DRAFT ENVIRONMENTAL IMPACT STATEMENT FOR THE OUTRIGGER TELESCOPES PROJECT

VOLUME I

Mauna Kea Science Reserve, Island of Hawai‘i

National Aeronautics and Space Administration
Office of Space Science
Washington, DC

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PREFACE

Rising 4,205 meters (13,796 feet) above sea level, the volcanic mountain 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. Its main mass is built up from flows of lava and deposits of ash; its summit and upper slopes are dotted with cinder cones from more recent fiery eruptions, the last of which occurred more than 2,000 years ago. To the northeast it descends steeply, reaching the ocean shore 27 kilometers (17 miles) from the summit; to the west it drops more gently to the upland Waimea plain. To the south, a high plateau built up of lava from numerous volcanic flows from both Mauna Kea and Mauna Loa forms a Saddle between the two towering volcanic peaks.

Snow often whitens the summit in winter, and 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 the meeting point of Wākea and Papa. In this cultural context, the island of Hawaiʻi was the first-born offspring of this union, the eldest of the islands. Wākea and Papa also became the parents of the first Native Hawaiian man, Hāloa, the first ancestor of the Hawaiian people.

These beliefs about Mauna Kea make it a highly significant and spiritual place to the Hawaiian people. Some Hawaiians view Mauna Kea as a natural temple, one built by the gods, a landscape that embodies their cultural values 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*).

Hawaiian Traditions and Place Names. Polynesians sailing from islands to the south, in east central Polynesia, may have arrived in the Hawaiian Islands as early as 1,600 years ago and had certainly reached the islands and created permanent settlements by 1,200 years ago. They kept no written records, but they maintained a rich oral tradition of legends of gods and demigods, stories of their early ancestors, carefully maintained genealogies, and histories of the important chiefs who ruled in the islands. Both Native Hawaiians and foreign visitors and settlers recorded many of these traditions in the early years after Western contact in 1778. These provide a valuable source of information on traditional Hawaiian beliefs and practices concerning Mauna Kea.

As mentioned above, the name of Mauna Kea is probably associated with the god Wākea, whose son became the ancestor of all Hawaiian people. The cinder cone peaks of the mountain are named for ancient ancestors, many of whom are regarded as gods and goddesses; prominent among these are Kūkahauʻula, the pink-tinted snow god, Poliʻahu, goddess of the snows of Mauna Kea, and Līlīnoe, the goddess of mists. Other place names are descriptive or document events that occurred on the mountain. This application of meaningful place names to landscapes and natural features within landscapes helps shape the way in which a traditional culture conceptualizes these landscapes, linking places with significant deities, stories, or past events and acting to unite culture and nature.

Mauna Kea's highest summit is Puʻu Kūkahauʻula, the traditional name for what is now often called Puʻu Wēkiu or Mauna Kea peak. Alternatively, Kūkahauʻula may include all the peaks in the summit cluster, encompassing all three of the highest volcanic cones, Puʻu Wēkiu, Puʻu Kea,

and Pu‘u Hau‘oki. Kūkahau‘ula (Kū of the red-hewed dew or snow) is a form of the god Kū, but the peak is also said to be named for a chief of Waimea in South Kohala, who became the husband of Līlīnoe. Līlīnoe was a chieftess, who became the woman of the mountains, the goddess of mists. They were ancestors of Pae, who was a high chief in the time of ‘Umi (ca. the 16th century) and a *kahuna* known as an exceptional fisherman. When Līlīnoe died, she is said to have been buried on Mauna Kea; in 1828, Queen Ka‘ahumanu visited the mountain to try to recover the bones. The high peak southeast of Kūkahau‘ula bears the name Pu‘u Līlīnoe.

Kūkahau‘ula, the pink-tinted snow god, was also the lover of Līlīnoe’s sister Poli‘ahu. Poli‘ahu, after whom the high peak west of Pu‘u Kūkahau‘ula was named, became the goddess of the snows of Mauna Kea. She was not only the sister of Līlīnoe, but the rival of Pele, the volcano fire goddess, who lives at Kīlauea.

Two other names for places on Mauna Kea with particular importance in Hawaiian history and legend are Waiau and Kaluakākoi. Lake Waiau and Pu‘u Waiau are named for one of the god companions of Poli‘ahu. The lake is also sometimes called Poli‘ahu’s pond or spring. Kaluakākoi (cave or pit for making adzes), also called Keanakako‘i, is one of the main special-purpose areas near the summit, the Mauna Kea Adze Quarry.

Traditional Land Units. Native Hawaiians divided the island landscapes in which they lived both “vertically” (in units running from the mountain or mountain ridge summits to the ocean) and “horizontally” (in zones that correspond with altitude, vegetation pattern, and the types of resources available). The largest vertical divisions are the *‘āpana* or *moku* (district); the island of Hawai‘i is traditionally divided into six districts, Kohala, Kona, Ka‘ū, Puna, Hilo, and Hāmākua. The *‘āpana* or *moku* were in turn divided into *ahupua‘a*, the basic territorial unit under the control of a chief in the traditional Hawaiian political and social system. Each *ahupua‘a* generally stretched in a narrow band from the mountain tops to the coastal fishing grounds, giving residents access to a diversity of resources.

The summit region and western slopes of Mauna Kea are located within Hāmākua, a district that lies along the northeast side of Hawai‘i island. The summit lands of Mauna Kea, most lands on the upper slopes, its western slopes, and Saddle lands between Mauna Kea and Mauna Loa fall within Ka‘ohe *ahupua‘a* – a very large, inland, vertical land division within Hāmākua. Humu‘ula, the *ahupua‘a* southeast of Ka‘ohe, lies within Hilo district and covers lands on the lower slopes on the Hilo side of Mauna Kea, continuing beside Ka‘ohe across the Saddle to the summit of Mauna Loa.

Hawai‘i’s lands were also traditionally defined horizontally, as environmental and cultural zones, *wao*, defined largely by altitude, physical features, and vegetation. Six main zones are found on the slopes of Mauna Kea. *Kuahiwi* is the very sacred summit reserved as the realm of deities and high chiefs and priests. *Kualono* consists of the near-summit lands where few trees grow; this also is a very special zone. Downslope are four less sacred zones: *wao ma‘u kele* (below *kualono*; a wet area of large *koa*, *‘ōhi‘a*, lobelia, and *māmane)*; *wao akua* (an area of more varied forest–the name connotes the region of the gods – where cloud cover settles upon the mountain slopes); *wao kanaka* (the lowest forested area, dominated by *māmane* and *naio*, the zone most used as a cultural resource); and *kula* (the upland grassy plains). Only *wao kanaka* and *kula* were used for everyday purposes by Hawaiians; the two higher forest zones were special and their resources conserved.

Mountain Resources and Traditional Land Use. Early Polynesian settlers established themselves at coastal locations that provided easy access to ocean resources and to land well-suited for growing taro (the main Hawaiian staple food) and other crops. The first evidence for use of the high inland areas of Hawai‘i island dates from the 12th or early 13th century. At this time Hawaiians began using the Saddle and the lower slopes of Mauna Loa to capture birds in the *māmane* and *naio* forests and to obtain basalt and volcanic glass for manufacturing tools. They sheltered overnight in the lava tube caves and blisters of the Pōhakuloa area.

At this same time, some journeyed up the slopes of Mauna Kea, camping in the shelter of overhanging rocks near the summit. The purposes of these early travelers are uncertain; most likely they made the arduous journeys for spiritual reasons to honor their ancestors and spirits associated with the mountains or perhaps even to make astronomical observations. On the summit plateau, they built shrines, each comprised of a single upright stone or of multiple upright stones set together in a row or rows or grouped within a paved court area. Unfortunately, in the absence of any organic remains associated with the summit shrines, it has not been possible to date directly the time of their construction and use.

The type of shrine built on Mauna Kea suggests that their construction dates quite early in Hawaiian prehistory. The use of uprights as the central focus of the shrines is similar to early *marae* (temples) common in the islands of central and eastern Polynesia, the area from which the Polynesian voyagers came to Hawai‘i. Later, religious structures focused on uprights were replaced with a new type of temple structure as the Hawaiian *heiau* developed.

Although historical documents record the presence of an *ahu* or *heiau* at the summit, no shrines are now found on the central summit cones or in their immediate vicinity. Most are located on the summit plateau between 3,901 and 4,023 meters (12,800 and 13,200 feet) in elevation and are concentrated most heavily on the north and northeast side of the mountain. The absence of shrines within the core summit region suggests that this area was largely avoided because of its high degree of sacredness.

The upper, sacred zones were also used for burials; there is one cairn site on a cinder cone that has been confirmed as containing burials and four others are considered likely to contain burials. Other shrines, including those for bird-snarers and adze makers, were built on the mountain. Hawaiian traditions mention a possible *heiau* at Pu‘u Līlīnoe, Pōhaku a Kāne, a sacred platform or *ahu* perched above the sacred water of Kāne; and an *ahu* or mound at Waiau. *Mele* (chants) were sung in special places within gulches including Kahawai Koikapue, whose waters were shared by Ka‘ohe and Humu‘ula.

The forested slopes of Mauna Kea from the Saddle up to the sacred zone above the forest were primarily an area into which Hawaiians came in search of specific resources or for specific purposes. Hawaiians collected colorful feathers from native honeycreepers, including the *‘ō‘ō* in the lower forests on the mountain and in the Saddle. They also captured seabirds, especially *‘ua‘u*, the dark-rumped petrel, that nested in the Saddle; the nestling chicks were prized as a special delicacy reserved for the chiefs. Oval cooking stones were heated and inserted into the body cavity of the birds to cook them; these stones are found at sites throughout the Saddle region. The Hawaiian duck (*kōloa*) and goose (*nēnē*) were hunted in the Saddle area, on the lower slopes (again, in *wao kanaka*), and possibly at higher elevations.

Hardwoods harvested from the forests included *koa* for canoe hulls and *ʻōhiʻa*. The very durable wood of *māmane* was valued for *ʻōʻō* (spades, digging sticks) and the runners on sleds. *Pili* grass, along with bananas and *hāpuʻu* (tree fern), were collected on lower slopes. Volcanic glass was gathered and fashioned into very fine cutting knives

Trails and footpaths served the lower slopes and also provided access to lower and upper forest zones on the mountain. The trail of Poliʻahu was an ancient trail, used by the powerful chief ʻUmi in the 16th century; it passed by Waiau (Poliʻahu's spring) and the adze quarry near the Mauna Kea summit, providing a route from Kohala, Waimea, and west Hāmākua to Hilo. The trail of ʻUmi passed around the east flank of the summit into the *koa* forests, providing the access for harvesting *koa*. This trail is also associated with important battles among chiefdoms when ʻUmi united the islands. Other trails link the ʻUmi trails and radiate to Hilo, Kona, and Waimea, as well as Hāmākua on the north flank of Mauna Kea.

Kaluakākoʻi, the Mauna Kea Adze Quarry. As Hawaiians made their journeys to the summit, they discovered on the south side of the mountain, above the forest near the summit, in the second highest zone, large deposits of a very hard, fine-grained volcanic rock, a stone of much higher quality for making tools than any found elsewhere in the islands. Geologists interpret the origin of this stone as a result of unusual conditions, lava eruptions beneath the glacial ice that capped the summit during the Pleistocene, causing the magma to cool exceptionally quickly. This quick-cooled lava yielded an especially fine-grained stone that could be turned into high-quality adzes, the Hawaiian's primary tool for woodworking and canoe-making.

One such eruption from the Puʻu Waiau cinder cone formed an escarpment of dense rock that became the focus of stone procurement and working. For nearly 700 years, continuing until the beginning of Western contact, craftsmen skilled in stone-working journeyed up the mountain to quarry stone from the face of this escarpment below Lake Waiau. Archaeologists have identified over 264 workshops, mostly in a 4-sq-km area between 3,350 and 3,780 meters (11,000 and 12,400 feet) in elevation. These include areas where the stone was obtained and initially processed into blocks that could be taken elsewhere. Others are places where these blocks were further refined by percussion chipping. Some of these workshops include huge piles of waste debitage over 5 meters (16 feet) high where the raw material was processed into "preforms" that could serve as blanks for making adzes.

When staying on the cold summit, the workers found protection from the elements in the small rockshelters on the mountain slopes. In these shelters they left evidence of the foods carried to the summit, hearths for cooking the food and for warmth, and stone flaking debitage from tool manufacture. Their diet included sea urchins, barnacles, *ʻōpihi*, several kinds of fish, birds (mostly dark-rumped petrel, but also including small numbers of native birds that are now rare or extinct, such as the Hawaiian rail, coot, goose, duck, crow, and honeycreepers), pig, dog, and Pacific rat. Taro was one of the most important foods, but ti, sugar cane, and gourd were also carried up from cultivated fields near the coast; seeds and fruits of wild plants were collected on the lower slopes of the mountain.

Also found in the rockshelters were tools and other indications of habitation. The entrances of many shelters were enclosed by rock walls. *ʻŌpihi* shells may have been used as peelers for removing the corm or underground stem of the taro. Bird bone awls and volcanic glass flakes, used respectively to pierce and scrape wood and other soft materials, were other common tools. Normally perishable materials recovered in the shelters include a possible ti-leaf rain cape,

sandal fragments, pandanus leaves, twisted cordage, and braided sennit. A silversword was wrapped with pieces of tapa cloth, pandanus leaf, and a wooden bottle gourd stopper with sennit cord attached.

An important aspect of the quarrying was the construction of shrines. As many as 45 shrines, identified by the presence of one or more upright stones, are found within the quarry. Most of these are directly associated with stone workshops or are above rockshelters, and their construction is therefore interpreted as relating to quarry activities. The surfaces of many shrines mimic workshops, with adze-manufacturing by-products scattered beneath the uprights, suggesting their use as ritual offerings. The quarry shrines clearly reflect the close integration of spiritual beliefs and material practices in traditional Hawaiian culture.

Post-Contact Land Uses and Environmental Change. Contact with the Western world, beginning with the arrival of Captain James Cook in 1778, altered in significant ways the relationship of the Native Hawaiians with Mauna Kea. The effect that appears to have been felt first after Contact was the reduction of the demand for stone tools with the introduction and then rapid and widespread adoption by the Hawaiians of iron tools. As a result, the need for new lithic raw material disappeared and quarrying activities on the Mauna Kea summit appear to have ceased very soon after Contact. No remains of tools, plants, or animals introduced by Cook or later voyagers are found in sites at the Mauna Kea Adze Quarry complex. Early European visitors to Mauna Kea, such as Joseph Goodrich in 1823, observed the piles of flakes and adze preforms and the shelters, but they say nothing about Hawaiian stone procurement or tool manufacture.

Several other factors reduced significantly the presence of Hawaiians on the mountain after Contact. Western apparel and paraphernalia replaced the traditional symbols of rank, such as the wearing of feathered cloaks and helmets, thus reducing the demand for colorful feathered birds from the upland forests. The introduction of foreign diseases to which the Hawaiians had no developed immunity severely reduced the population. The abolition of the *kapu* system in 1819 and the coming of Christian missionaries the next year meant that certain traditional ritual practices were discouraged. Those who continued to follow the traditions did so less conspicuously. Even though old shrines may have continued in use, new shrines were probably no longer erected on the mountain. While the traditional practices associated with the mountain were certainly not completely abandoned, as might be thought from reading 19th-century documents of those foreign visitors who traveled around or up the mountain, they were not as prevalent as in pre-Contact times.

