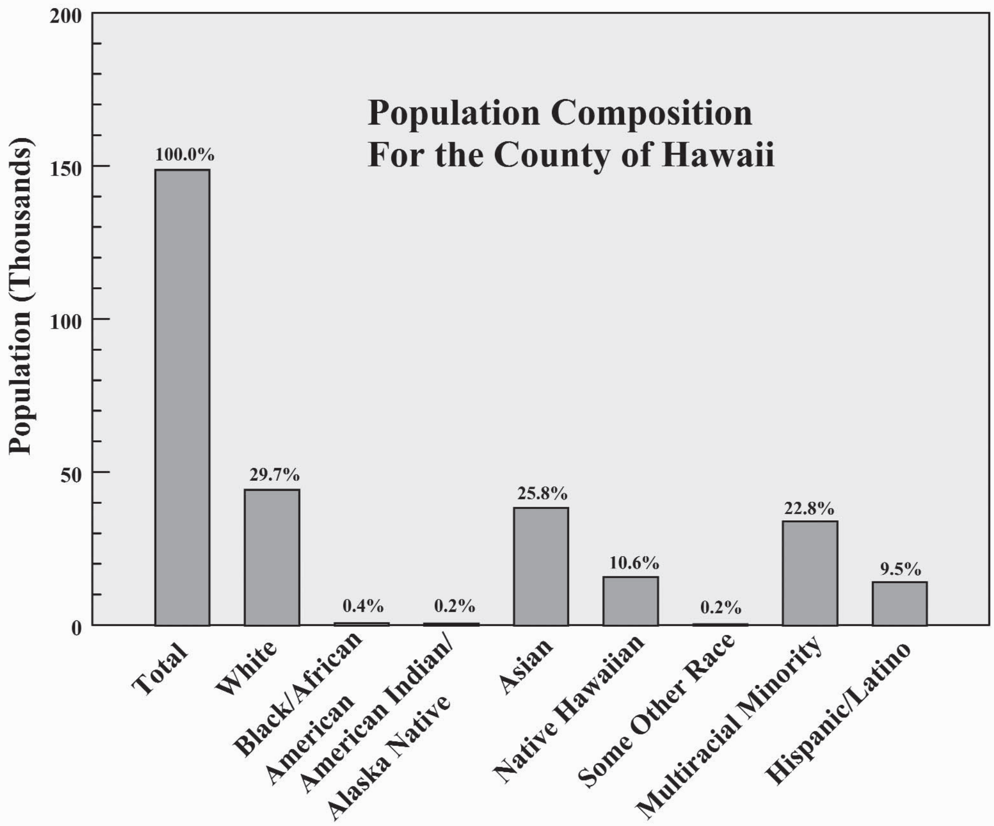


FIGURE 3-11. POPULATION FOR THE STATE OF HAWAI'I IN 2000

and visiting scientists, but no permanent residents. The average visitor census for the County of Hawai'i increased during the 1980's and 1990's. The County of Hawai'i has attracted an increasing share of the State's visitors. In comparison with 1999, visitor days for the island of Hawai'i declined by 3.7 percent in 2000 due to lower domestic and international arrivals. The average daily visitor census in 2000 was 21,831, approximately 4 percent less than the corresponding visitor census for 1999. Hale Pōhaku is visited by 100 or more visitors daily. Summit tours are increasing in number growth; tourism on Mauna Kea is a large part of a trend towards active tourism on the island of Hawai'i (see Table 3-10).

Economy, Employment, Expenditures, and Revenues. The average employed civilian labor force in the County of Hawai'i numbered 65,450 in 2000, an increase of 2,100 over the previous year. The County's average unemployment percentage declined from 8.7 percent in 1999 to 6.7 percent in 2000. The State of Hawai'i's average unemployment rate declined from

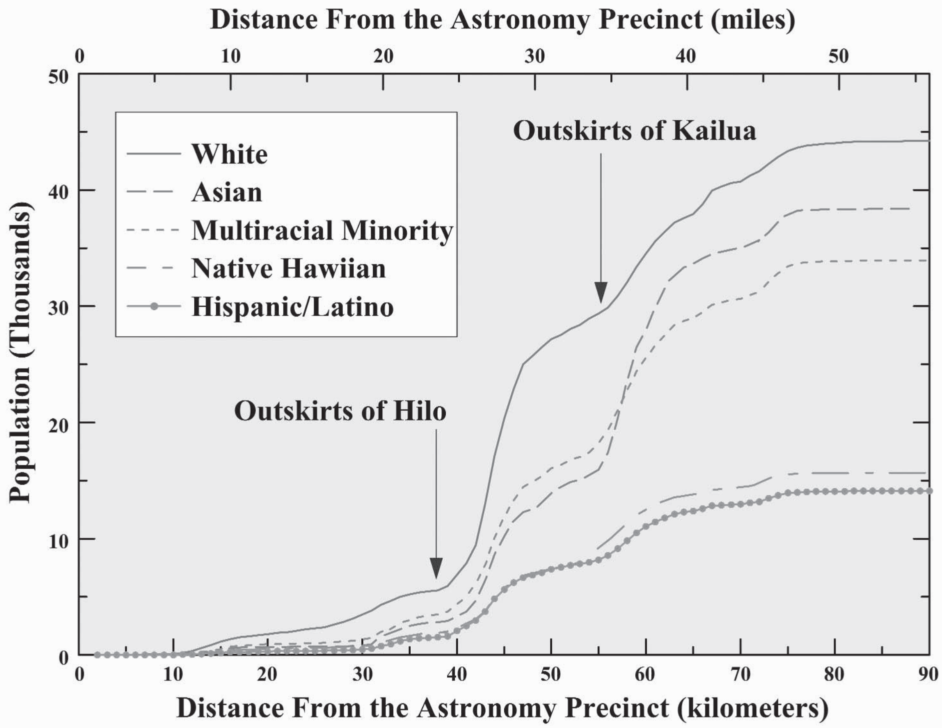


Source: USDOC 2000

FIGURE 3-12. POPULATION FOR THE COUNTY OF HAWAI‘I IN 2000

5.6 percent in 1999 to 4.3 percent in 2000. The unemployment rate for the County of Hawai‘i remains larger than that for the State of Hawai‘i as a whole. The closing of sugar plantations in Hāmākua, North Hilo, and Kau Districts contributed to the larger unemployment rate for the County of Hawai‘i. Median household income in the County in 1997 was estimated to be $34,557, which is approximately $9,000 less than the median household income for the State as a whole.