Widespread environmental change began on the slopes of Mauna Kea soon after the introduction of cattle and sheep in 1793 by the English explorer Captain George Vancouver, who brought them as a gift to Kamehameha I. Kamehameha banned killing of cattle and sheep for 10 years, and cattle soon began grazing over wide areas that included the slopes of the mountain. By the 1820s, the hunting of wild cattle became commercial, first supplying meat to the whaling ships and later tallow and hides for distant markets. Wild cattle, sheep, and goats soon destroyed much of the vegetation cover on slopes where they grazed, turning native forests, shrub lands, and grasslands into pasturelands covered by introduced grasses. Wild pigs spread invasive introduced plants, harming the forest understory and the native forest birds who had formerly fed in it. Pigs would also have fed on tree ferns, as they do elsewhere, encouraging water to pool in

the stumps and inviting mosquitoes to breed. In the first half of the 19th century, the native *nēnē* was nearly hunted to extinction in the Saddle area.

Commercial harvesting of firewood and other lumber decimated *koa* forests on Mauna Kea and elsewhere. Sugar mills, in need of large amounts of firewood, depleted the mountain forests; their flumes both diverted mountain water and transported forest lumber downslope. *Pulu*, a silky fiber collected from *hāpu'u,* the tree fern, was collected for export as pillow and mattress stuffing.

In the 1830s cattle hunter John Parker established the beginnings of the ranch that would eventually cover the western half of the mountain. At mid-century, a sheep operation was established informally to take advantage of feral sheep already present in the Saddle. These two large ranches competed for the rights to raise cattle and sheep and hunt feral animals in the Saddle and on the lower slopes of the mountain. A wagon road was built from the sheep station at Humu'ula to Waimea to transport wool to the harbor at Kawaihae. Parker Ranch leased western Ka'ohe, while in 1885 the Humu'ula Sheep Station Company obtained the lease for the east side. The sheep station hired immigrant Japanese stonemasons to build stone walls around their grazing lands in the 1890s; portions of these are still standing. After 1900, Parker Ranch expanded and took over control of the Humu'ula Sheep Station Company, and most of the lands in the Saddle became a part of Parker Ranch.

In the late 19th century, the main trails on Mauna Kea increasingly merged with the wagon trails serving the Humu'ula Sheep Station and Umikoa Ranch, providing easier access to all the traditional *wao* (environmental zones), and to the summit. By 1890, grass had replaced forest on much of the slopes; the *māmane* forests had all but disappeared on the western side of the mountain; even the high mountain *'ahinahina* (silversword) had nearly vanished. The stripping of tree and shrub cover must have led to increasing erosion on all slopes in the uppermost zones and in deforested areas below.

Nineteenth-Century Visits to the Mountain. Early European and American visitors reported difficulty obtaining guides to the highest areas on Mauna Kea. Although the reason was almost certainly the sacredness and special status of the mountain in Hawaiian culture, especially the uppermost zones, some visitors concluded that the interior area was a virtually unknown wilderness. Foreign visitors apparently began to climb the mountain soon after Contact, as Goodrich and Ellis in 1823 found a rock cairn at the summit, probably left by an even earlier visitor.

Visits to the mountain increased in both frequency and in the numbers of people involved throughout the 19th century. In 1830, Kamehameha III, in the company of missionary Hiram Bingham, visited the mountain on horseback, their journey taking 5 days. In 1840, the Wilkes party (the U.S. Exploring Expedition party) documented Lake Waiau, and in 1862 Wiltse and others began surveying boundaries on the mountain for the Boundary Commission. Later, government surveyor J. S. Emerson sketched Mauna Kea. In 1883, Queen Emma traveled over the mountain to Waimea; a pillar or cairn built to commemorate her visit was observed in 1892 by W.D. Alexander. Surveyor E. D. Baldwin mapped the summit and near-summit areas, preparing a map in 1891. The Wilkes, Baldwin, and Alexander parties all erected cairns on the summit. The journals of these foreigners describe the wild cattle and the contrasts from tropical forest to grass and parkland to the severe starkness of the summit.

Recent Developments. The early 20th century brought additional change, with the planting by foresters of imported trees and other plants and early road construction. Sheep – some 40,000 around the mountain – were still numerous on the slopes in the 1930s. L. W. Bryan, head of the Civilian Conservation Corps (CCC) built a 97 kilometer (60-mile) long sheep-proof fence around the mountain to protect the remaining *māmane* forest and silversword, which had been devastated by wild sheep. Bryan directed the reforestation of denuded lands, planting large numbers of trees – most of them introduced species – to control erosion. The reforestation undoubtedly prevented much soil erosion, but also resulted in the additional isolation of the remaining patches of native forest.

The CCC improved roads, so that vehicles could now circumnavigate the mountain, the first step toward making the mountain more accessible. During World War II, the U.S. Army took control of a large area in the western portion of the Saddle that would become the Pōhakuloa Training Area. Military needs led to the construction of a graded, all-weather road through the Saddle by the CCC and U.S. Army Corps of Engineers in 1943. After the war, the Saddle Road, linking Hilo with Waimea, was paved, further easing access to Mauna Kea.

In the early 1960s, interest grew in using the summit for astronomical observations. In 1964, a road was cut to the summit, and four years later the Air Force 0.6-meter (24-inch) optical telescope was erected south of the summit ridge. In subsequent years, the existing twelve observatories were installed in the summit region, including the Keck, Subaru, and Gemini Telescopes in the central summit cone region.

Increased access to the mountain and the need to evaluate the consequences of the development of the observatories has led to a number of cultural resource and environmental studies during the past 30 years. This research has included an intensive archaeological study of the Mauna Kea Adze Quarry, cultural resource surveys that have recorded many of the shrines, and the biological discovery and study of the rare Wēkiu bug.

Today Mauna Kea is among the premier sites in the world for the study of the universe. Telescopes on Mauna Kea have been used to study disks of gas and dust surrounding young stars—nurseries of potential worlds—and to discern evidence for giant planets orbiting nearby stars. The Outrigger Telescopes Project would continue this record of discovery. As documented in this Environmental Impact Statement, the Project has been planned to minimize disturbance to the cultural and environmental resources of the mountain. The knowledge that the Outrigger Telescopes would provide would increase human understanding of the universe in the tradition of the great Hawaiian navigators.

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DRAFT ENVIRONMENTAL IMPACT STATEMENT FOR THE OUTRIGGER TELESCOPES PROJECT

ABSTRACT

Lead Agency: National Aeronautics and Space Administration (NASA), Office of Space Science

Proposed Action: NASA's Proposed Action is to fund the on-site construction, installation, and operation of four, and possibly up to six, Outrigger Telescopes near the twin Keck Telescopes at the W.M. Keck Observatory site within the Mauna Kea Science Reserve on the island of Hawai'i. It is anticipated that the on-site construction and installation of four of the six Outrigger Telescopes, along with on-site construction of the underground structures for Outrigger Telescopes 5 and 6, would begin in 2005, with start of operations anticipated in 2007. If funding becomes available, NASA intends to complete the on-site construction, installation, and operation of Outrigger Telescopes 5 and 6, with above-ground construction and installation likely to begin no earlier than 2007.

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Abstract: NASA's Draft Environmental Impact Statement (EIS) for the Outrigger Telescopes Project addresses the environmental impacts associated with the Proposed Action and reasonable alternatives. The environmental impacts of principal concern for the Proposed Action are those that would affect cultural resources, the visual integrity of the summit region of Mauna Kea, and impacts to the Wēkiu bug, a candidate for listing under the Endangered Species Act. The environmental impacts of the Outrigger Telescopes Project on other environmental resource areas are also addressed as are the cumulative impacts of the Outrigger Telescopes when considered with past, present, and reasonably foreseeable future projects on or near Mauna Kea. NASA has also identified a reasonable alternative to the Mauna Kea site in Spain's Canary Islands. NASA's initial determination is that all of the science objectives set out for the Outrigger Telescopes Project can also be attained at this alternative site. This EIS addresses the environmental impacts associated with implementing the Outrigger Telescopes at the Canary Island site. The No-Action Alternative is also addressed. Should NASA decide not to fund the Outrigger Telescopes Project at either the proposed Mauna Kea site or at the alternative site in the Canary Islands, it may choose to implement a Reduced Science Option. The Reduced Science Option would consist of locating four Outrigger Telescopes at an existing observatory that does not have the large diameter telescope needed to achieve all of the science objectives possible with either the Proposed Action or the Canary Islands alternative site. Two Reduced Science Option sites have been identified. The environmental impacts associated with implementing the Reduced Science Option at each of the two sites in California are also addressed in this EIS.

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EXECUTIVE SUMMARY

This Draft Environmental Impact Statement (EIS) has been prepared in accordance with the National Environmental Policy Act of 1969, as amended (42 U.S.C. §4321 *et seq.*); the Council on Environmental Quality Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act (40 CFR Parts 1500-1508); and the National Aeronautics and Space Administration's (NASA) policy and procedures (14 CFR Subpart 1216.3) to support decision-making on whether to fund the on-site construction, installation, and operation of the Outrigger Telescopes Project. No final action will be taken by NASA regarding funding for the on-site construction, installation, and operation of the Outrigger Telescopes until the decision-making process under the National Environmental Policy Act has been completed.

This Federal National Environmental Policy Act process is separate and distinct from the State environmental process completed by the University of Hawai‘i in accordance with applicable State of Hawai‘i environmental statutes and regulations.

ES.1 PURPOSE AND NEED

A detailed description of the purpose and need for the Outrigger Telescopes Project can be found in Chapter 1 of the EIS.

NASA has a central Mission with three components: (1) to understand and protect our home planet, (2) to explore the universe and search for life, and (3) to inspire the next generation of explorers. The second component, to explore the universe and search for life, addresses two of humanity's oldest and most profound questions: "Where did we come from?" and "Are we alone?" Understanding where we come from requires knowledge of how today's universe of galaxies, stars, and planets came to be, and how stars and planetary systems form and evolve. Understanding whether or not we are alone requires knowledge about the building blocks of life, the conditions necessary to sustain life, and the diversity of planets—particularly those that might harbor life. Acquiring knowledge in all of these areas is the goal of NASA's Origins Program. In pursuit of this knowledge, NASA supports space flight missions, related research programs, and technology development.

Interferometry is a critical technology for accomplishing the Origins Program. It is a technique for overcoming an inherent limitation of single telescopes: the "sharpness" or amount of image detail is limited by the size of the telescope's main mirror. An interferometer combines two or more telescopes optically so they function as if they were a single larger telescope. The number of individual telescopes and the distances between them determines the sharpness of the image from an interferometer. Because the separation between telescopes can be much larger than the diameter of even the largest telescope mirrors, interferometers in general acquire images that capture much more detail than individual telescopes.

Interferometers also can measure positions of stars with exquisite accuracy. This is important because it is possible to find planets around other stars by measuring the stars' positions very accurately over a substantial period of time. As a planet orbits a star, it exerts a gravitational tug that causes the star to move back and forth. An interferometer can detect this slight "wobble," thus revealing the presence of the orbiting planet.

NASA is developing interferometry for use both in space and on the ground. Space flight missions, such as the Space Interferometry Mission scheduled for launch in 2009, can achieve even finer measurements than are possible from the ground by getting above the Earth's atmosphere to avoid its image distortion. However, ground-based interferometers are essential for projects that require a longer operating life than is possible with a space flight mission. They can also involve telescopes that are larger and more sensitive than the ones that can be flown in space.

The Outrigger Telescopes Project is part of NASA's program to develop ground-based interferometry. The project as proposed addresses four of NASA's six scientific objectives for ground-based interferometry. These six objectives are:

1. Detect the thermal dust emissions from dust clouds around other stars.
2. Detect the light from and characterize the atmospheres of hot, Jupiter-mass planets located within approximately 20 million kilometers (km) (12 million miles (mi)) of the stars they are orbiting.
3. Detect the astrometric signature (*i.e.*, the wobble of a star due to the gravitational influence of an unseen planetary companion) of planets as small as Uranus.
4. Make images of proto-stellar disks (*i.e.*, disks of dust and gas in space believed to be an early stage of star formation) and stellar debris disks (*i.e.*, clouds of gas or other material remaining after the star is formed).
5. Provide high-resolution information about some faint objects outside our galaxy.
6. Make high-resolution observations of objects within the solar system, including asteroids, comets, and outer planets.

The first two objectives can be accomplished by the Keck-Keck Interferometer which links the two 10-m (33-ft) Keck Telescopes. Objectives 3 through 6 require the Outrigger Telescopes. Objective 3, finding planets around nearby stars by means of astrometry, can be accomplished with four Outrigger Telescopes alone. Objectives 4 through 6 require that the Outrigger Telescopes be connected to one or more large (8-meter (m) (26-foot (ft)) diameter or larger) telescopes. Six Outrigger Telescopes would provide almost twice as much image detail as four in pursuit of objectives 4 through 6, yielding much higher quality scientific data.

TERMS TO KNOW

Outrigger Telescope refers to any of the proposed 1.8-meter (6-foot) diameter telescopes.

Keck Telescope refers to one of the two 10-meter (33-foot) diameter telescope.

Keck-Keck Interferometer refers to the Keck I and Keck II Telescopes used together as an interferometer (without the Outrigger Telescopes).

Keck Interferometric Array refers to any combination of some or all of the Outrigger Telescopes with one or both of the Keck Telescopes.

ES.2 PROPOSED ACTION AND ALTERNATIVES

A detailed description of NASA's Proposed Action and reasonable alternatives can be found in Chapter 2 of this EIS.

NASA's Proposed Action is to fund on-site construction, installation, and operation of four, and possibly up to six, Outrigger Telescopes at the W.M. Keck Observatory site located within the Astronomy Precinct on the summit of Mauna Kea, island of Hawaii.

NASA also systematically evaluated ten other potential sites for locating the Outrigger Telescopes Project. Of the ten sites evaluated, one site emerged as a reasonable alternative to the Mauna Kea site. This site, located in Spain's Canary Islands, is called the Gran Telescopio Canarias (GTC) site. NASA's initial evaluation of this site indicates that all of the science objectives established for the Outrigger Telescopes Project could be achieved at this site as well as at Mauna Kea. The environmental impacts of funding on-site construction, installation, and operation of the Outrigger Telescopes Project at this alternative site are also addressed in this EIS.

The remaining alternative addressed in this EIS is the No-Action Alternative.

ES.2.1 Description of the Proposed Action

The W.M. Keck Observatory site on Mauna Kea is the location of the two most powerful optical telescopes in the world—Keck I and Keck II. The proposed Outrigger Telescopes would be placed strategically around the existing Keck Telescopes on the area of the cinder cone, Pu'u Hau'oki, that was previously disturbed for construction of the two Keck Telescopes. NASA anticipates that on-site construction and installation of four Outrigger Telescopes along with on-site construction of the underground structures for Outrigger Telescopes 5 and 6 would begin in 2005 (assuming all permits and approvals have been received) with start of operations anticipated in 2007. If funding becomes available, NASA intends to complete the above-ground construction, installation, and operation of Outrigger Telescopes 5 and 6, with on-site construction and installation likely to begin no earlier than 2007.

Each proposed Outrigger Telescope would consist of a 1.8-m (6-ft) diameter, f/1.5 primary mirror, a secondary mirror, a tertiary mirror, and other optical equipment. A dome, measuring 9.1 meters (30 feet) in diameter at its widest point and 8 meters (26 feet) in diameter at its base, would enclose each telescope to protect it from the harsh conditions on Mauna Kea. The domes would stand 10.7 meters (35-feet) high as measured from the top of the level grade at elevation 4,146 meters (13,603 feet). By comparison, each of the Keck domes is 37 meters (121 feet) in diameter at its widest point and 33.9-meters (111-feet) high. Each proposed Outrigger Telescope would be supported by an underground concrete telescope instrument room, which would serve as a telescope pier. Junction boxes would house the mirrors that direct the light beams through underground light pipes to the basement of the Keck II Telescope building, where the interferometer instrumentation is located.

ES.2.2 Environmental Impacts of the Proposed Action

ES.2.2.1 Cultural Resources

The Hawaii State Historic Preservation Division (SHPD) believes that Kūkahau'ula, the area of the three summit cones of Mauna Kea, meets the criteria for listing in the National Register of Historic Places primarily because of its importance as a traditional cultural property. Some Native Hawaiians have identified the larger area of Mauna Kea, from the 1,829-m (6,000-ft) elevation to the summit, as a sacred landscape valued for its spiritual significance.

Pursuant to regulations under the National Historic Preservation Act (NHPA), NASA proceeded with the Section 106 process. Initially, NASA formally invited four Native Hawaiian organizations to act as Consulting Parties:

(1) Hui Mālama I Nā Kūpuna o Hawai‘i Nei (this organization is referenced in the NHPA),

(2) Hawai‘i Island Burial Council,

(3) OHA (also referenced in the NHPA), and

(4) The Royal Order of Kamehameha I.

The Advisory Council on Historic Preservation (ACHP) also agreed, at NASA's invitation, to participate in the Section 106 process. Two more Native Hawaiian organizations later requested and were given Consulting Party status: Ahahui Ku Mauna and Mauna Kea Anaina Hou.

NASA also consulted with and invited the Office of Mauna Kea Management (OMKM), the Mauna Kea Management Board, and Kahu Kū Mauna to participate in the development of mitigation measures under the Section 106 process.

As part of the Section 106 consultation process, NASA prepared proposals for on-site and off-site mitigation of potential impacts to cultural resources for consideration by the SHPD, ACHP, and the other Consulting Parties. These proposals subsequently led to a Memorandum of Agreement (MOA) which stipulates mitigation measures.

Signatories to the MOA included NASA, the Advisory Council on Historic Preservation, the Hawai‘i State Historic Preservation Officer, UH, the California Association for Astronomy (CARA), the California Institute for Technology (Caltech), and Ahahui Ku Mauna (with caveat). Consulting Parties who did not sign the MOA included the Hawaii Island Burial Council, Hui Mālama I Nā Kūpuna o Hawai‘i Nei, Mauna Kea Anaina Hou, the Office of Hawaiian Affairs, and The Royal Order of Kamehameha I.

No archaeological sites have been identified in the area of the Proposed Action. However, there are archaeological sites and historical architectural resources in the vicinity of the staging area at Hale Pōhaku. These are extremely unlikely to be adversely affected by the Proposed Action.

In addition, no area at or near the summit is assumed to be devoid of archaeological resources. NASA has therefore proposed mitigation measures that assume that archaeological resources could be found anywhere during on-site construction. A Draft Burial Treatment Plan has been prepared that stipulates procedures to be followed if burial remains are found.

If an archaeological resource is discovered during excavation for the Outrigger Telescopes, the mitigation measures as described in the MOA will prevent or reduce adverse effects.

The Outrigger Telescopes Project would have an small adverse effect on traditional cultural properties and practices in the summit region. The primary impact would be the continued visual presence of the telescope structures within the Kūkahau‘ula traditional cultural property. However, because the Outrigger Telescopes would be located next to the much larger Keck I and II structures, their impact would be a small increment to the impact that has already occurred. The Outrigger Telescopes Project would not in any way restrict access of Native Hawaiians to the summit region.

ES.2.2.2 Biological Resources and Threatened and Endangered Species

The major focus of potential biological impacts of the Outrigger Telescopes Project is the Wēkiu bug. The Wēkiu bug (*Nysius wekiuicola)* is a candidate for listing under the Endangered Species Act of 1973. The proposed Outrigger Telescopes Project would displace a small amount of previously disturbed Wēkiu bug habitat (0.008 hectare (0.019 acre)). A Wēkiu Bug Mitigation Plan has therefore been developed to reduce or avoid adverse impacts. This plan includes habitat restoration to replace the displaced habitat in a restoration ratio of at least 3:1. The habitat restoration portion of the plan was developed in conjunction with the U.S. Fish and Wildlife Service (USFWS) and other scientists familiar with Wēkiu bug ecology. A qualified entomologist would be on-site monthly to monitor implementation of the proposed mitigation measures and measure the effectiveness of habitat protection and restoration efforts.

When the Wēkiu Bug Mitigation Plan and the Wēkiu Bug Monitoring Plan are implemented, the anticipated adverse impacts to the biological resources as a result of the Outrigger Telescopes Project would be small. Through restoration, the amount of Wēkiu bug habitat adjacent to the W.M. Keck Observatory would increase. The Outrigger Telescopes Project would have no significant impacts on the biological resources within the ROI.

ES.2.2.3 Hydrology, Water Quality, and Wastewater

Three principal activities could potentially have impact on water quality during construction: (1) the process of washing cinder for Wēkiu bug habitat restoration in Submillimeter Valley directly south of Pu‘u Hau‘oki, (2) using water to control dust, and (3) accommodating the water supply and wastewater treatment and disposal needs of construction workers. Similarly, two aspects of the Outrigger Telescopes operations have potential hydrologic and/or water quality impacts: (1) change in surface runoff from the W.M. Keck Observatory site, and (2) generation and disposal of domestic wastewater.

An analysis under a very conservative set of assumptions shows that the Outrigger Telescopes Project would have no impact to hydrology and/or water quality. In particular, percolating wastewater from the W.M. Keck Observatory site would not travel to Lake Waiau or to the springs on the west side of Pōhakuloa Gulch.

ES.2.2.4 Solid Waste and Hazardous Materials Management

On-site construction activity associated with the Outrigger Telescopes Project would generate waste debris consisting of wood, scrap insulation, packaging material, waste concrete, and various construction-related wastes. On-site construction and installation contract(s) would contain provisions regarding the management of these wastes. Particularly important are measures to secure solid wastes against dispersal by high winds. Given appropriate precautions, no impacts from solid wastes are anticipated.

No mercury would be used for the Outrigger Telescopes. The rinse water from the mirror recoating process would be collected and transported off the mountain.

Some hazardous materials, such as paints, thinners, solvents, and fuel, would be used for the Outrigger Telescopes Project. Unused products and spent containers would be collected and transported offsite for proper disposal. Handling of these materials would be guided by best management practices. With these measures in place, no

impacts from hazardous materials handling are anticipated.

ES.2.2.5 Geology, Soils, and Slope Stability

There would be only small impacts to geology, soils, and slope stability during the construction phase of the Outrigger Telescopes Project. Because Outrigger Telescopes 3 and 4 are to be built close to the steep edges of Pu‘u Hau‘oki, retaining walls would be built at the upper edges of these slopes so that excavated cinders and debris do not cascade downslope during construction. This would also prevent foot traffic from degrading the slope edge following construction. All construction activities will be conducted in accordance with a Construction Best Management Practices Plan.

There would be no impacts during the operations phase of the Outrigger Telescopes.

ES.2.2.6 Land Use and Existing Activities

The Outrigger Telescopes Project would be consistent with uses permitted in the Astronomy Precinct of the Mauna Kea Science Reserve and with the 2000 MKSR Master Plan.

Although some transportation, noise, and visual impacts would occur, it is anticipated that the Outrigger Telescopes Project would not result in a long-term conflict with or have a substantial impact on existing activities. In particular, use of the land for cultural and religious practices, astronomical and other scientific research, and a variety of recreational activities would remain consistent with the current use.

ES.2.2.7 Transportation

Vehicular traffic would occasionally delay traffic along the Mauna Kea Access Road. The greatest traffic delays would occur when the telescopes and domes are trucked up the mountain. This traffic would occur only intermittently and thus should not regularly interfere with normal traffic flow. Construction vehicles would not have any long-term impact on either the road or overall traffic flow. The slight increase in traffic associated with operations would be insignificant.

ES.2.2.8 Utilities and Services

Although the Outrigger Telescopes Project would increase demand for potable water on Mauna Kea, there would be no impact to the existing water supply at the W.M. Keck Observatory site or at Hale Pōhaku.

There would be only a minor increase in electrical demand during construction and installation. The Hale Pōhaku power substation has capacity to accommodate the power requirements of all six Outrigger Telescopes.

The communications system for Mauna Kea has adequate capacity to accommodate the addition of the Outrigger Telescopes.

The impacts on emergency services and fire suppression would be small.

ES.2.2.9 Socioeconomics

The Outrigger Telescopes Project would have a small positive socioeconomic impact on the County and State of Hawai‘i.

ES.2.2.10 Air Quality

The Outrigger Telescopes Project would result in short, small, but measurable levels of air pollution during construction and installation. Strict compliance with the State Department of Health (DOH) Administrative Rules and the County of Hawai’i grading permit would minimize the short-term effects on air quality. Potable water will be applied to excavation sites and

cinder stockpiles to minimize dust during trenching, bulldozing or other soil disturbance activities. In summary, there would be a small impact.

The operation of the Outrigger Telescopes would have no impact on air quality in and around Mauna Kea.

ES.2.2.11 Noise

Construction and installation activities would generate noise. Actual noise levels would depend upon the mix and duration of construction equipment and methods used. A noise level increase could affect cultural and religious practices. However, any noise disturbances or interruptions would end once on-site construction and installation is completed. It is anticipated that noise increases during construction and installation would be moderate.

Operation of the Outrigger Telescopes would result in a negligible increase in noise.

ES.2.2.12 Visual/Aesthetics

The Outrigger Telescopes would be visible from most locations within the Astronomy Precinct. However, they would not be visible from the true summit, and one or more Outriggers would generally be obscured by the Keck Telescope domes.

Below the summit area, the mountain topography would determine visual impacts from the Outrigger Telescopes. The Outriggers would generally be visible from off-mountain locations to the north and west of the summit such as Waimea and Honoka'a. They would not be visible from locations to the east and south such as Hilo and the Saddle Road. Where visible, the Outrigger Telescopes' visual impact would be small compared to the impact of the much larger Keck Telescope domes.

ES.2.2.13 Cumulative Impacts

The Council on Environmental Quality NEPA implementing regulations define cumulative impacts as the incremental environmental impacts of the action when added to other "past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions." Cumulative impacts can result from individually minor, but collectively significant, actions taking place over time.

During the scoping process for this EIS, NASA consulted with interested agencies and the public who identified the following important cumulative impact concerns associated with the Outrigger Telescopes Project: the Wēkiu bug and its habitat on Mauna Kea; the release of sewage system effluents into subsurface cinder at the summit; and, even more importantly, the central role of Mauna Kea in the cultural and spiritual life of Native Hawaiians.

NASA also determined that, in general, the time frame for the cumulative impact evaluation would extend from about 1964, before the first telescope was installed on Mauna Kea until the year 2033 when the lease agreement between the State of Hawaii and UH ends. NASA consulted with the community, local organizations, government agencies, and the existing observatories on Mauna Kea to identify projects and activities on or near Mauna Kea that could occur within the reasonably foreseeable future, i.e., between the present and 2033.

Past activities considered in the cumulative impact analysis include all observatory construction and related activities. Foreseeable future activities include both astronomy and non-astronomy related projects and activities. Activities at the end of the lease agreement in 2033 have been

addressed by considering two bounding possible outcomes.

Cultural Resources. Mauna Kea has a rich traditional history and many archaeological sites, including some that have yet to be discovered. Before 1982, only limited cultural and archaeological surveys were conducted in preparation for developments on the mountain. Thus, it is not known whether development of the Astronomy Precinct beginning in 1964 has damaged subsurface cultural resources. However, such development has clearly altered the appearance of the Kūkahauʻula traditional cultural property, interfered with views to and from the summit, and affected traditional cultural uses and practices. Grading and removal of earth for new structures, redeveloped structures, roads, and other astronomy projects could further affect these resources adversely. Following appropriate mitigation measures, such as those described in the NHPA Section 106 MOA, and developing project-specific mitigation measures for future activities would reduce adverse effects.

Mitigation measures developed for the Outrigger Telescopes Project and made part of the Section 106 MOA would minimize the impact of the Outrigger Telescopes Project and could potentially provide beneficial impacts, including community outreach and cultural stewardship.

From a cumulative perspective, the impact to cultural resources on Mauna Kea is substantial and adverse. The addition of the Outrigger Telescopes to the existing observatories on the mountain would have a small incremental impact.

Biological Resources and Threatened and Endangered Species. There have been substantial impacts to biological resources, particularly the Wēkiu bug, a candidate species for listing under the Endangered Species Act, but the best available information does not always permit complete understanding of the causes of those impacts. The impact of reasonably foreseeable future activities is likely to be moderate to substantial. The incremental impact of the Outrigger Telescopes Project is small and not significant. Further, on balance, the Project's impact is likely to be beneficial to biological resources. Overall, the cumulative impact to biological resources is adverse and significant.

Hydrology, Water Quality, and Wastewater. The impact of all past, present, and reasonably foreseeable future astronomy related projects, including the Outrigger Telescopes Project, on the hydrologic system is virtually zero. Therefore, the cumulative impact on hydrology and water quality is not significant.

Solid Waste and Hazardous Materials Management. Impacts of solid waste on biological or hydrological resources or aesthetics from past, present, and reasonably foreseeable activities have been small, if any, transient, and not significant. The incremental impact of the Outrigger Telescopes Project would be small and not significant.

Impacts of hazardous materials on biological and hydrological resources and aesthetics from past, present, and reasonably foreseeable activities have been small and not significant. The incremental impact of the Outrigger Telescopes Project would be small and not significant.

Geology, Soils, and Slope Stability. The impact of past and present activities on geology, soils, and slope stability has been substantial. The impact of foreseeable future activities is anticipated to be small. The Outrigger telescopes would add a small and not significant incremental impact. The

overall cumulative impact has been significant.

Land Use and Existing Activities. Most past, present, and reasonably foreseeable future activities on Mauna Kea have been consistent with State and local plans and compatible with State land use designations. The Outrigger Telescopes Project would have no incremental impact on land use.

From a cumulative perspective, the impacts of past, present, and reasonably foreseeable future activities on existing activities on Mauna Kea are substantial. The addition of the Outrigger Telescopes to the existing observatories on the mountain would have a small incremental impact.

Transportation. Past, present, and reasonably foreseeable future activities result in greater access for visitors and Native Hawaiians traveling to Mauna Kea. As a result, there has been a substantial increase in traffic volume along the access road. This increase has resulted in a substantial impact on the natural setting of Mauna Kea.

The on-site construction and installation of the Outrigger Telescopes would result in a small, short-term increase in the current traffic volume. Operations of the Outrigger Telescopes would contribute only a small increase in current traffic levels. From a cumulative perspective, the transportation impact on Mauna Kea has been significant. The addition of the Outrigger Telescopes to the existing observatories on the mountain would have a small incremental impact.

Utilities and Services. Past, present, and reasonably foreseeable future activities on Mauna Kea have led to the development of a water supply system, which constitutes a substantial impact on water supply. The water usage and traffic associated with water delivery are small and not significant in comparison to overall island water usage and Mauna Kea traffic levels. The addition of the Outrigger Telescopes to the existing observatories on the mountain would have almost no incremental impact.

Past and present activities on Mauna Kea have led to the development of electrical power and communications infrastructure, which constitutes a substantial impact on such capability. Reasonably foreseeable future activities are anticipated to have a small additional impact on electrical power and communications. The Outrigger Telescopes Project would have no incremental impact on the existing electrical distribution and communications systems.

Past and present activities on Mauna Kea have led to the development of emergency services and fire suppression capability. It is anticipated that foreseeable future activities would require similar additional development. The addition of the Outrigger Telescopes to the existing observatories on the mountain would have no incremental impact.

Socioeconomics. The impact of past, present, and reasonably foreseeable future activities within the Astronomy Precinct on socioeconomics is substantially positive. The Outrigger Telescopes Project would add a small positive incremental impact. The overall cumulative impact on socioeconomics is substantial and positive.