From the construction of new astronomy facilities, to the employment of trained technicians, to the purchases made by visiting scientists, the astronomy industry has contributed substantially to the island of Hawai‘i's economy. All of the telescopes on Mauna Kea have been built with funds coming from outside the State of Hawai‘i. Typically, a minimum of one-third of the funds for construction and more than 80 percent of the operating funds are spent in Hawai‘i, mostly on the island of Hawai‘i. Currently the telescope facilities on Mauna Kea represent a total capital investment of over $600 million dollars (not adjusted for inflation) and support nearly 500 direct operations jobs; the great majority of the jobs are located at base facilities in Waimea



Source: USDOC 2000

FIGURE 3-13. DISTRIBUTION OF POPULATIONS SURROUNDING THE ASTRONOMY PRECINCT IN THE MAUNA KEA SCIENCE RESERVE

TABLE 3-11. POPULATION TRENDS FOR HILO AND WAIMEA

Population	1990	2000	Percent Increase/Decrease
Hilo			
Minority	28,308	34,000	20.1
Non-Minority	9,420	6,759	-28.2
Total	37,728	40,759	8.0
Waimea			
Minority	3,718	4,964	33.5
Non-Minority	2,216	2,064	-6.9
Total	5,934	7,028	18.4

Source: USDOC 2001a

and Hilo (see Table 3-12). These employees are hired from a mix of Big Island and off-island locations. The best available information indicates that the majority of observatory employees are from the State of Hawai‘i. These jobs include astronomers, engineers and engineering technicians, software programmers, equipment technicians and administrative personnel. Such jobs in general command pay levels much higher than the Island average. Salaries of employees at the observatories on Mauna Kea range from mid-$20,000 to almost $150,000.

Total economic activity (direct, indirect and induced) as a result of Mauna Kea observatories is estimated at $130.9 million annually for the County and $141.7 million annually for the State (UH 1999). Direct employment and expenditures associated with the operation of the telescopes in the Astronomy Precinct represent approximately $61.1 million for the County and $63 million for the State annually. Indirect economic expenditures occur when astronomy-related firms purchase goods and services from other firms. There are also induced expenditures by the astronomy workforce, which are spent in the local community. Construction costs for all facilities built total approximately $826 million (converted to 1998 dollars). Roughly one fourth of the $826 million, or over $200 million was spent in the County of Hawai‘i (UH 1999).

All jobs generated by observatory purchases from other firms and spending by the direct and indirect workforce results in about 750 jobs on the island of Hawai‘i with a total payroll of about $45 million. State-wide employment consists of about 820 jobs, generating a total payroll of approximately $50 million (UH 1999).

Table 3-12 shows the capital and operating costs and employment generated by each telescope facility currently within the Astronomy Precinct.

3.1.11 Climate/Meteorology/Air Quality

3.1.11.1 Climate/Meteorology

MKSR, located above the 3,660-m (12,000-ft) elevation of Mauna Kea, is well above the 2,130-m (7,000-ft) altitude of atmospheric temperature inversions for the area. The northeastern or windward flanks of Mauna Kea are subjected to extensive rainfall that is a consequence of warm, moisture laden surface air driven up the slopes of the mountain from northeast to southwest by the trade winds (Arvidson 2002). The trade winds are a consequence of the synoptic scale (*i.e.*, pertaining to regional scales) meteorology associated with the Pacific Ocean anticyclone (high pressure zone) that is centered to the north (summer) and northeast (winter) of Hawai‘i (Erasmus 1986). Precipitation occurs as the air expands and cools as it moves up the slopes of the mountain, a process known as adiabatic expansion and cooling. Since cool air cannot hold as much vapor as warm air, the dew point temperature is reached and precipitation results. For example, the annual precipitation ranges from approximately 600 cm (236 in) at the Makahanaloa Station on the lower slopes (UH 1998) to approximately 50 cm (20 in) at the Very Long Baseline Array Station at an altitude of 3,840 meters (12,599 ft) (Metcalfe 2001). The summit is even drier as evidenced by Cruikshank's (1986) report of an annual average precipitation of 15 cm (6 in) based on data from 1969 to 1977 for optical telescope sites located on the summit cones.

High precipitation values associated with trade wind induced lifting of surface air masses extend to approximately 2,000 m (6,562 ft). At that altitude the ascending air meets subsiding, warmer air associated with

TABLE 3-12. MAUNA KEA OBSERVATORIES COSTS AND EMPLOYMENT BY FACILITY

Facility (mirror diameter in meters m=3.3 ft)	**Capital Cost ($ million)**	**Annual Operating Cost ($ million)**	**County of Hawai‘i Based Staff (No. of people)**	**Operational**
UH 0.6-m Telescope (Optical)	0.3	a	a	1968
UH 2.2-m Telescope (Optical/Infrared)	5	1.2	7	1970
Canada-France-Hawai‘i 3.6-m (Optical/Infrared)	30	6.2	50	1979
NASA IRTF 3.0-m (Infrared)	10	3.3	18	1979
United Kingdom 3.8-m (Infrared)	5	3.3	28	1979
James Clerk Maxwell 15-m Submillimeter	32	4.55	35	1986
Caltech 10.4-m Submillimeter	10	2.6	11	1986
W.M. Keck Observatory (Keck I & II) 2- 10-m (Optical/Infrared)	170	11.0	115	1992/96
VLBA Antenna 25-m (Radio)	7	0.25	2	1992
Submillimeter Arrays 8 x 6-m	80	6.0	36	2003
Subaru (Japan Nation Large Telescope) 8.2-m (Optical/Infrared)	170	15.0	70	1999
Gemini North 8.1-m (Optical/Infrared)	92	8.0	87	1999
Mauna Kea Observatories Support Services	Not applicable	2.4[b]	28	N/A
Total	611	63.8	487	—

Sources: adopted from UH IfA 2002a; CSO 2004c; JAC 2004c; Gemini 2004b; IRTF 2004; UH IfA 2004g

a. Combined budget and staffing with UH 2.2-m Telescope.

b. Not included in the total since derived from facility operating funds.

the Pacific Ocean anticyclone. This meeting of air masses produces an atmospheric inversion layer in which the air temperature actually increases by a few degrees Celsius (C) with a small increase in altitude. Above the inversion layer the air tends to become cooler with increasing altitude and to be dry and stable. The altitude of the inversion layer varies between 1,500 to 3,000 m (4,921 to 9,843 ft), depending on weather systems and season. The upper slopes and summit of Mauna Kea are located above the inversion layer, providing a climate for these areas that is best described as a dry, cold tundra-like environment.

Minimum nighttime winter temperatures at the summit are around –4ºC (25ºF); maximum daytime temperatures are about +4ºC (40ºF), but wind chill and the high altitude can make it seem much colder. Between April and November the weather is much milder, with daytime temperatures varying from freezing to almost 15º C (60ºF).

Particularly during the winter, storms from the southeast and southwest can reach the upper slopes and summit of the mountain. These storms are associated with a number of synoptic systems, including tropical cyclones. As a consequence, most precipitation above the inversion layer occurs during winter storms as snow, freezing rain, and rain. Typically the storm systems provide the majority of annual precipitation over a very small period of time (Arvidson 2002). Finally, fog is common just below the inversion layer and fog drip from leaves provide a source of soil moisture for the upland Māmane-Ohia shrub systems and Koa-Ohia forests (Arvidson 2002).

Winds at the summit follow a diurnal pattern of prevailing west/northwest winds during the day, and east/northeast winds at night. Wind velocity usually ranges from 16 to 48 km (10 to 30 mi) per hour. During severe winter storms, winds can exceed 160 km (100 mi) per hour on exposed summit areas, such as the top of cinder cones (UH 2000b). Such extreme weather conditions on the mountain make all activities potentially dangerous.

Hale Pōhaku. The climate at Hale Pōhaku is relatively dry and cool with a temperature range of -1 to 21ºC (30 to 70º F). With an annual average rainfall of about 64 cm (25 in), rain mostly occurs between November and March. Fog is common, while snow is rare (UH 2000b).

3.1.11.2 Air Quality

The existing meteorology, climate, air quality, ambient air quality standards, and estimated on-site construction-related emissions and impacts to air quality and mitigation measures are described in Dames & Moore (1999b).

Regulations. The National Ambient Air Quality Standards (NAAQS) are established by the Clean Air Act of 1970, as amended in 1977 and 1990. Under the Clean Air Act, States retain the option to develop more stringent standards. The NAAQS define the maximum levels of air pollution considered safe, with an adequate margin of safety, to protect the public health and welfare. The NAAQS are not to be exceeded more than once per year. The Hawaiʻi Department of Health (DOH) has developed the State Ambient Air Quality Standards (SAAQS). The SAAQS limit the time-averaged concentrations of specified pollutants dispersed or suspended in the ambient air of the State. Limiting concentrations specified in the SAAQS for a twelve-month period of a calendar quarter shall not be exceeded. Limiting concentrations specified in the SAAQS for 1-hour, 3-hour, 8-hour, and 24-hour periods shall not be exceeded more than once in any twelve-month period. The currently applicable State and Federal standards are shown in Table 3-13.

Air Quality Monitoring. The DOH has been monitoring ambient air quality in the State of Hawaiʻi since 1957. Before 1971, there was only one air monitoring station located on Oʻahu. Today the air-monitoring network has expanded to include twelve national, State, and local air quality monitoring stations on Oʻahu, Kauaʻi and Maui. A number of non-DOH air quality monitoring programs have been undertaken on the island of Hawaiʻi, most aimed at understanding volcanic emissions and human health effects. Ambient air measurements of selected parameters have been made at the Mauna Loa Observatory and would be the most comparable (Dames & Moore 1999b). The Mauna Loa data shows the following:

<u>Ozone</u>. Monthly averages range from 0.0243 to 0.063 parts per million (ppm), and the approximate range of hourly averages are from 0.015 to 0.08 ppm. No distinction was provided between baseline values and those collected during volcanic plume episodes. The highest hourly values, presumably collected during volcanic plume episodes would exceed the SAAQS, but not the NAAQS.

TABLE 3-13. NATIONAL AND STATE AMBIENT AIR QUALITY STANDARDS

Pollutant	Averaging Time	SAAQS[a]	NAAQS	
			Primary[b]	Secondary[c]
Ozone	8 Hour	157 µg/m^3 (0.08 ppm)	157 µg/m^3 (0.08 ppm)	No Standard
	1 Hour	No Standard	0.12 ppm	No Standard
Carbon Monoxide	8 Hour	5 mg/m^3 (4.4 ppm)	10 mg/m^3 (9.0 ppm)	No Standard
	1 Hour	10 mg/m^3 (9 ppm)	40 mg/m^3 (35 ppm)	No Standard
Nitrogen Dioxide	Annual (Arithmetic Mean)	70 µg/m^3 (0.04 ppm)	100 µg/m^3 (0.05 ppm)	Same as Primary
Sulfur Dioxide	Annual Average	80 µg/m^3 (0.03 ppm)	80 µg/m^3 (0.03 ppm)	No Standard
	24 Hour	365 µg/m^3 (0.14 ppm)	365 µg/m^3 (0.14 ppm)	No Standard
	3 Hour	1,300 µg/m^3 (0.5 ppm)	No Standard	1,300 µg/m^3 (0.5 ppm)
Particulate Matter (PM_{10})	Annual (Arithmetic Mean)	50 µg/m^3	50 µg/m^3	Same as Primary
	24 Hour	150 µg/m^3	150 µg/m^3	Same as Primary
Particulate Matter ($PM_{2.5}$)	Annual	No Standard	15 µg/m^3	No Standard
	24 Hour	No Standard	65 µg/m^3	No Standard
Lead	Calendar Quarter	1.5 µg/m^3	1.5 µg/m^3	Same as Primary
Hydrogen Sulfide	1 Hour	35 µg/m^3 (25ppb)	No Standard	No Standard

a. Designated to protect public health and welfare and to prevent significant deterioration of air quality. Source: HAR 11-59-1.

b. Designated to protect the public health. Source: 40 CFR Part 50.

c. Designated to protect the public welfare from known or anticipated adverse effects including the effects on economic values and personal comfort (*e.g.*, protect against environmental damage, such as damage to soils, crops, wildlife, weather, climate and personal comfort). Source: 40 CFR Part 50.

Carbon Monoxide. The long-term (1994 to 1995) average is 0.0925 ppm, with a range of 0.054 to 0.164 ppm. The given averages are well below the SAAQS and NAAQS.

Sulfur Dioxide. The background average is less than 0.00001 ppm, again below the SAAQS and NAAQS annual average (Dames & Moore 1999b).

Mauna Kea Summit Area. Although air quality has not been sampled or monitored at MKSR, its geographic and meteorological isolation produces excellent air quality (Dames & Moore 1999b). The summit of Mauna Kea is well above the altitude of temperature inversions for the area. Air pollutants generated below the inversion layer (smog, smoke, dust, salt spray, etc.)

generally do not affect air quality at the summit of Mauna Kea.