Air Quality. Past and present activities have had a minor continuing impact on air quality. Foreseeable future activities would have similar impacts. The Outrigger Telescopes Project would employ mitigation measures and would have a very small incremental impact. Overall, the cumulative impacts to air quality are small.

Noise. The impact of noise from past, present, and reasonably foreseeable future activities is generally small. The Outrigger Telescopes Project would have almost no

incremental impact. Although individual construction events would continue to produce occasional increased noise levels, overall noise conditions in the ROI would remain low.

Visual/Aesthetics. The visual impacts of past and present astronomy-related activities in the MKSR have been substantial. Future visual impacts may be minimized by new design guidelines and careful site selection of new development projects. Mitigating dust generation, enforcing strict trash control, and minimizing on-site staging areas would reduce local short-term visual impacts. The Outrigger Telescopes Project would add a small incremental visual impact. Overall, the cumulative visual impact from past, present, and reasonably foreseeable activities is substantial.

Cumulative Impact Summary. In conclusion, the overall cumulative impact of past, present, and reasonably foreseeable activities is substantial, adverse, and significant. In general, the Outrigger Telescopes Project would add a small incremental impact.

ES.2.3 Description of the Gran Telescopio de Canarias (GTC) Alternative

The Gran Telescopio de Canarias, a 10-m (33-ft) telescope modeled after the Keck Telescope, is currently under construction on the island of La Palma in Spain's Canary Islands, about 1,800-km (1,100-mi) southwest of Madrid, Spain. The GTC site is located within the Roque de Los Muchachos Observatory near the northern end of the island.

The Roque de Los Muchachos Observatory is located at an elevation of approximately 2,400 m (7,900 ft) above mean sea level and occupies the north slope of a large volcanic caldera, the most prominent feature on La Palma. The 189-ha (467-ac) science site supports more than a dozen observatories. The GTC site may be characterized as a broad northwest sloping (18 percent) plain of altered volcanic material. A sizeable area adjacent to the GTC site has been disturbed by material staging and construction activities, but other adjacent area is undisturbed.

Locating the Outrigger Telescopes Project at the GTC site would involve the construction of four, and possibly up to six, 1.8-m (6-ft) Outrigger Telescopes together with their enclosures and domes, light pipes to transport the light from each telescope to a central beam combiner, and a separate structure to house the beam combiner facility. The GTC is being constructed with a coudé tunnel beneath the building which allows light from the 10-m (33-ft) telescope to be brought outside the observatory structure. This light path would feed directly into the beam combiner facility. The light pipes relaying light from the Outrigger Telescopes would also feed into the beam combiner facility, where a complex system of optics would combine the light of the various telescopes together interferometrically.

ES.2.4 Environmental Impacts of the Canary Islands Alternative

ES.2.4.1 Cultural Resources

There are no groups that consider the ORM to be sacred or of religious importance, thus on-site construction and installation will have no impact on traditional cultural practices. Certain configurations of the Outrigger Telescopes could involve placing some of the Outrigger Telescopes in areas not previously surveyed for archeological properties. For that configuration, additional archeological surveys would be required. Based on prior experience, there is

a reasonable likelihood that one or more additional archaeological sites would be discovered. However, suitable mitigation is likely to be possible.

Impacts to archaeological resources are likely to be small.

ES.2.4.2 Biological Resources and Threatened and Endangered Species

A sizeable area adjacent to the GTC has been disturbed by material staging and construction activities. The relative impact of the Outrigger Telescopes Project would depend on the location of these telescopes in relation to the GTC. While it may be feasible to locate the Outrigger Telescopes wholly in previously disturbed areas, from a science and research perspective the optimal configuration would likely be similar to that on Mauna Kea (the Outrigger Telescopes placed in a configuration surrounding the GTC). Such a configuration would involve siting of some telescopes in previously undisturbed areas, leading to destruction of flora. Because of the nature of the site and flora involved, there would be difficulty in flora reestablishing itself. However, the relatively small size of the Outrigger Telescopes would necessarily limit the area of disturbance.

Animals temporarily may leave the immediate vicinity during the period of construction and installation due to human presence and activity, and noise. Many of those species would return after on-site construction and installation are complete.

The 1999 environmental survey for the GTC resulted in a finding of no impact to protected species within the GTC site area. Since construction and installation activities associated with the Outrigger Telescopes would be similar to but smaller in scale than the GTC, no impact to any protected species is anticipated.

In summary, the impact on flora and fauna would be minor. Impacts to fauna would be temporary; it could take some period of time for flora to reestablish itself.

ES.2.4.3 Hydrology, Water Quality, and Wastewater

Water would be trucked to the site. The septic system and leach field at GTC have been approved by local authorities.

Some of the water applied for dust control would be lost to evaporation and the remainder would percolate downward. While the percolation process should be similar to that on Mauna Kea, a clay-like sub-layer in the soil at the GTC may result in some horizontal displacement of the percolating water. Minor hydrologic impact from dust control would be expected.

Outrigger Telescopes construction activities may affect precipitation run-off from the site, but impacts to hydrology and water quality would be small. No water channels or drainages cross the site. Implementation of a BMP would minimize alteration of drainage.

Potential impacts from operations of the Outrigger Telescopes at the GTC site are similar to those of the Proposed Action.

ES.2.4.4 Solid Waste and Hazardous Materials Management

The analysis of these impacts and mitigation measures (with the exception of Wēkiu bug mitigation measures) for the W.M. Keck Observatory site generally apply to the GTC site as well. With appropriate handling of hazardous materials, there would be no impact arising from such materials.

ES.2.4.5 Land Use and Existing Activities

Spanish law has designated astronomy activities as compatible with other

traditional uses within the ORM. Thus on-site construction, installation, and operation of the Outrigger Telescopes would be compatible with and not adversely affect land use designation. Other than astronomy and a relatively small amount of tourism there are no existing activities of any note in the area of ORM. There would be no impact.

ES.2.4.6 Geology, Soils, and Slope Stability

The altered state due to weathering of the volcanic material in the upper soil layers results in a surface subject to erosion as a result of project related activities. Careful design would ensure that the Outrigger Telescopes are placed on stable foundations. Best management practices would include measures to minimize erosion. Such measures would likely need to be more extensive than at the W.M. Keck Observatory site. With available mitigation methods, the adverse impacts to soils and slope stability are anticipated to be small.

ES.2.4.7 Transportation

Since traffic can use two routes to the ORM and visitor activity is relatively low, there is likely to be much excess traffic capacity. Overall adverse transportation impact would be small and less than at Mauna Kea.

ES.2.4.8 Utilities and Services

Except for electrical power, the impacts on utilities and services are similar to those for the Proposed Action.

The electrical load of the Outrigger Telescopes combined with that of GTC would approach and perhaps exceed existing capacity. The situation would be even more problematic in the event of an emergency. Overall, the adverse impact to electric power supply would be substantial without upgrades. With such additional infrastructure, the adverse impact would be small.

ES.2.4.9 Socioeconomics

Excluding the need to add certain facilities at the GTC site that presently exist at the W.M. Keck Observatory (e.g., an interferometer and associated equipment, electric power upgrades, etc.), on-site construction, installation, and operations costs would be approximately the same. There would relatively be a greater socioeconomic benefit to La Palma and the Canary Islands than to the Island and State of Hawai‘i because of the relative sizes of the local economies. Overall, Outrigger Telescopes Project would offer a moderate socioeconomic benefit to La Palma and small benefit to the Canary Islands.

ES.2.4.10 Air Quality

The two highway routes to the GTC are entirely paved. There would therefore be no dust generated by construction or operations traffic to and from the GTC. With the implementation of mitigation measures similar to those that would be employed for the Mauna Kea site the environmental impacts on air quality are expected to be small and slightly less than for the W.M. Keck Observatory site.

ES.2.4.11 Noise

The analysis for the W.M. Keck Observatory site generally applies to Outrigger Telescopes construction at the GTC site with the following exceptions: there are no religious practices conducted in the vicinity of the GTC site; there is little recreational use in the vicinity of the GTC site. Noise impacts from construction would be small and less than at Mauna Kea. Operation noise impacts would be effectively zero.

ES.2.4.12 Visual/Aesthetics

Approval of the GTC project by the National Park de la Caldera de Taburiente was dependent, in large part, upon the fact that it would not be visible from the south rim visual overlooks. The Outrigger Telescope enclosures would be much shorter than the GTC thus would not be visible from the south rim. The adverse impact would be effectively zero.

ES.2.5 Reduced Science Option

Should NASA decide not to fund the Outrigger Telescopes Project at either the Mauna Kea site as proposed, or at the alternative site in the Canary Islands, it may choose to implement a Reduced Science Option. The Reduced Science Option would consist of locating four Outrigger Telescopes at an existing observatory that does not have the large diameter telescope needed to achieve all of the science objectives that would be possible with either the Proposed Action or the Canary Islands alternative.

NASA identified two candidate sites for the Reduced Science Option that warranted detailed study. Both sites are in California: Mount Wilson and Palomar Mountain. Chapter 6 of the EIS contains detailed analyses of the environmental impacts of locating the Reduced Science Option at each of the two sites. While implementation of the Reduced Science Option at either candidate site would result in environmental impacts, the intensity of which would vary between the two sites, no significant environmental impacts would occur at either site.

ES.2.6 No-Action Alternative

Under the No-Action Alternative, NASA would not fund on-site construction, installation, or operations of the Outrigger Telescopes Project. NASA's purpose and need for the project would not be met.

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ACRONYMS AND ABBREVIATIONS

ac	acre
ACHP	Advisory Council on Historic Preservation
AU	astronomical unit
BLNR	Board of Land and Natural Resources
BMP	Best Management Practices Plan (construction)
Caltech	California Institute of Technology
CARA	California Association for Research in Astronomy
CARB	California Air Resources Board
CCR	California Code of Regulations
CDUA	Conservation District Use Application
CDUP	Conservation District Use Permit
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFHT	Canada-France-Hawai‘i Telescope
CFR	Code of Federal Regulations
CHARA	Center for High Angular Resolution Astronomy
CIW	Carnegie Institution of Washington
cm	centimeter
CO	carbon monoxide
CO_2	carbon dioxide
CSO	Caltech Submillimeter Observatory
CZM	Coastal Zone Management
dBA	A-weighted decibel
DHHL	Department of Hawaiian Homelands
DLNR	Department of Land and Natural Resources (State of Hawai‘i)
DOH	Department of Health (State of Hawai‘i)
EA	Environmental Assessment
EHS	Extremely Hazardous Substance
EIS	Environmental Impact Statement
EMS	Emergency Medical Service
EMT	Emergency Medical Technician
EPCRA	Emergency Planning and Community Right-to-Know Act
FHWA	Federal Highway Administration
FONSI	finding of no significant impact
ft	foot
gal	gallon
gpd	gallons per day

ACRONYMS AND ABBREVIATIONS (CONTINUED)

GTE HTCo	GTE Hawaiian Telephone Company
ha	hectare
HAR	Hawai‘i Administrative Rules
HELCO	Hawai‘i Electric Light Company
Hg	mercury
HRS	Hawai‘i Revised Statutes
in	inch
IR	infrared
IRTF	NASA Infrared Telescope Facility
JAC	Joint Astronomy Center
JACH	Joint Astronomy Center Hilo
JB	junction box
JCMT	James Clerk Maxwell Telescope
JPL	Jet Propulsion Laboratory
kl	kiloliter
km	kilometer
klpd	kiloliters per day
kV	kilovolt
kVA	kilovolt-ampere
kW	kilowatt
l	liter
lb	pound
LBT	Large Binocular Telescope, Arizona
LEPC	Local Emergency Planning Committee
m	meter
mgd	milligrams per day
mi	mile
MKOOC	Mauna Kea Observatories Outreach Committee
MKSR	Mauna Kea Science Reserve
MKSS	Mauna Kea Support Services
mm	millimeter
MOA	Memorandum of Agreement
mph	miles per hour
MSDS	Material Safety Data Sheet
mt	metric ton
N	newton

ACRONYMS AND ABBREVIATIONS (CONTINUED)

NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NGLT	Next Generation Large Telescope
NHPA	National Historic Preservation Act
No(s)	number
NO_x	nitrogen oxide
NPDES	National Pollution Discharge Elimination System
NRAO	National Radio Astronomy Observatory
NRHP	National Register of Historic Places
NSF	National Science Foundation
OEQC	Office of Environmental Quality Control (State of Hawai‘i)
OMKM	Office of Mauna Kea Management
OSHA	Occupational Safety and Health Administration
OSS	NASA’s Office of Space Science
Pan-STARRS	Panoramic Survey Telescope & Rapid Response System
ppm	parts per million
PTA	Pōhakuloa Training Area
RQ	reportable quantity
RWD	Report of Waste Discharge
RWQCB	Regional Water Quality Control Board
SAAQS	State Ambient Air Quality Standards
SAO	Smithsonian Astrophysical Observatory
SCAB	South Coast Air Basin
SCAQMD	South Coast Air Quality Management District
SCBA	self-contained breathing apparatus
SDAB	San Diego Air Basin
SDCAPCD	San Diego County Air Pollution Control District
SERC	State Emergency Response Commission
SHPD	State Historic Preservation Division
SHPO	State Historic Preservation Officer
SMA	Smithsonian Submillimeter Array
SMT	Submillimeter Telescope
SOP	standard operating plan
SO_x	sulfur oxide
SWRCB	State Water Resources Control Board
TMT	Thirty Meter Telescope
TOTS	Temporary Optical Test Site

ACRONYMS AND ABBREVIATIONS (CONTINUED)

TPQ	Threshold Planning Quantity
UBC	Uniform Building Code
UH	University of Hawai‘i
UH IfA	University of Hawai‘i Institute for Astronomy
UKIRT	United Kingdom Infrared Telescope
U.S.C.	U.S. Code
USDA	U.S. Department of Agriculture
USDOT	U.S. Department of Transportation
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
VATT	Vatican Advanced Technology Telescope
VIS	Visitor Information Station
VLBA	Very Long Baseline Array
VLTI	Very Large Telescope Interferometer, Chile
VOC	volatile organic compound
VQO	Visual Quality Objective
WDR	Waste Discharge Requirement

USEFUL TERMS

aa — geological term meaning rough clinker lava; from Hawaiian word *ʻaʻā*.

adaptive optics — an optical system that corrects for blurring or other optical effects of the atmosphere so that a ground-based telescope can form sharp images.

ʻahinahina — silversword (a high-altitude native plant).

ahu — cairn, altar, sacred platform, mound.

ahupuaʻa — land division, usually extending from the uplands to the sea.

Akua — god, goddess; spiritual or human being of immense power.

aliʻi — chief, chiefess, priest, priestess; member of elite class.

angular resolution — the level of detail that you can see; measure of how sharp the view is of the object being observed.

anticyclone — high pressure zone.

ʻāpana — district (traditional vertical land section); land parcel; piece.

astrometric signature — the wobble of a star due to the gravitational influence of an unseen planetary companion.

astrometry — the precise measurement of the motions and positions of celestial bodies.

ʻaumakua —personal or family gods; deified ancestral spirits who might take several shapes.

autecology — branch of ecology that focuses on individual organisms (or species) and how those organisms influence or are influenced by their environment.

cinder cone — steep conical hill of volcanic fragments that accumulates around and downwind from a vent. Can range in size from tens to hundreds of meters tall.

entomologist — a scientist who studies insects.

Ghyben-Herzberg lens (fresh water) — a body of fresh water buoyantly overlying marine water.