Locally generated atmospheric pollutants at the summit are primarily emissions from combustion engines and fugitive dust from construction activities and unpaved surfaces. Winds at the summit area aid in the dispersion of air pollutants generated by summit activity.

3.1.12 Noise

Background noise levels at the summit of Mauna Kea (including the W.M. Keck Observatory site) and the Mid-Elevation Support Facilities consist primarily of sounds associated with the wind and vehicular noise. The summit of Mauna Kea normally has a low ambient noise level. Existing facility operations generate extremely low noise levels and there are few nearby noise-sensitive receptors. Temporary construction-related noise is discussed in Section 4.1.11.2.

3.1.13 Visual/Aesthetics

The W.M. Keck Observatory site at Puʻu Hauʻoki is presently occupied by the two 10-m (33-ft) Keck Telescopes and associated domes and support structures (see Figure 3-14). The two Keck Telescope domes are each about 34-m (111-ft) high by 37-m (121.4-ft) wide, are white in color, comprising the most prominent visual feature at the W.M. Keck Observatory site.

The existing Keck I and Keck II Telescopes, as well as the other existing telescope facilities within the Astronomy Precinct, are generally visible from within the summit area. Below the summit, the view of these facilities from the Mauna Kea Access Road is typically blocked by the topography of the mountain (UH 2000b). Some of the existing facilities are visible from lower elevation areas such as Hilo, Honokaʻa, and Waimea (see Figure 3-14). The twin Keck Telescopes are not visible from the city of Hilo. The facilities at Hale Pōhaku consist of the astronomy support facilities and construction camp facilities, all of which are generally visible from the Mauna Kea Access Road (UH 2000b). These facilities have been sited and constructed to follow mountain contours and colored to blend with the surrounding features. The single-story construction camp facilities are located to avoid the existing *māmane* trees. Materials and roof colors of the newer facilities were chosen to blend with the surrounding terrain.

3.2 AFFECTED ENVIRONMENT OF THE CANARY ISLANDS ALTERNATIVE

3.2.1 Land Use and Existing Activities

Land Use. The Canary Islands are seven volcanic outcrops, scattered over 480 km (300 mi) in the middle of the Atlantic Ocean. To the east of the island of La Palma (about 450 km (280 mi)) lies Western Sahara and to the northeast of the island lies Morocco. As an Autonomous Region of Spain, the islands are over 1,600 km (1,000 mi) from Madrid, which is located near the center of the Iberian Peninsula. The Canary Islands are included in the Greenwich Mean Time (GMT) zone, (although geographically their longitude places them within the GMT -1). The time in the islands is the same as in Great Britain, Ireland, Portugal, Iceland and Western Africa, (one hour behind the rest of Spain and other Western European countries.

Historically, the "Canarias" have survived on an agricultural based economy, growing consuming and exporting, bananas, sugar cane, tobacco and wines. A massive growth in tourism in the islands since the 1960s has in many locations refaced the landscape. New resorts such as Playa de Las Americas are springing up across the shorefronts, particularly in the most easterly of the

FIGURE 3-14. EXISTING VIEW OF THE W.M. KECK OBSERVATORY

islands. However, the islands of La Gomera, El Hierro and La Palma in the west are only now beginning to provide the most basic tourist facilities.

The island of La Palma supports a population of about 80,000 people. The island capital of Santa Cruz de la Palma, a city of 18,000 lies along the eastern shore and is the sole shipping seaport on the island. The majority of the island is occupied by the large central volcanic caldera, rising to an elevation of over 2,400 m (7,900 ft) above sea level along its steep rim. Most of the remaining 730 km^2 (280 mi^2) of the island is a rural setting of banana plantations, vineyards and forests. The majority of the islands population lives within and around the city of Santa Cruz de La Palma and the land around the city of Los Llanos on the western shore. The island is divided into 14 municipalities: Barlovento, Breña Alta, Breña Baja, Fuencaliente, Garafía, Los Llanos de Aridane, El Paso, Puntagorda, Puntallana, San Andrés y Sauces, Santa Cruz de la Palma, Tazacorte, Tijarafe, Villa de Mazo. The central portion of the island is occupied by a large ring of extinct volcanic summits creating a large caldera or basin on the order of 8 km (5 mi) in diameter. This geologic feature is the most prominent geographic element of the island. The Observatorio del Roque de Los Muchachos (ORM) is located within the boundaries of the National Park of the Caldera of Taburiente on the northern facing slope of the caldera. One of the objectives of the Governing Plan of Use and Management of the National Park of the Caldera of Taburiente it is to promote the socioeconomic development of the communities located on the periphery of the National Park while being consistent with environmental conservation. For that reason, different types of activities exist in the interior of the National Park.

"The entire ORM compound is Federal property owned by the government of Spain and made available to the international scientific community through the Agreement on Cooperation in Astrophysics. Administration and management of ORM is by the Instituto de Astrofisica de Canarias (IAC) which is headquartered on the island of Tenerife in the town of La Laguna. There would be no purchase or lease involved in establishing a site for the Outrigger Telescopes Project at ORM. Official authorization would require unanimous consent of the International Scientific Committee (CCI), in accordance with the provisions of the Protocol on Cooperation in Astrophysics" (ATST).

Traditionally, the terrain in and around the ORM site was used for pasture during the summer months on the island. The Law 4/1981 (25 of March, 1981) reclassified the park as the National Park of the Caldera of Taburiente. Under this same law provisions were made for construction activities that were favored by the patronage of the park. The Gran Telescopio Canarias (GTC) is located in the ORM, and astronomical activities have been declared compatible with the traditional use of the grounds within the ORM.

Existing Uses. Tourism is not a major factor on this agriculturally based island, but there is a large amount of lodging available on a short and long term basis.

Inside the National Park of La Caldera de Taburiente, park camping and hiking are allowed by permits issued through the National Park offices. Camping duration is limited to 2 through 6 night stays. There are two zones within the caldera that are off limits excepts for scientific and management purposes. Park visits for 2003 were about 378,000. The small amount of agriculture permitted within the National Park is limited to small fruit orchards. Most of tourism to the edge of the caldera occurs on the south rim due to developed overlook areas.

Access to the ORM is not restricted to astronomy-related personnel. Observatory facilities themselves are open for public guided tours on only 3 to 4 days per year.

3.2.2 Cultural Resources

The Canary Islands have been recorded in history as far back as the ancient Greeks, but as ancient beliefs placed the islands at the rim of the world there was limited travel to the “Fortunate Islands”. Europeans re-discovered the Fortunate islands in the first half of the 14th century. Upon arrival they found a people living there who later came to be known as the Guanches. It is thought that the Guanches (a tall and light skinned people) originated from the Berbers of the Atlas region in Africa (modern day Morroco) who share a close locality and similar characteristics. On the island of La Palma, the native Guanches went by the name of *Benahoare*, pronounced "Ben-Ajuar", and meaning "from the tribe of Ahoare" (tribe of the African Atlas). Today, some inhabitants of the island still possess this ancient lineage.

According to the tourist board, the real lifestyle and personality of La Palma and its inhabitants can be found in its celebrations, which begin with Christmas and Epiphany, and finish with the festival of Lucía a year later. Such importance is given to celebrations on this island that every week there is a competition of the typical Canarian sport Lucha Canaria (Canarian ringfighting). There are groups that perform typical dances and sing all over the island, competitions between horses and stalls selling grilled pork meat.

3.2.3 Biological Resources and Threatened and Endangered Species

The ORM is located within the National Park of La Caldera de Taburiente near the Roque de Los Muchachos landmark at an elevation of approximately 2,400 m (7,900 ft). The locale has an arid climate and is primarily populated by small birds and reptiles that live in the rocks and sparse vegetation. The soil makeup of the observatory area has been formed from the alteration of the lava and pyroclastics into clays fundamentally through the process of water infiltration. The depth of the topsoil is generally very thin and ranges from 20 to 30 cm (8 to 12 in) in the most weathered regions to areas of exposed rock breccia and tuffa. The presence of organic matter is very low in most areas. Due to the shallow nature of the soil and its low organic makeup it is easily disturbed and slow to recover once a disruption occurs.

The island of La Palma is host to approximately 900 species of flora. Of this number approximately 104 are endemic to the Canary Islands, 33 to Macaronesia (*i.e.*, Madeira, the Azores, the Canary Islands, and Cape Verde Islands), and the remaining 700-plus have been introduced on purpose or by accident.

Plant species in La Palma are grouped into communities distributed, according to climate and altitude, into different layers of vegetation. These layers are determined by the physical geography of mountain regions and the predominance of certain species over others. Climatic conditions at the island of La Palma have given rise to a stratum of vegetation zones that ascend from sea level up to the 2,400-m (7,900-ft) elevations at the ORM. At the lowest elevation, coastal vegetation grows, including types typical of cliffs and sandy regions. Along the transition zone from 50 to 500 m (160 to

1,600 ft), between the sea level coastal community and giving way to laurisilva (*i.e.*, a specific type of forest) vegetation, there are thermophiles (*i.e.*, heat loving flora) and pre-steppe bush. Humid and shady laurisilva forest grows between 500 and 1,400 m (1,600 and 5,600 ft) in elevation, with some species reaching more than 20 m (66 ft) in height. Endemic Macaronesian heaths, also known as fayal-brezal, grow from 500 to 1,700 m (1,600 to 5,600 ft), as transition vegetation between laurisilva and Canarian endemic pine forests, with which they share some species (*Ilex canariensis, I. perado, Larus azorica,* and *Picconia excelsa)*.

Canarian endemic pine forests (*Pinus canariensis*) are found almost at sea level in southern areas but in the northern parts of the islands are found from 1,200 to 2,400 m (3,900 to 7,900 ft) in elevation. Finally, vegetation grows in the high mountains above 2,000 m (6,600 ft) on La Palma and Tenerife. This flora consists mostly of grasses and low shrubs. The ORM and, within it, the GTC site are located at the uppermost elevation of vegetation types.

The area surrounding the GTC site is populated with a subalpine groundcover composed of mountain scrub, predominantly wild codeso (*adenocarpus viscosus var sapartioides*) with a small amount of medium stature spartocytisus supranubius. The distribution of vegetation in this area is dependent on the presence of sufficient soil and is therefore more prominent on the slope faces than the run-off areas where rainwater has carried away the soil. The flora of this site, like the soil, is easily damaged by foot traffic and machinery.

There has been no identified protected endemic plant species identified in the area surrounding the GTC. The protected species list for this region consists of:

- Retamón (*teline benehoavensis*)
- Violet of The Palm (*violates palmensis*)
- Lettuce of The Palm (*lactose palmensis*)
- Tajinaste (*Echium gentianoides*)

During the 1999 GTC Environmental Impact Study only one type of mammal was found in the area surrounding the GTC site. The mammal was the rabbit of the species oryctolagus cuniculus and is not endemic to the island. Of the mammals found in the Park, the only endemic ones are three species of bats of which none were found on the site.

The largest population of vertebrates found in the area surrounding the GTC in the 1999 survey were birds, however, there were no nesting sites identified. The species of these birds are:

- Kestrel (*falco tinnunculus conariensis*)
- Dove turqué (*columba trocaz bollei*)
- Rook, ravens, mirlos, herrerillos, etc.

No reptiles were identified in the 1999 survey, though there is a possibility of encountering the Lacerta galloti or Tizon Lizard.

During the 1999 environmental survey, there were no species of protected flora or fauna identified in the area surrounding the GTC site. According to Law 4/1989 pertaining to the Conservation of the Natural Species and the Wild Flora and Fauna, enacted on the 27 of March, 1989 the following species are to be protected by measures necessary to conserve their populations and habitats. The species are divided into two categories denoted with the roman numerals I and II. Species pertaining to the Rouque de Los Muchachos Observatory are:

I. Species or Subspecies catalogued "in danger of extinction" in the Observatorio del Roque de Los Muchachos, ORM *None*

II. Any Species or Subspecies catalogued "of special interest" in the Observatorio del Roque de Los Muchachos, ORM

Birds

- Sparrowhawk (*Accipiter nisus*)
- Mousy (*Buleo buleo*)
- Vulgar kestrel (*Falco tinnunculus*)
- Bisbita runner (*Anthus berthelotii*)
- Petirrojo (*Erithacus rubecula*)
- Curruca tornillera (*Sylvia conspicillata*)
- Curruca cabecinegra (*Sylvia melanocephala*)
- Common mosquito netting (*Phylloscopus collybita*)
- Simple little king (*Regulus regulus*)
- Common Herrerillo (*Parus caeruleus*)
- Alcaudón real (*Lanius excubitor*)
- Chova piquirroja (*Pyrrhocorax pyrrhocorax*)

Mammals

- Moorish sprocket wheel (*Erinaceus algirus algirus*)
- Orejudo canario (*Plecotus tenerifiae*)
- Bat of Madeira (*Pipistrellus maderensis*)

Reptiles

- Lizard tizón (*Gallotia galloti*)

In the 1999 survey there was a finding of no impact concerning type I and type II protected species within the GTC area of the ORM.