Hāloa — first Hawaiian man.

handhole — a re-enterable container, usually buried to at least grade level or lower, used as a pull box for buried cable.

hāpuʻu — Hawaiian tree fern (*Cibotium chamissoi*).

he mau wai koloa — ponds inhabited by the native Hawaiian duck.

heiau —place of worship; temple; shrine.

interferometry —combining light from two or more telescopes to produce greater angular resolution than each telescope separately could produce.

USEFUL TERMS (CONTINUED)

kahuna — priest, expert, religious practitioner.

kaluakāko'i — cave or pit for making adzes.

kapu — taboo, prohibited, forbidden; sacred.

kauhale — house compound; groups of buildings, including eating houses, sleeping houses, and cookhouses.

Keck Interferometric Array — any combination of the four Outrigger Telescopes with one or both of the Keck Telescopes.

Keck-Keck Interferometer — Keck I and Keck II used together as an interferometer (without the Outrigger Telescopes).

Keck Telescope —the Keck I or Keck II Telescope.

kahakai — ocean edge (7th horizontal land unit).

kuahiwi — very sacred summit lands.

kualono — near-summit lands (2nd horizontal land unit).

kula — upland grassy plains (used as cultural resource—everyday purposes) (6th horizontal land unit).

kea — white, clear, pale (Kea, abbreviation for Wakea: great sky god).

keanakāko'i — cave or pit for making adzes.

koa — large native forest tree (wood used for canoe hulls) (*Acacia koa*).

kuahu — altar.

kuahu manu — altar for bird catchers.

Kūkahau'ula — pink-tinted snow god (traditional name for highest peak at summit; also called Pu'u Wēkiu or Mauna Kea peak).

kupuna —grandparent, ancestor, relative, or close friend of the grandparent's generation; grandaunt; granduncle (Kūpuna — plural of Kupuna).

light-year — the distance that light would travel in a vacuum in one year, 9.46 trillion kilometers or 5.8 trillion miles, used in measuring astronomical distances.

Līlīnoe — goddess of mists

māmane —native tree common in upland forests (*Sophora chrysophylla*).

marae — Polynesian temple with uprights.

mauna —mountain, mountainous region, mountainous.

USEFUL TERMS (CONTINUED)

mele — chant, song.

mo'olelo — story, tale, legend, myth.

moku o loko — district (traditional large vertical land section and political division).

naio — a type of native tree common in upland forests (*Myoporum sandwicense*).

nēnē — native Hawaiian goose.

'ōhi'a —native tree common in upland forests (*Metrosideros* spp.)

'okana — district (traditional vertical land section and political division comprising several *ahupua'a*).

'ō'ō — digging stick or spade.

'ō'ō — type of honeycreeper (extinct native bird once hunted for colorful feathers).

'ōpihi — limpet (meat eaten; shells used as scraping/peeling tool) (*Cellana* spp.).

Outrigger Array — any combination of the Outrigger Telescopes alone.

Outrigger Telescope — any of six 1.8-m (6-ft) telescopes.

Pae — high chief in the time of 'Umi (16th century); an exceptional fisherman.

Papa — earth mother.

Pele — volcano goddess.

permafrost — perennially frozen ground occurring wherever the temperature remains below 0° C (32° F) for several years, whether the ground is consolidated by ice or not and regardless of the rock and soil particle composition of the earth.

pili — a grass.

pixel — smallest unit of an image on a television or computer screen.

po'ina nalu — ocean edge (7th horizontal land unit).

Poli'ahu — goddess of the snows of Mauna Kea.

proto-stellar disk — disk of dust and gas in space believed to be an early stage of star formation.

pulu — silky fiber collected from *hāpu'u* (tree fern) for pillow and mattress stuffing.

pu'u — (singular and plural) any kind of protuberance, from a pimple to a hill: hill, peak, cone, hump, mound, bulge, heap, pile, portion, bulk, mass, quantity, clot, bunch, knob.

Pu'u Hau'oki — frosty peak (westernmost summit cone).

USEFUL TERMS (CONTINUED)

seeing —amount of degradation of an optical image by the Earth's atmosphere. Good seeing implies minimal degradation.

stellar debris disk — cloud of gas or other material remaining after a star is formed.

synoptic scale — pertaining to regional scales.

taro — aroid with edible leaves and corm (underground stem) (*Colocasia esculenta*); main Hawaiian staple food (*kalo*).

tephra — a rock composed of fragmented volcanic material ejected in eruptions.

'ua'u —dark-rumped petrel, an endangered sea bird considered by some an *'aumakua* (personal god).

vadose zone —the zone immediately below the land surface and above the water table.

vent — the opening at the Earth's surface through which volcanic materials (lava, tephra, and gases) erupt. Vents can be at a volcano's summit or on its slopes.

Waiau — one of Poli'ahu's companions (Lake Waiau (also known as Poli'ahu's pond) and Pu'u Waiau are named for her).

wao — environmental and cultural zone.

wao ma'u kele — (below ke kualono) large area of koa, *'ohi'a*, lobelia, and mamane (3rd horizontal land unit).

wao akua — varied forest land (4th horizontal land unit).

wao kanaka — lowest forested area (used as cultural resource—everyday purposes) (5th horizontal land unit).

wēkiu — tip, top, topmost, summit.

CONVERSION FACTORS

Linear

1 centimeter (cm) = 0.3937 inch (in)	1 in = 2.54 cm
1 cm = 0.0328 foot (ft)	1 ft = 30.48 cm
1 meter (m) = 3.2808 ft	1 ft = 0.3048 m
1 m = 0.0006 mile (mi)	1 mi = 1609.3440 m
1 kilometer (km) = 0.6214 mi	1 mi = 1.6093 km
1 km = 0.53996 nautical mile (nmi)	1 nmi = 1.8520 km
	1 mi = 0.87 nmi
	1 nmi = 1.15 mi

Area

1 square centimeter (cm^2) = 0.1550 square in (in^2)	1 in^2 = 6.4516 cm^2
1 square meter (m^2) = 10.7639 square ft (ft^2)	1 ft^2 = 0.09290 m^2
1 square kilometer (km^2) = 0.3861 square mi (mi^2)	1 mi^2 = 2.5900 km^2
1 hectare (ha) = 2.4710 acres (ac)	1 ac = 0.4047 ha
1 hectare (ha) = 10,000 square m (m^2)	1 ft^2 = 0.000022957 ac

Volume

1 cubic cm (cm^3) = 0.0610 cubic in (in^3)	1 in^3 = 16.3871 cm^3
1 cubic m (m^3) = 35.3147 cubic ft (ft^3)	1 ft^3 = 0.0283 m^3
1 cubic m (m^3) = 1.308 cubic yards (yd^3)	1 yd^3 = 0.76455 m^3
1 liter (l) = 1.0567 quarts (qt)	1 qt = 0.9463264 l
1 l = 0.2642 gallon (gal)	1 gal = 3.7845 l
1 kiloliter (kl) = 264.2 gal	1 gal = 0.0038 kl

Weight

1 gram (g) = 0.0353 ounce (oz)	1 oz = 28.3495 g
1 kilogram (kg) = 2.2046 pounds (lb)	1 lb = 0.4536 kg
1 metric ton (mt) = 1.1023 tons	1 ton = 0.9072 metric ton

Energy

1 joule = 0.0009 British thermal unit (BTU)	1 BTU = 1054.18 joules
1 joule = 0.2392 gram-calorie (g-cal)	1 g-cal = 4.1819 joules

Pressure

1 newton/square meter (N/m^2) = 0.0208 pound/square foot (psf)	1 psf = 48 N/m^2

Force

1 newton (N) = 0.2248 pound-force (lbf)	1 lbf = 4.4478 N

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1 SUMMARY AND PURPOSE AND NEED FOR THE PROPOSED ACTION

This Draft Environmental Impact Statement for the Outrigger Telescopes Project has been prepared by the National Aeronautics and Space Administration (NASA) to assist the decisionmaking process in accordance with the National Environmental Policy Act of 1969, as amended (NEPA) (42 U.S.C. §4321 et seq.) and NASA's policy and procedures (14 CFR Subpart 1216.3).

1.1 SUMMARY OF THE PROPOSED ACTION

The National Aeronautics and Space Administration (NASA) is proposing to fund the on-site construction, installation, and operation of four, and possibly up to six, Outrigger Telescopes at the W.M. Keck Observatory site located within the Astronomy Precinct of the Mauna Kea Science Reserve on the island of Hawai‘i.

The State of Hawai'i leases the Mauna Kea Science Reserve to the University of Hawai‘i (UH). UH subleases the W.M. Keck Observatory site to the California Institute of Technology (Caltech). The California Association for Research in Astronomy (CARA), a non-profit corporation established by the University of California and Caltech, operates and maintains the Keck Telescopes and the W.M. Keck Observatory site.

1.2 PURPOSE AND NEED FOR ACTION

Since its inception in 1958, NASA has achieved countless scientific and technological breakthroughs in air and space science and technology. NASA continues to be a driving force in scientific research and in stimulating public interest in space science and exploration.

NASA has a central Mission with three components: (1) to understand and protect our home planet, (2) to explore the universe and search for life, and (3) to inspire the next generation of explorers. The second component, to explore the universe and search for life, addresses two of humanity's oldest and most profound questions: "Where did we come from?" and "Are we alone?" Understanding where we come from requires knowledge of how today's universe of galaxies, stars, and planets came to be, and how stars and planetary systems form and evolve. Understanding whether or not we are alone requires knowledge about the building blocks of life, the conditions necessary to sustain life, and the diversity of planets—particularly those that might harbor life. Acquiring knowledge in all of these areas is the goal of NASA's Origins Program. In pursuit of this knowledge, NASA supports space flight missions, related research programs, and technology development.

Interferometry is a critical technology for accomplishing the Origins Program. It is a technique for overcoming an inherent limitation of single telescopes: the "sharpness" or amount of image detail is limited by the size of the telescope's main mirror. An interferometer combines two or more telescopes optically so they function as if they were a single larger telescope. The number of individual telescopes and the distance between them determines the sharpness of the image from an interferometer. Because the separation between telescopes can be much larger than the diameter of even the largest telescope mirrors, interferometers in general acquire images that capture much more detail than individual telescopes.

Interferometers also can measure positions of stars with exquisite accuracy. This is

important because it is possible to find planets around other stars by measuring the stars' positions very accurately over a substantial period of time. As a planet orbits a star, it exerts a gravitational tug that causes the star to move back and forth. An interferometer can detect this slight "wobble," thus revealing the presence of the orbiting planet.

NASA is developing interferometry for use both in space and on the ground. Space flight missions, such as the Space Interferometry Mission scheduled for launch in 2009, can achieve even finer measurements than are possible from the ground by getting above the Earth's atmosphere to avoid its image distortion. However, ground-based interferometers are essential for projects that require a longer operating life than is possible with a space flight mission. They can also involve telescopes that are larger and more sensitive than the ones that can be flown in space.

The Outrigger Telescopes Project is part of NASA's program to develop ground-based interferometry. The project as proposed addresses four of NASA's six scientific objectives for ground-based interferometry. These six objectives are:

1. Detect the thermal dust emissions from dust clouds around other stars.
2. Detect the light from and characterize the atmospheres of hot, Jupiter-mass planets located within approximately 20 million kilometers (km) (12 million miles (mi)) of the stars they are orbiting.
3. Detect the astrometric signature (*i.e.*, the wobble of a star due to the gravitational influence of an unseen planetary companion) of planets as small as Uranus.
4. Make images of proto-stellar disks (*i.e.*, disks of dust and gas in space believed to be an early stage of star formation) and stellar debris disks (*i.e.*, clouds of gas or other material remaining after the star is formed).
5. Provide high-resolution information about some faint objects outside our galaxy.
6. Make high-resolution observations of objects within the solar system, including asteroids, comets, and outer planets.

The first two objectives can be accomplished by the Keck-Keck Interferometer which links the two 10-m (33-ft) Keck Telescopes. Objectives 3 through 6 require the Outrigger Telescopes. Objective 3, finding planets around nearby stars by means of astrometry, can be accomplished with four Outrigger Telescopes alone. Objectives 4 through 6 require that the Outrigger Telescopes be connected to one or more large (8-meter (m) (26-foot (ft)) diameter or larger) telescopes. Six Outrigger Telescopes would provide almost twice as much image detail as four in pursuit of Objectives 4 through 6, yielding much higher quality scientific data.

The Outrigger Telescopes Project would also support a key Origins Program flight mission, the Terrestrial Planet Finder. The Terrestrial Planet Finder, scheduled for launch sometime in the second decade of this century, would undertake the extraordinarily difficult task of separating the light of a terrestrial (Earth-like) planet orbiting another star from the light of its parent star. It then would measure the spectrum of the planet's light to determine the planet's properties and determine if it might be capable of supporting life. Finding and characterizing the best possible target stars for the Terrestrial Planet Finder to examine is crucial to the success of the mission. By undertaking Objective 3, finding larger planets around nearby stars, the Outrigger Telescopes Project would contribute to our understanding of planetary system architectures and help characterize stars to be examined with the Terrestrial Planet Finder.

In order to enhance this nation's capabilities to pursue the answers to the age-old questions concerning the origin of life and whether life exists on other planets, NASA must further develop and refine interferometry. Accordingly, NASA, as the Federal agency charged with exploring the universe, has an interest in developing experience and expertise within the American astronomical community in the design and operation of ground-based interferometric arrays. One of the purposes of the Outrigger Telescopes Project is to provide American astronomers opportunities to develop this expertise.

1.3 FEDERAL ENVIRONMENTAL PLANNING ACTIVITIES TO DATE

Federal Processes. Pursuant to the National Environmental Policy Act (NEPA), NASA completed an Environmental Assessment (EA) for the Outrigger Telescopes Project in February 2002 and issued its decision document (Determination of Required Mitigation and Decision) on March 4, 2002.

In addition to its NEPA activities, NASA conducted consultations in accordance with Section 106 of the National Historic Preservation Act of 1966, as amended (NHPA) (16 U.S.C. § 470 *et seq*.), it began this process in July 1999 by authorizing UH to begin working-level consultations on behalf of NASA. UH, in consultation with the Hawaii State Historic Preservation Division (SHPD), contacted a number of Native Hawaiian organizations to determine their interest in participating in the Section 106 process. In November 1999, a NASA representative met with the Hawai‘i Island Burial Council. In August 2000, NASA formally provided copies of draft mitigation proposals to the State Office of Hawaiian Affairs, the Royal Order of Kamehameha I, the Hawai‘i Island Burial Council, and Hui Mālama I Nā Kūpuna O Hawaii Nei, and invited them to join with NASA and the SHPD in formal consultation under the Section 106 process as Consulting Parties. In September 2000, NASA formally invited the Advisory Council on Historic Preservation (ACHP) to join in the Section 106 process. The ACHP agreed to participate.

NASA consulted with and invited the Office of Mauna Kea Management, the Mauna Kea Management Board, and Kahu Kū Mauna to participate in developing a Memorandum of Agreement (MOA) under Section 106. Two more Native Hawaiian organizations, Ahahui Kū Mauna and Mauna Kea Anaina Hou, requested and were given Consulting Party status. NASA held formal Section 106 meetings in Hilo on February 1, 2001, and again on January 16 and 17, 2002. NASA completed the Section 106 consultation process February 22, 2002 with the signing of an MOA by NASA, ACHP, SHPD, CARA, Caltech, UH, and Ahahui Kū Mauna (with caveat).