According to statements within the Advanced Technology Solar Telescope project "Site Feasibility Report" dated June 18, 2003, the entire ORM compound is within the Peripheral Protection Zone for the National Park and as such is legally defined as an Ecologically Sensitive Area. Construction of ATST or other facilities at the ORM would require the completion of an Environmental Impact Study. This document would be prepared by an environmental engineering firm and submitted to the Municipality of Garafía. The municipality would then transmit their findings to the Caldera de Taburiente National Park Board and to the Regional Government Ministry of the Environment (*Viceconsejería de Medio Ambiente*) for their review and a positive or negative recommendation regarding the project.

Three groups that are active in biological conservation on the island of La Palma are:

1. **The Canary Island Network of Protected Natural Areas** was set up to develop a complete management model to reconcile the conservation of biodiversity in the islands, the protection of cultural and aesthetic values, and the supply of environmental goods and services to society.
2. **Natura 2000** The main objective of the Natura 2000 Network is preservation of European biodiversity, *i.e.,* habitats and species of Community interest. Although it also aims to guarantee conservation of these values through sustainable development, it is more selective with the habitats and species of the Canary Islands. It focuses mainly on endangered habitats listed in Annex I

of the Habitats Directive (Council Directive 92/43/EEC, of 21st May, on the conservation of natural habitats and of wild fauna and flora) and species whose habitats need to be conserved, as included in Annex II of the Directive.

3. **The United Nations Educational Scientific, and Cultural Organization World Network of Biosphere Reserves** has the difficult task of reconciling conservation and sustainable development in the planet. It combines conservation of the natural environment with research, environmental monitoring, environmental education and training, contribution to development and social participation. Its work encompasses large territorial areas, as can be seen in the archipelago's three reserves, Los Tiles (which extends over 4 municipalities of La Palma), the island of Lanzarote and the island of El Hierro.

3.2.4 Hydrology and Water Quality

La Palma, "Isla Bonita", possesses a wide variety of land shapes and erosional features as a result of its volcanic origins and the affects of rainfall and subterranean water. The Caldera de Taburiente is testament to these natural processes. Water has shaped the great kettle, La Caldera, and large monolithic volcanic formations can be seen standing out from the surrounding basin walls as a result of massive avalanches referred to as "afterbreaks" in the huge walls resting on the ancient bottom of the Caldera. There are also a large number of springs in the National Park. Their waters either fall in gentle torrents or from great heights thus producing picturesque waterfalls.

The GTC site sits on the north facing slope of this basin within the ORM boundary, where the more gentle slopes and altered surface rocks allow for more direct percolation and less catastrophic slope failures. Studies in the immediate vicinity of the GTC site confirmed the surface runoff characteristics as limited to the adjacent waterways to the east and to the west. No water channels or drainages cross the site itself. Further, within Section 10.4 of the environmental report for the GTC (1999) it states that no subterranean watercourses or aquifers cross the site intended for the GTC. Because of the small footprint and the relatively small increase in hard surface that the GTC represents, no further investigation was conducted. No water either non-potable or potable is derived from runoff catchments or cisterns at the GTC site. Utility and sanitary water requirements are met via weekly truck deliveries and all potable water is brought to the site in bottles.

Domestic Wastewater Collection, Treatment and Disposal. The effluent systems on the GTC site consist of bacterial septic tanks and leech fields (absorption wells). It is anticipated that within several years (3 or 4 years), island wide improvements will be mandated for protection of groundwater reserves.

3.2.5 Solid Waste and Hazardous Materials Management

As a component of GTC routine activities, mirror segment cleaning and recoating will be an ongoing operation. The liquids and byproducts associated with the scheduled, rotating maintenance of the 36 segments of the primary optics assembly represents the most important consideration of hazardous material handling at the site.

The frequency of changing and washing of mirrors is approximated at 3 segments every 2 months.

In this period the use of 615 l (162 gal) of potentially toxic fluids take place. The washing will be performed in an enclosed room located on the first floor of the telescope building.

The following substances are used for the washing of each primary mirror segment:

- 1 l (0.26 gal) of hydrogen chloride (HCl) Concentration of 4 percent
- 1 l (0.26 gal) of copper sulfate ($CuSO_4$); Concentration of 4 percent
- 2 l (0.53 gal) of KOH; Concentration of 10 percent
- 1 l (0.26 gal) of Isopropyl alcohol
- 200 l (53 gal) of H_2O.

3.2.6 Geology, Soils, and Slope Stability

The entire island of La Palma is comprised of overlying strata of volcanics. The central morphologic feature of the island is the Caldera de Taburiente. This caldera or "kettle" has been formed from a series of volcanic eruptions with spires or "roques" rising above sea level in some locations to over 2,400 m (7,900 ft). This ring of summits has resulted in the large central basin, (caldera), nearly 8 km (5 mi) in diameter. At the Roque de Los Muchachos, the highest point on the island, the drop to Dos Aquas at the park entrance is nearly 1,830 m (6,000 ft). The dramatic geomorphology of this steep sided basin is the result of water and wind erosion of the largely weathered and stratified volcanic lava beds, pyroclastics and tuffa (ash), deposits.

The ORM occupies 190 ha (470 ac) of land on the north-facing slope of this large caldera. Situated at an elevation of 2,426 m above mean sea level (AMSL) (about 8,000 ft AMSL) the volcanic rocks and deposits of the mountain sustain little vegetation and a minimal soil profile. The GTC site may be characterized as a broad northwest sloping (18 percent) plain of altered volcanic pyroclastics and dykes bounded on both the east and west by steep, relatively parallel, "vaguadas" or waterways that course down the mountain through the weathered rock. The geomorphologic unit in which this site sits, is believed to be the remnants of a volcanic cone formed from outcrops of a strata known as the "Lava of the Galileo". Studies conducted as a portion of the site investigations for the GTC published in 1999 indicate a three-component complex layering of volcanics in the immediate vicinity of the proposed site.

The upper 1 to 3 m (3 to 10 ft) of this area is comprised of altered lava that has been weathered into clays interrupted by lenses of pyroclastic deposits. The compressive strength of this layer, according to GTC studies is low, (50-60 Kp/cm²). Below this zone a "medium level" from 1 to 6 m (3 to 20 ft) in thickness is identified. This layer consists of basaltic lava, exhibiting shrinkage fractures with minimal separation as a result of initial cooling. Breaking strengths of these formations are substantially higher than the upper materials with capacities ranging from 720 to 1,404 Kp/cm². Below this level the rock once again has been found to be severely weathered with low load bearing capacity. Throughout the volcanic deposits and occurring at various depths are a series of monolithic dikes.