The Office of Hawaiian Affairs challenged NASA's EA and decision in Federal Court. In June of 2003 the court remanded the EA and instructed NASA to reassess the cumulative impacts of the proposed Outrigger Telescopes Project. In November of 2003, NASA announced its decision to voluntarily go beyond the Court's direction to reassess cumulative impacts in a new Environmental Assessment. NASA announced that it would instead prepare an Environmental Impact Statement (EIS). NASA's decision to prepare an EIS recognized the deep concerns and feelings expressed for Mauna Kea by members and representatives of the Native Hawaiian community. On December 30, 2003, NASA published in the Federal Register its Notice of Intent (NOI) to prepare an EIS (68 Federal Register (FR) 75285). The NOI was also published in the *Honolulu Star-Bulletin, West Hawaii Today*, and the *Honolulu Advertiser*. NASA held five public

scoping meetings on the islands of Hawai‘i and O‘ahu in January 2004 and accepted public scoping comments until February 16, 2004.

The comments NASA received during the public scoping period focused primarily on cultural impacts, hazardous materials handling, hydrology, visual impacts to the view planes to and from Mauna Kea, impacts to the Wēkiu bug and its habitat, and overall cumulative impacts to the summit region. The Wēkiu bug is a candidate for listing under the Endangered Species Act of 1973, as amended (16 U.S.C. §1531 *et seq*.). Some comments raised issues, such as overall management of the summit of Mauna Kea and ceded lands, that are beyond the scope of the Outrigger Telescopes Project and this document.

1.4 ORGANIZATION OF THE EIS

This EIS is organized into two volumes. Volume 1 contains Chapters 1 through 10, and Volume 2 contains Appendices A through F.

	VOLUME 1
Chapter 1	Summary and Purpose and Need for the Proposed Action
Chapter 2	Proposed Action and Alternatives
Chapter 3	Affected Environment
Chapter 4	Environmental Impacts
Chapter 5	Mitigation and Monitoring Measures for the Outrigger Telescopes Project
Chapter 6	Reduced Science Options
Chapter 7	List of Preparers
Chapter 8	Agencies, Organizations, and Persons Consulted
Chapter 9	Index
Chapter 10	References

Chapter 2 describes the Proposed Action and addresses the results of NASA’s consideration of alternative sites for the Outrigger Telescopes Project. Chapter 2 identifies a reasonable alternative site for the Outrigger Telescopes Project on La Palma in the Canary Islands.

Chapter 3 provides a comprehensive description of the environment at and near the W.M. Keck Observatory site.

Chapter 4 addresses the environmental impacts of the Proposed Action, including the cumulative environmental impacts of implementing the Proposed Action. It considers past, present, and reasonably foreseeable future actions within or near the Mauna Kea Astronomy Precinct.

Chapter 5 provides a description of the numerous mitigation commitments made by NASA, CARA, and UH in implementing the Outrigger Telescopes Project.

If NASA, in the Record of Decision for this EIS, should decide not to fund the Proposed Action at Mauna Kea or at a reasonable alternative site, NASA would consider the option of implementing the Outrigger Telescopes Project at an existing U.S. observatory facility where only reduced science returns would be possible. This is called the Reduced Science Option. Two potential reasonable observatory sites have been identified for this option, Mount Wilson, California and Palomar Mountain, California. The Reduced Science Option would achieve only one scientific objective of the Outrigger Telescopes Project. Chapter 6 addresses the environmental impacts of constructing and operating the Outrigger Telescopes at each of the two reduced science sites.

Chapters 7 through 9 contain a list of preparers of this EIS, entities consulted during

EIS preparation, an index to key topics in the EIS, and the references used in preparing the document.

Volume 2 of this EIS contains Appendices A through F, which provide detailed and/or focused information relative to key environmental impacts and topics addressed in Volume 1.

	VOLUME 2
Appendix A	NEPA Consultations
Appendix B	Memorandum of Agreement
Appendix C	Draft Burial Treatment Plan
Appendix D	Wēkiu Bug Mitigation Plan
Appendix E	Wēkiu Bug Monitoring Plan
Appendix F	Construction Best Management Practices Plan

For this EIS, the preparers conducted a comprehensive search for environmental information on past and ongoing activities on Mauna Kea. The following is the principal environmental documentation reviewed:

1. General Lease #S-4191. Signed June 21, 1968 (65-year lease of Mauna Kea summit).
2. *CFHT Final Environmental Impact Statement Proposed Telescope and Observatory Facilities.* Prepared by Neighbor Island Consultants, May 1974.
3. *UH/IRTF/UKIRT Final EIS.* Prepared by University of Hawai‘i, May 1975.
4. *Environmental Impact Analysis of the NASA Infrared Telescope Facility at Mauna Kea, Hawaii.* Prepared by Booz-Allen Applied Research, July 1975.
5. *Hale Pohaku: Mid-Elevation Facilities Master Plan Revised Environmental Impact Statement.* Prepared by Group 70, February 1980.
6. *10-Meter Telescope for Millimeter and Submillimeter Astronomy at Mauna Kea, Hamakua, Hawaii: Final Environmental Impact Statement.* Prepared by Group 70, August 1982.
7. *Mauna Kea Science Reserve: Complex Development Plan—Final EIS.* Prepared by Research Corporation of the University of Hawai‘i, January 1983.
8. *Amendment to the Mauna Kea Science Reserve Complex Development Plan—Final Supplemental Environmental Impact Statement for Construction Camp Housing.* Prepared by MCM Planning, October 1985.
9. *Saddle Road Improvements, CDUA, CDUA Supplement and Environmental Impact Assessment*. County of Hawai‘i, June 1986.
10. *Amendment to the Mauna Kea Science Reserve Complex Development Plan: Final Supplemental EIS—VLBA Antenna Facility.* Prepared by Research Corporation of the University of Hawai‘i, September 1988.
11. *Project Description: Japan National Large Telescope (JNLT).* Prepared by MCM Planning, January 1991.
12. *Project Description: Gemini 8-Meter Telescopes Project.* Prepared by Townscape, Inc., July 1992.
13. *Environmental Assessment for the Gemini Northern 8-Meter Telescope.* Prepared by Engineering-Science, Inc., December 1993.
14. *Project Description and Environmental Review: Smithsonian Astrophysical Observatory Submillimeter Array Telescope.* Prepared by MCM Planning, January 1994.

15. *Project Description and Environmental Review: GTE Hawaiian Telephone Company Fiber Optic Cable Project—Pohakuloa to Hale Pohaku Link.* Prepared by MCM Planning, September 1995.

16. *Mauna Kea Ranch Pipe Line, Hamakua Coast, Hawaii, Final Environmental Assessment*. Prepared by Waimea Water Services Inc. Mauna Kea Ranch John Hancock Insurance, August 1996.

17. *Final Environmental Assessment/Finding of No Significant Impact, Saddle Road Well A*. Prepared by Planning Solutions, Inc. Department of Water Supply, County of Hawai‘i, November 1997.

18. *Project Description and Environmental Review: Temporary Optical Test Sites for the W.M. Keck Observatory Twin Keck Telescope Interferometer.* Prepared by MCM Planning, March 1998.

19. *Final Environmental Assessment: Temporary Optical Test Sites for W.M. Keck Observatory Twin Keck Telescope Interferometer.* Prepared by MCM Planning, September 1998.

20. *Environmental Impact Statement Preparation Notice, Saddle Road Extension: From Mamalahoa Highway to Queen Ka‘ahumanu Highway*. Department of Transportation, July 1999.

21. *Mauna Kea Science Reserve Master Plan, Final Environmental Impact Statement*. University of Hawai‘i, December 1999.

22. *Mauna Kea Science Reserve Master Plan.* University of Hawai‘i, June 2000.

23. *Final Environmental Assessment for the Outrigger Telescopes Project*. NASA, March 2002.

24. Final State Environmental Assessment for Mauna Kea Astronomy Education Center. University of Hawai‘i, August 2002.

2 PROPOSED ACTION AND ALTERNATIVES

This Chapter describes the Proposed Action and the Alternatives.

2.1 DESCRIPTION OF THE PROPOSED ACTION

The National Aeronautics and Space Administration's (NASA) Proposed Action is to fund the on-site construction, installation, and operation of four, and possibly up to six, Outrigger Telescopes at the W.M. Keck Observatory site. NASA anticipates that on-site construction and installation of four Outrigger Telescopes along with the on-site construction of the underground structures for Outrigger Telescopes 5 and 6 would begin in 2005 (assuming all permits and approvals have been received) with start of operations anticipated in 2007. If funding becomes available, NASA intends to complete the above-ground construction, installation, and operation of Outrigger Telescopes 5 and 6, with on-site construction and installation likely to begin no earlier than 2007.

NASA would strategically place the proposed Outrigger Telescopes around the 10-meter (m) (33-foot (ft)) Keck I and Keck II Telescopes that are currently being operated by the California Association for Research in Astronomy (CARA) within the Mauna Kea Science Reserve (MKSR). Figure 2-1 illustrates the location of the MKSR on the island of Hawai‘i.

Related activities that would take place at Hale Pōhaku during the construction phase include use of the approved materials staging area and the existing construction camp.

This Environmental Impact Statement (EIS) also describes alternatives to the Proposed Action that NASA has considered: funding on-site construction, installation, and operation of the Outrigger Telescopes at an alternative site and the No-Action Alternative. NASA also systematically evaluated ten other potential sites for locating the Outrigger Telescopes Project. Of the ten sites evaluated, one site emerged as a reasonable alternative to the Mauna Kea site. This site, located in Spain's Canary Islands, is called the Gran Telescopio Canarias site. NASA's initial evaluation of this site indicates that all of the science objectives established for the Outrigger Telescopes Project could be achieved at this site as well as at Mauna Kea. Section 2.2 describes the process by which this reasonable alternative site was identified and Section 2.3 provides a description of the Outrigger Telescopes Project at the Gran Telescopio de Canarias (GTC) site in La Palma, Canary Islands. Section 2.4 describes the No-Action Alternative.

In addition, NASA may choose to implement a Reduced Science Option if it decides not to fund the Outrigger Telescopes Project at either the Mauna Kea site as proposed or at the alternative site in the Canary Islands. Chapter 6 addresses the Reduced Science Option.

2.1.1 Summit Area of the MKSR and the Mid-Elevation Support Facilities

The proposed site is located in the Astronomy Precinct in the summit area of the MKSR (Figure 2-2). The State leases the MKSR, about 4,568 hectares (ha) (11,288 acres (ac)) in size, to the University of Hawai‘i (UH). UH, in turn, has subleased parcels of the MKSR in the summit area to

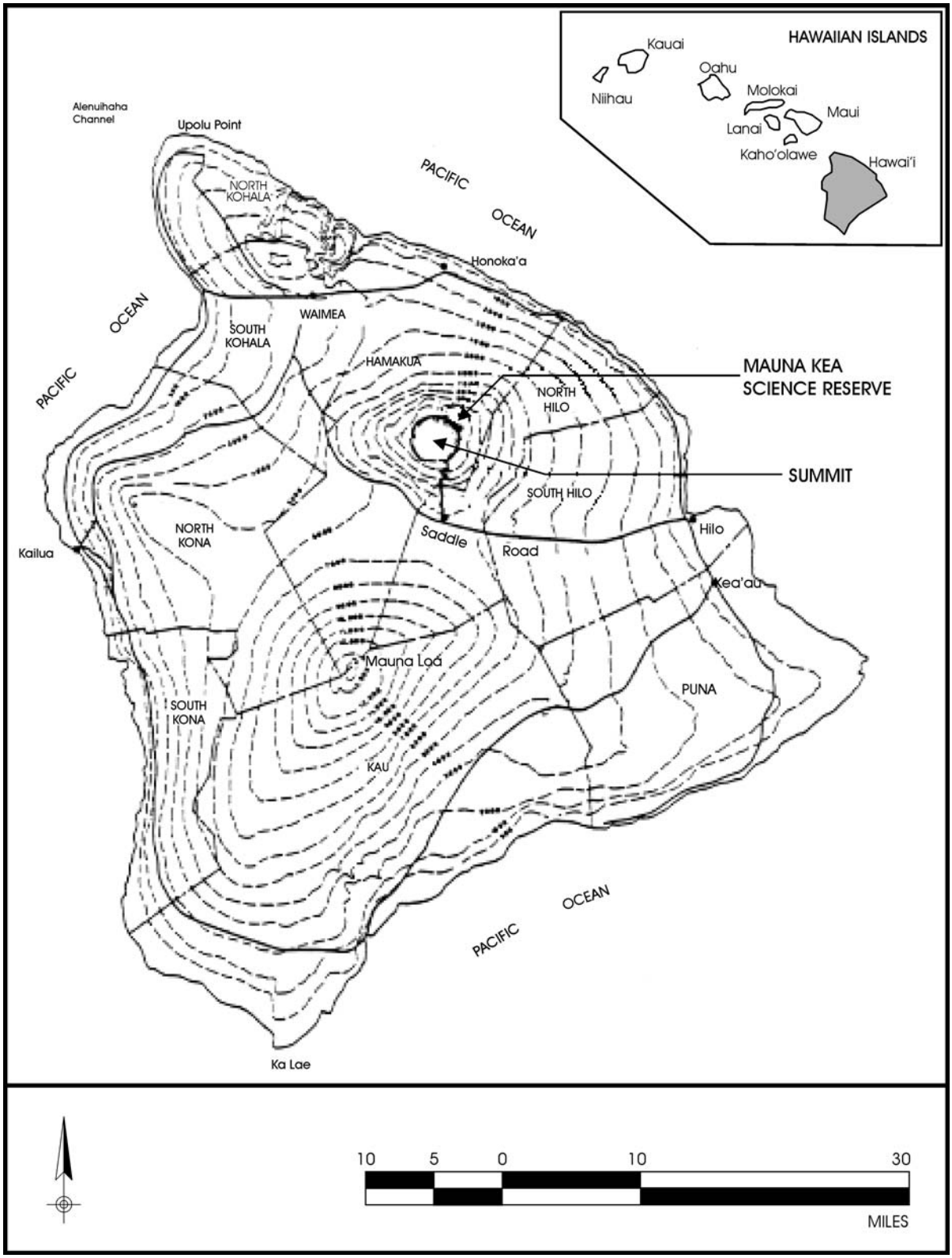
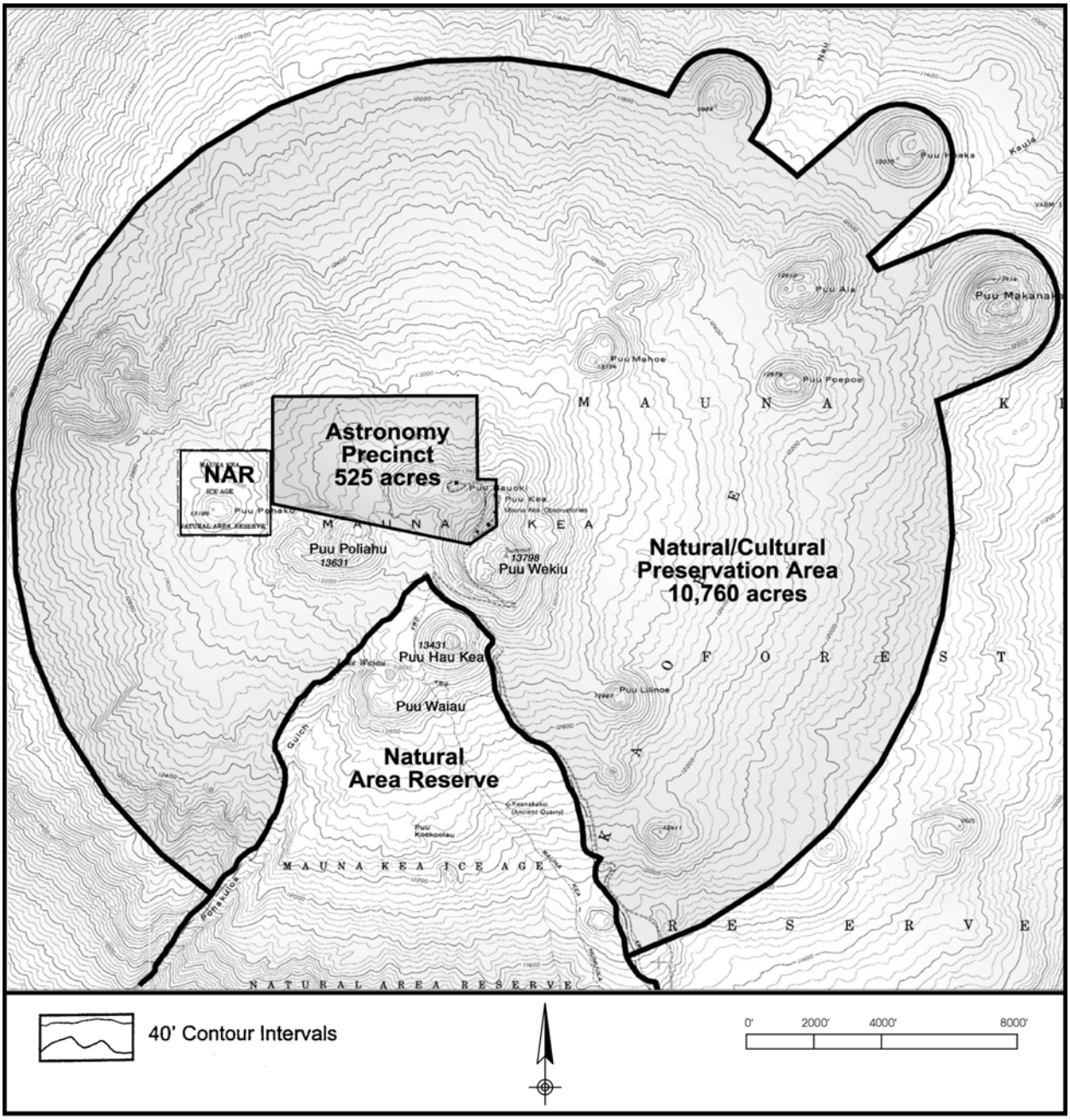


FIGURE 2-1. MAUNA KEA SCIENCE RESERVE ON THE ISLAND OF HAWAI'I



Source: UH 2000b

FIGURE 2-2. MAUNA KEA SCIENCE RESERVE (INCLUDES THE ASTRONOMY PRECINCT AND THE NATURAL/CULTURAL PRESERVATION AREA)

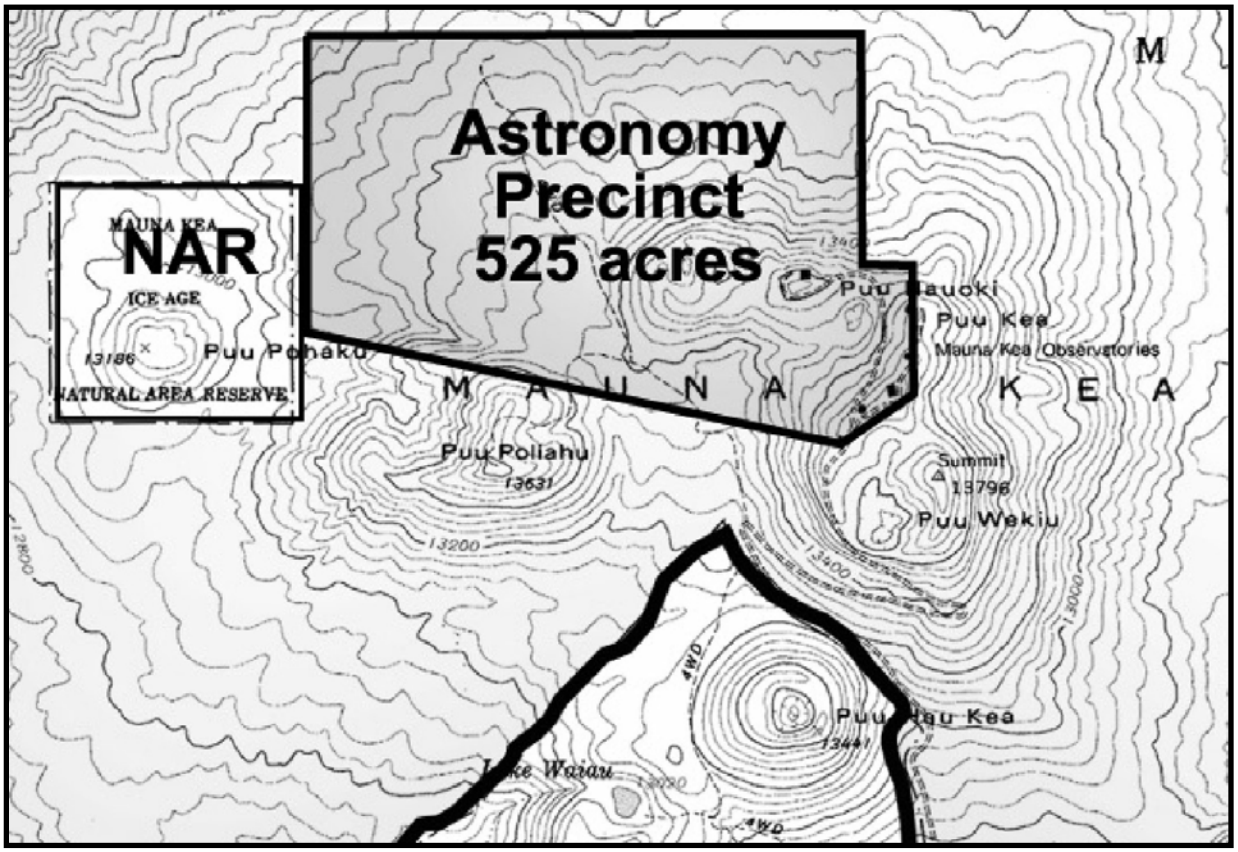


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FIGURE 2-3. ASTRONOMY PRECINCT

various observatory facilities. The California Institute of Technology (Caltech) subleases the W.M. Keck Observatory site. The site is located in the Resource Subzone of the State Conservation District in an area the recently adopted MKSR Master Plan defines as the Astronomy Precinct (see Figure 2-3). The MKSR Master Plan requires that all future astronomy development in the MKSR be restricted to the Astronomy Precinct, totaling about 212 ha (525 ac).

In addition to Department of Land and Natural Resources (DLNR) review through the Conservation District Use Application process, and application approval by the Board of Land and Natural Resources (BLNR), future proposed development within the Astronomy Precinct will be subject to review and approval by the UH Board of Regents and President. The Office of Mauna Kea Management (OMKM), the Mauna Kea Management Board, the Kahu Kū Mauna Council (Guardians of the Mountain).

The MKSR Master Plan has designated the remainder of the MKSR leasehold, about 4,355 ha (10,760 ac), as a Natural/Cultural Preservation Area (see Figures 2-2 and 2-3). This area will not be developed in the future, but will be preserved and protected. Figure 2-4 shows the location of the existing astronomy facilities within the Astronomy

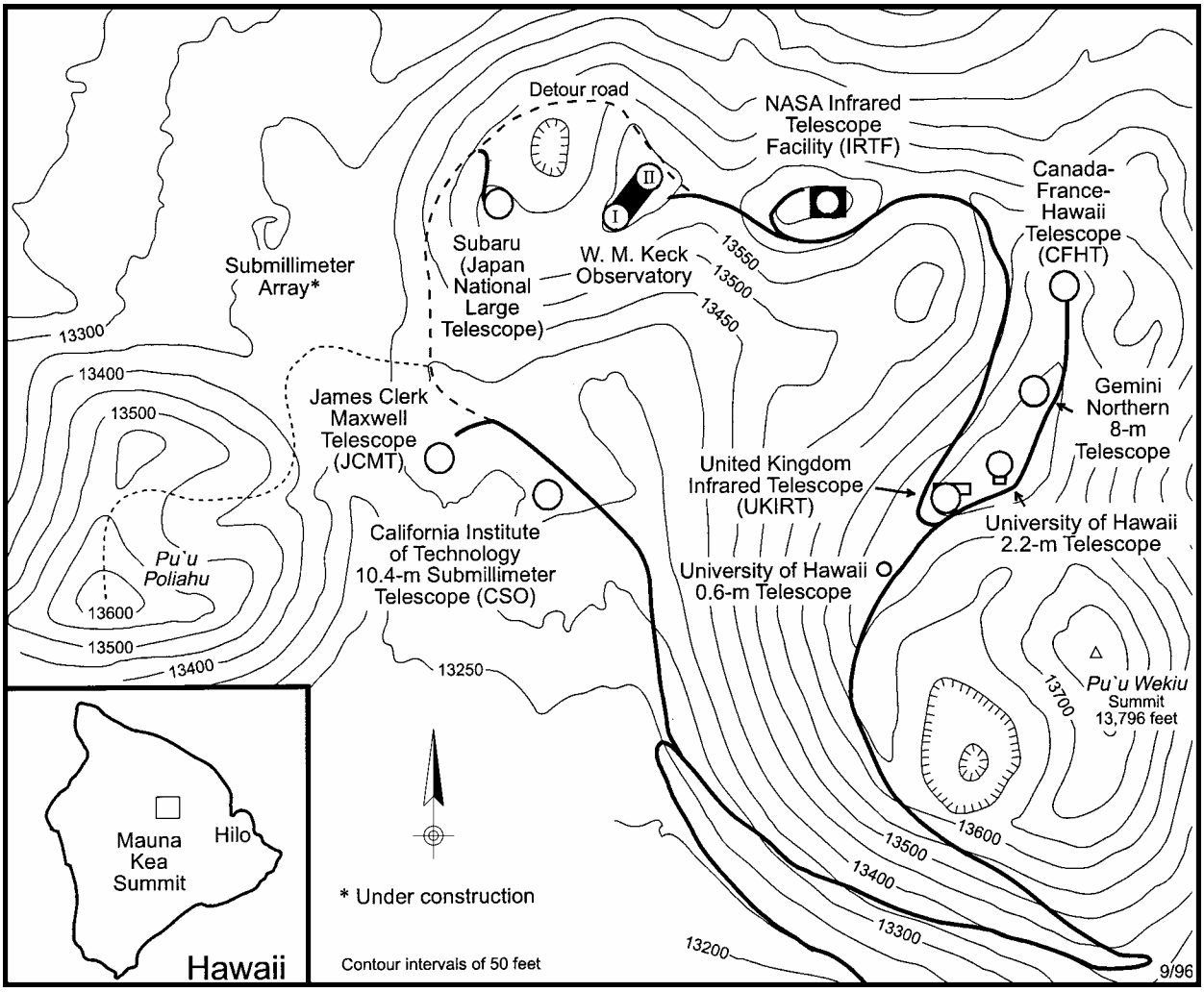


FIGURE 2-4. EXISTING OBSERVATORIES IN THE SUMMIT AREA OF THE MAUNA KEA SCIENCE RESERVE

Precinct relative to the other observatories and the Keck Telescopes.

Mauna Kea Science Reserve/Astronomy Precinct. The MKSR site is the proposed location for the Outrigger Telescopes because it is one of the finest locations in the world for ground-based astronomical observations: the sky above the mountain is generally cloud-free, and Mauna Kea has one of the highest number of clear nights (approximately 300) in the world.

The atmosphere at Mauna Kea, which is free from disturbance caused by neighboring landforms, is stable and allows more detailed observations (better astronomical "seeing") than those available elsewhere. The summit's height above the tropical inversion layer provides conditions that are free from atmospheric pollutants (UH IfA 2002b).

Finally, the County of Hawai‘i has a strong island-wide lighting ordinance in place to ensure an extremely dark sky, enabling observation of the faintest galaxies at the edge of the observable Universe.

W.M. Keck Observatory Site. The proposed Outrigger Telescopes Project would be located on the existing W.M. Keck Observatory site near the Keck I and Keck II Telescopes, the world's largest optical/infrared telescopes. Each Keck Telescope has a revolutionary primary mirror, composed of 36 hexagonal segments that work in concert as a single piece of reflective glass (WMKO 2004). The observatory is developing interferometric observations using both telescopes, a technical feat that achieves the resolution of a single telescope equal in size to the distance spanned by the two Keck Telescopes, 85 m (280 ft).

This capability is enhanced by the use of an advanced adaptive optics system. Adaptive optics corrects for the blurring of the earth's atmosphere to provide resolution equivalent to that of a telescope in space. The W.M. Keck Observatory implemented an adaptive optics system on the Keck II Telescope in 1999. This system has subsequently enabled imaging volcanoes on a moon of Jupiter, viewing the first images of material falling into the black hole at the center of our galaxy, and initial understanding of the structure of galaxies nearly as old as the universe. Adaptive optics on both Keck Telescopes are required to allow the interferometric combination of the two Keck Telescopes. The current system is limited because it requires the presence of a bright star to sense and correct for turbulence in the atmosphere.

The addition of a new laser guide star has removed this limitation. The laser creates a virtual star for use by the adaptive optics system almost anywhere across the sky by exciting sodium atoms, left over from meteors, in the mesosphere about 90 km above sea level. The observatory installed the laser guide star system on the Keck II Telescope in December 2001 and subsequently integrated it with the existing adaptive optics system. First light for laser guide star correction occurred in 2003 (CARA 2004n).

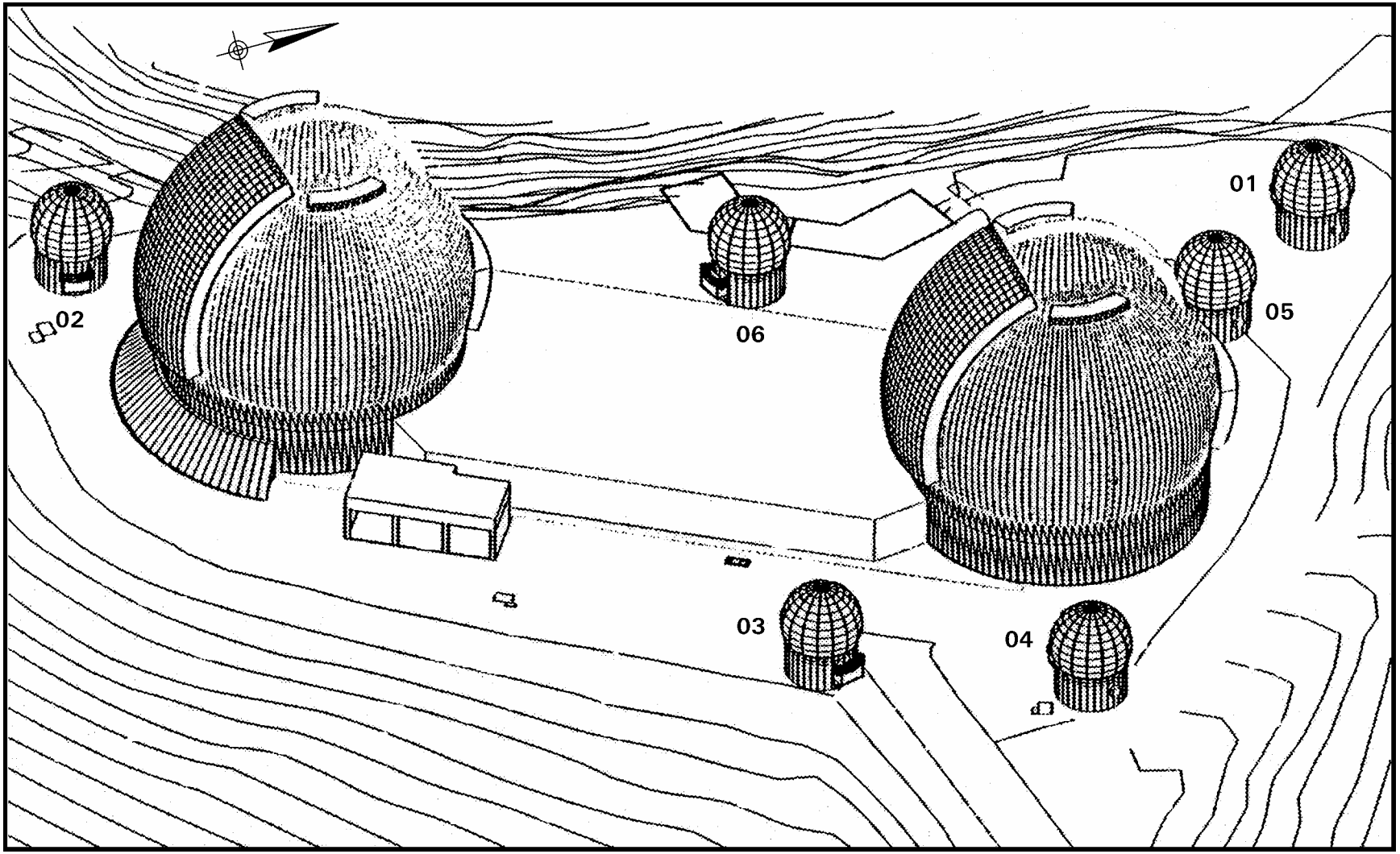
Permission to reprint photo obtained from CARA.