The altered state of the volcanics that comprise the upper layers of the strata at the GTC site result in a surface susceptible to erosion and disruption as a result of project related activities. The slopes on which the GTC project is situated, particularly in the vicinity of the waterways, therefore require consideration during project planning and execution to avoid accelerated degradation or slope failure.

According to historical records seismic activity on La Palma is very low and most commonly associated with past volcanism in the southern portion of the island. Recent studies as a part of the Advanced Technology Solar Telescope site investigations at the ORM considered the risk of anticipated lateral ground motion as a result of possible eruption or collapse along the volcanic rift zones in the south portions of the island, relatively minor. The Spanish building code assigns the region surrounding the ORM its lowest level of seismic risk and a very low ground motion coefficient.

3.2.7 Geologic Hazards

Seismic Activity. As reported by the GTC in *Atmospheric Parameters for Site Selection* authored by C. Muñoz-Tuñón, A.M. Varela & B. García Lorenzo (Instituto de Astrofísica de Canarias). The ORM is located in a degree 7 zone (seismic resistance regulation NCSE 94), which corresponds to a horizontal acceleration of 0.08 g. Contrary to what happens on other volcanic islands, *e.g*,. Hawai'i, earthquakes are very rare in the Canaries.

The Canarian archipelago is relatively old, 3 to 4 million years "… therefore seismic activity is not a problem to be taken into account" (Anguita & Hernán 2000). Furthermore, in the ATST survey for site selection, it was found that seismic activity on La Palma is historically very low and mostly centered around volcanism in the south part of the island. The study points out that the Spanish building code assigns the region is its lowest level of seismic risk and a very low ground motion coefficient.

Volcanism. The island of La Palma is volcanic in origin. Never a part of the African continent, it formed through volcanic accumulation associated with the mid-Atlantic ridge (tectonic plate juncture). Eruptions on this island have occurred in the recent past and take place at the southern end of the island.

Following is a list of recent eruptions and their locations:

- **Tacande** (between 1470 and 1492). This volcano erupted in the upper part of the Valle de Aridane before the arrival of the Spanish on the island. The aborigines called it Tacande or "burned mountain" due to its black color.
- **Tajuya-Jedey** (1585). On the night of May 19th, on a flat hill above the last few houses, a mountain began to form as rocks and lava were launched from various vents. The eruption finished on August 10th and formed one of the most complex morphological groups of volcanoes in La Palma: spectacular phonolithic blocks can be seen here.
- **Martín** (1646). On September 31st smoke was seen to rise from Cumbre Vieja. In the following days enormous quantities of ash, rock and four streams of lava spilled out onto the western part of the island. At the same time, on the seashore below, at Fuencaliente, two more vents burst open. Activity ceased on December 18th.
- **San Antonio** (1677). On November 13th, the first tremors were felt. They continued without any other sign until the eve of the 17th, when smoke began to rise from around the mountain below the village of Los Canarios. A main vent burst open. This together with smaller ones, formed a stream of fire, which slowly flowed in the direction of Fuente Santa thermal spring, here it was buried as molten lava fell in cascades over it and into the sea. This volcano stopped erupting on January 21st of the following year.

- **Charco** (1712). On October 4th the ground began to tremble and several tremors took place. On the 8th smoke began to emerge from the earth at the Charco estate, the property of Mrs. Ana Teresa Massieu, exactly where a spring was located. Eruption began on Sunday, the following day when two fissures burst open. Another twelve or so smaller vents slowly opened up and two large cracks appeared. The volcano ceased activity before dawn on December 3rd.
- **San Juan** (1949). On June 24th at 9am, with a loud roar, ash, fire and lava were thrown over Cumbre Vieja and the first crater opened (El Duraznero). On July 8th at 4.30am in the morning, a large crack appeared in a plain known Llano del Banco, from which large quantities of lava flowed down to the sea. On July 13th, the Duraznero crater exploded, hurling ash, burning stones and gases into the air. A new crater opened at 4pm in Hoyo Negro, producing a shower of ashes over Los Llanos de Aridane with a strong smell of sulphur. The eruption ceased on August 3rd.
- **Teneguía** (1971). On October 26th shortly after 3pm a new volcano erupted on some plains close to the Teneguía outcrop, after which the volcano was named. From an impressive crack, several vents spouted ash and burning rock forming a stream of lava. Eruptions stop suddenly on November 18th.

3.2.8 Transportation

The island of La Palma has an international airport that is located on its eastern coast just outside the capital of Santa Cruz de La Palma. The island is also accessible from neighboring islands by plane or ferry. The road to the observatory is two-way and entirely paved. The ORM is accessible via two routes, LP 1032 from the capital of Santa Cruz de La Palma is a direct route but is made up of many curves, precipitous sections and requires about an hour to reach the site, and LP 113 from the town of Santa Domingo de la Garafia is a more forgiving route, one that entails a circuitous route around the northern end of the island if departing from Santa Cruz.

3.2.9 Utilities and Services

3.2.9.1 Water Supply

Non-potable water is trucked to site weekly. There are water storage tanks at the residence buildings and each telescope has its own cistern. The GTC site has two 1,000-l (260-gal) cisterns that are used for sanitary/utility purposes and one 30,000-l (7,900-gal) storage to be used for fire suppression. Drinking water is brought to site in bottles. The GTC facility and all other observatories maintain and supply water as a part of their own independent systems.

3.2.9.2 Electrical Power and Communications

The main electrical service for ORM is provided by the local power company UNELCO controls electricity on the island of La Palma and provides a 4-megawatt capacity to the ORM. The primary feed is from a substation below at about the 1,000 m (3,281 ft) level. The line runs mostly overhead to get to the vicinity of the observatory and underground for the last 2 km (1.2 mi).

When this main power line is out, which is normally for 2 or 3 hours at a time and a total of about 24 hours per year, back-up power is provided by dedicated individual generators at each of the telescope facilities. GTC generator capacity 969 kW for about 24 hours at full load.

Due to the infrequency and short duration of the outages, most of the facilities at ORM only provide enough back-up power for safe shut-down, keeping instruments warm (or cool), and other essentials, but not for full observing operation. The peak power demand experienced at ORM during the ATST site survey was about 500 KVA. However, the main substation capacity made an upgrade to newer equipment with higher capacity to serve the needs of the GTC telescope. The GTC is supplied with 1megawatt but has an anticipated load of less than 850 kW. The high-tension line voltage of 15,000 V is stepped down at several locations on the ORM compound to 380 V, 3-phase/220 V 1-phase, 50 Hz. for use at the telescope facilities. The GTC receives its power distribution from bank of 6 8000 volt/400 amp sections located in the main telescope building adjacent to the control room.

Telecommunications. The telecommunication network at the ORM site consists of a fiber optic network. The network connects all the facilities on the observatory site and then is run down the mountain to Garafia. From Garafia the fiber routes to Santa Cruz de La Palma were it runs underwater to the island of Tenerife and connects directly to the IAC.

3.2.9.3 Emergency Services and Fire Suppression

Emergency Services. There are four helipads located within several hundred yards of the observatory these allow an emergency victim to be lifted off the mountain in much less time than the drive would require. The nearest hospital is located in the municipality of Garafia at the northern base of the mountain.

Fire Suppression. The GTC facilities store approximately 30,000 l (7,900 gal) of water for fire suppression. The approximate duration of water availability for fire suppression when pumps are at full power is less than two hours.

3.2.10 Socioeconomics

The inhabitants of La Palma are traditionally a farming based island society. The crops that they cultivate include bananas, tobacco, almonds, grapes (for winemaking), and sugar (both for export and to be used in rum). Tourism draw on the island is small and is primarily reserved to hiking and natural sightseeing in the national park. The island population is approximately 80,000 people. The largest City is Santa Cruz and harbors the largest population on the island (about 18,000).

The area of the 1999 GTC Site study was the municipality of Garafía. Outside this municipality in the surrounding areas land is generally classified as rural land and is therefore prohibited for urban building. However, according to the Classification of Use of Suelo established in the Special Plan of Arrangement of the Roque de Los Muchachos, the observatory land is located in zone Class I, and is therefore allowed to undertake the construction of facilities for astronomical observation.

The population affected by the project was divided into three groups in the GTC survey:

- The small community of scientists and personal to help that it lodges in the town
  - Those at the ORM in the installations dedicated to such effect
  - Those that will work in the future as a result of the operation of the GTC
- Workers during the construction of the GTC
- Tourists and local population.

In the 1999 GTC Site survey it was found that in all three cases the construction of an additional telescope at the ORM would not have a negative socioeconomic effect on these groups.

3.2.11 Climate/Meteorology/Air Quality

Along the coastline of the Canary Islands the year round average temperatures range between 19 and 22 ºC (66 and 72 ºF). The coasts along southern shores are usually more sunny and arid while the shores along northern exposures are much greener. Storms generated out in the Atlantic, although not frequent, generally visit the islands from mid-November until March.

The trade winds blow from the northeast consistently below an altitude of 1,500 m (4,900 ft) and bring with them moist air which counterbalances the heat of the nearly tropical latitude. These lower trade winds arrive at the islands after blowing along hundreds of kilometers in contact with the ocean.

They are generally constant mild breezes, but they tend to be stronger in summer than in winter. Above the 1,500-m (4,900-ft) altitude blows the hot, dry trade winds from the northwest. The moist fresh air brought by lower trade winds does not rise, because the warmer air brought by the upper trade winds form an inversion, thus prohibiting the formation of vertically developing cumulus clouds.

On the island of La Palma, at the Observatorio Del Roque de Los Muchachos, (elevation about 2,400 m (7,900 ft) AMSL), in the winter, when cold fronts from the north and northeast move in, snow often falls on the summits. Occasionally, however, the seasonal weather pattern is interrupted by the "tiempo sur" or east wind that periodically brings hot dry air from Africa. This periodic phenomenon occurs several times a year and normally lasts for a period of a few days. These winds carry with them the potential of high altitude dust particles from the Sahara Desert.

A two-year weather study was conducted as a part of the site analysis for the GTC at the ORM. Measurements were obtained from a station 6 m (20 ft) above the surrounding terrain. The following information summarizes this effort:

- Temperatures: Maximum high: 25º C (77º F); Minimum low –8º C (18º F). The eight year average temperature from November through May was 4º C (39º F) and from the months of April through October 12º C (54º F).
- Relative Humidity: Maximum absolute: 100 percent. Minimum absolute: 1 percent. Media: Between 10 and 50 percent.
- Pressure barométrica: between 720 and 800 millibar (mbar).
- Wind: Velocity: Maximum to 198 km/h (124 mph), with wind gusts to 241 km/s (151 mph). Dominant direction: North – Northwest.
- Precipitation: Maximum precipitation for 24 hours: 300 mm (11.8 in). Maximum precipitation for 1 hour: 120 mm (4.7 in).
- The IAC utilized data from an 8-year study to (at an elevation of 2,367 m (7,766 ft) at Izana) estimate an average annual precipitation of 45 cm (18 in).
- Thickness of the layer of snow: Variable between 1 and 2.25 m (3.3 and 7.4 ft).
- Thickness of the layer of ice: Maximum of 0.25 m (0.82 ft).
- Occasional electric storms are registered.

- Presence of high static electricity levels.
- Sporadic incident at night with high levels of dust Sahariano (tiempo sur – “winds from the east”) in suspension.
- Very low levels of noise in the zone in study (sporadic noise produced by traffic).

The marine inversion layer (wind induced) that occurs throughout the Canary Islands is situated between 800 and 1,500 m (2,600 and 4,900 ft) AMSL for 90 percent of the year. This fact creates excellent seeing conditions at the ORM and the neighboring Teide Observatory on Tenerife. Well established island-wide “dark sky” lighting ordinances help to preserve the character of this high quality astronomical site.

3.2.12 Noise

The ambient levels of noise generated by existing science and infrastructure support facilities/personnel at the ORM are related to the movements of telescopes, domes, vehicles and generators as a part of both daytime and night time routine activities.

3.2.13 Visual/Aesthetics

Approval of the GTC project by the National Park de La Caldera de Taburiente, was dependent, to a great extent upon the fact that the observatory would not be visible from “sensitive positions” within the Park itself, including the overlooks known as the Cumbrecita and the Mirador of the Back of the Huts, along the south rim of the main caldera. At a distance of 500 m (1,600 ft) from the edge of the Caldera the GTC site, (the Outrigger Telescopes Project alternative site), is well out of the critical viewscape region. Additional statements indicate that development of sites compatible with those already existing at the ORM, and not visible from specific, scenic vantage points, are anticipated and welcomed, “…. In fact a great part of the tourist attraction of the zone consists of the view of installations that conform to the ORM…….” (GTC 1999 Environmental Impact Study). The ORM is not visible from the north shore communities of the island due to the steep slopes and barrancas (*i.e.*, steep-walled, narrow canyons) that make up this mountainous terrain.