FIGURE 2-5. W.M. KECK OBSERVATORY SITE

The W.M. Keck Observatory site sits on a 2 ha (5 ac) parcel within the summit area of Mauna Kea. Approximately 1.1 ha (2.8 ac) was leveled during construction of the Keck I and Keck II Telescopes (Towill 1981). The four, and possibly up to six, Outrigger Telescopes would be placed at strategic locations around the two Keck Telescopes within the previously disturbed site. Figure 2-6 shows the six Outrigger Telescopes relative to the Keck I and Keck II Telescopes. Figure 2-7 shows a plan view of the six proposed Outrigger Telescopes at the W.M. Keck Observatory site.

Figure 2-7 also shows underground pipes, tunnels, and junction boxes that would provide the underground optical paths to connect the telescopes to instrumentation in the beam-combining room in the basement of the Keck II Telescope building.

Hale Pōhaku. The Outrigger Telescopes Project would require temporary use of the approved materials staging area and



Source: UH IfA 2001a

FIGURE 2-6. PERSPECTIVE VIEW OF THE TWIN KECK TELESCOPES AND THE SIX OUTRIGGER TELESCOPES

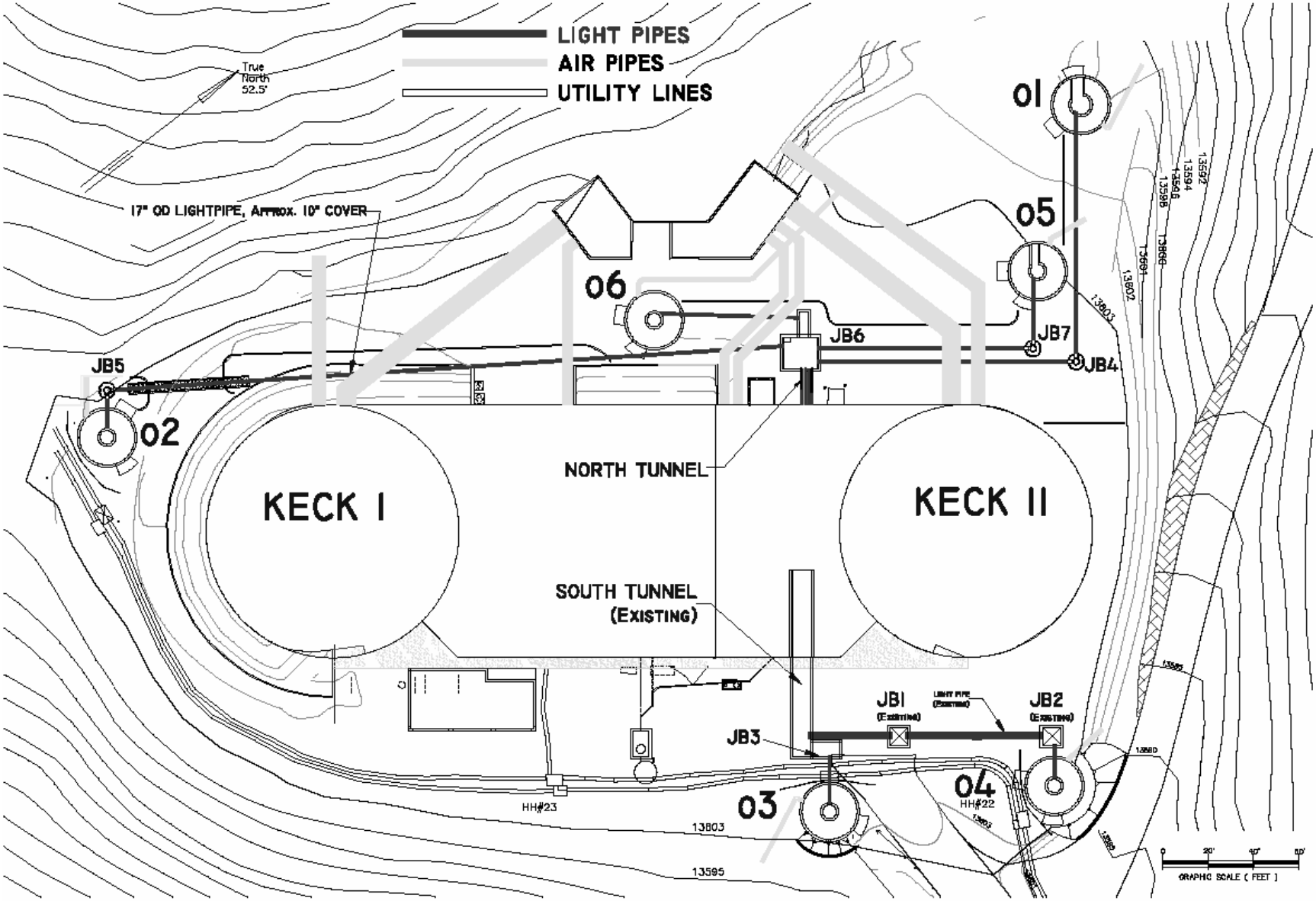


FIGURE 2-7. PROPOSED OUTRIGGER TELESCOPES ON THE WMKO SITE

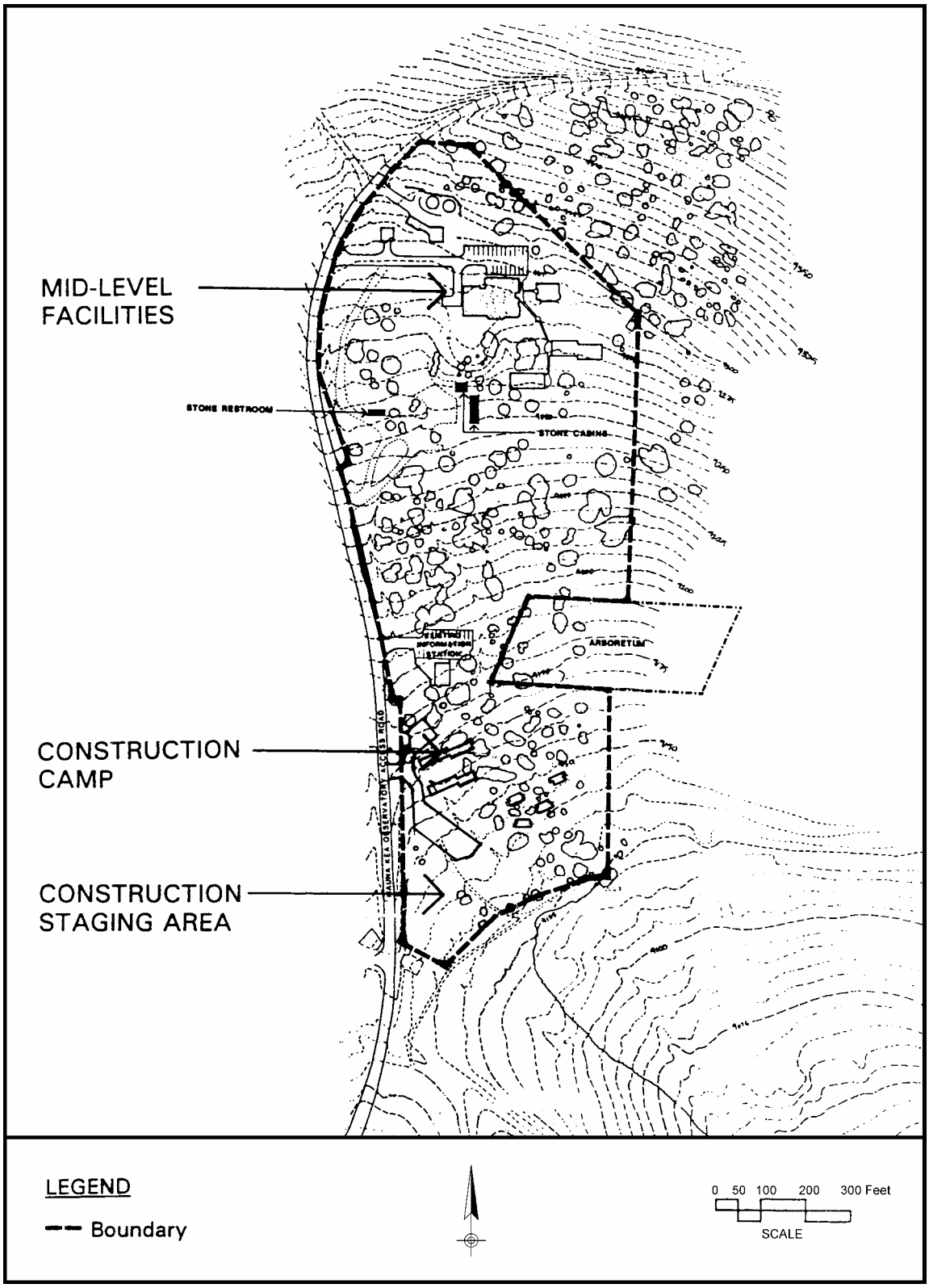


FIGURE 2-8. HALE PŌHAKU

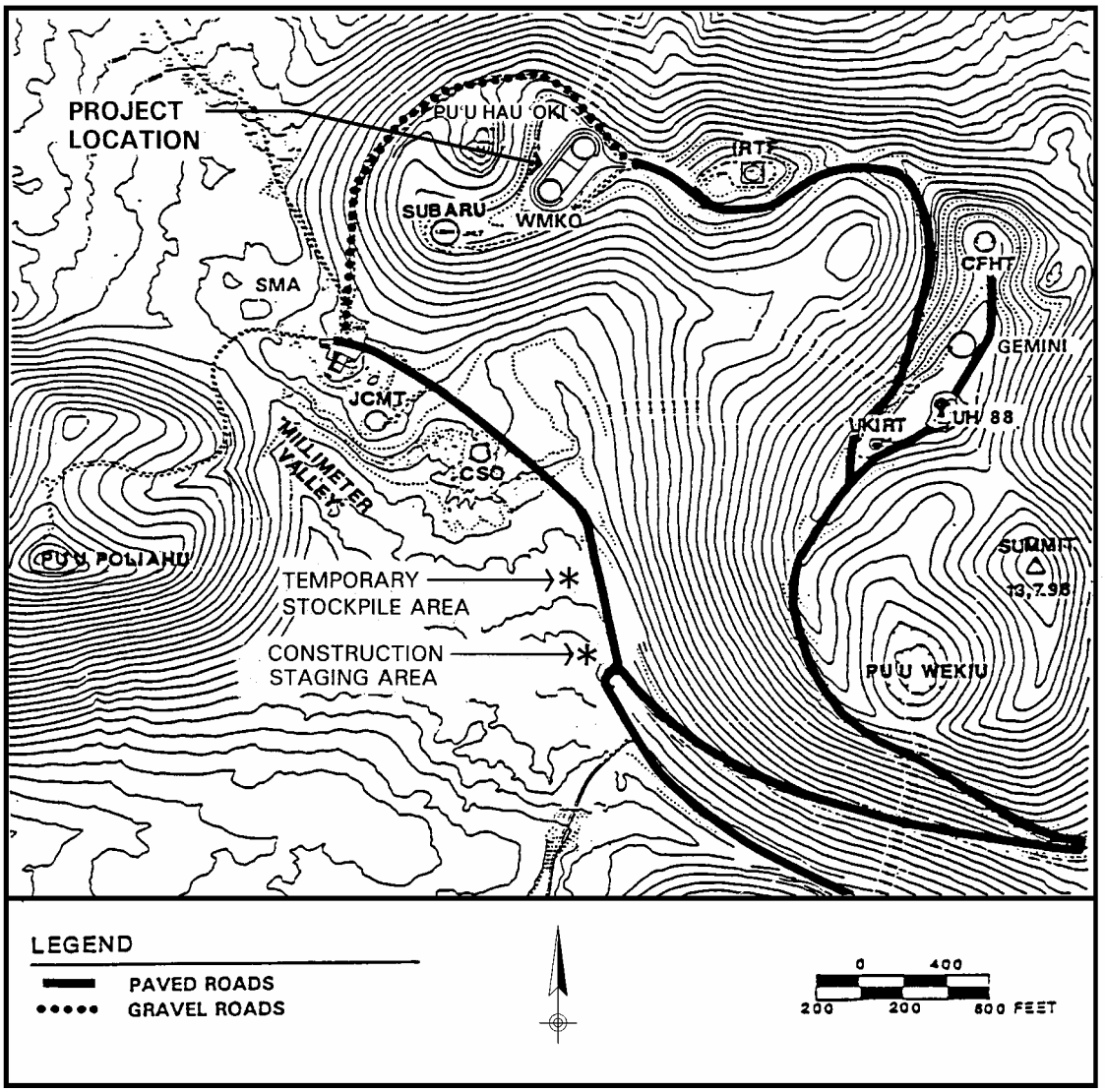


FIGURE 2-9. LOCATION OF THE TEMPORARY STOCKPILE AND CONSTRUCTION STAGING AREA

temporary use of the construction camp at Hale Pōhaku, located at an elevation of 2,804 m (9,200 ft) along the Mauna Kea Access Road on the southern slopes on Mauna Kea (see Figure 2-8). Use of these facilities would allow the most efficient and least disruptive on-site construction and installation of the Outrigger Telescopes.

Construction Staging Area. The Outrigger Telescopes Project would temporarily use the construction staging area and temporary stockpile area located at the 4,039-m (13,250-ft) elevation of the summit, previously used for activities in connection with the Subaru and Keck II Telescopes (see Figure 2-9).

2.1.2 Proposed Facilities

The proposed facilities include the Outrigger Telescopes, dome enclosures, and associated underground pipes and structures. The following sections address the engineering design of these facilities.

No substantial changes to the project are expected. Some specifications are under design review and could change slightly in the final design.

As required by the Conservation District Use Permit (CDUP), final grading and construction plans will be submitted to DLNR for approval before the County of Hawai‘i permits are obtained. In the unlikely event that any design change results in any substantial differences in the environmental impacts as described in Chapter 4 of this EIS, NASA will determine whether additional environmental documentation would be required.

2.1.2.1 Outrigger Telescopes and Dome Enclosures

As proposed, each Outrigger Telescope would consist of a 1.8-m (6-ft) diameter, f/1.5 primary mirror, secondary mirror, tertiary mirror, and associated optical equipment. A dome would enclose each Outrigger Telescope to protect it from the harsh conditions on the summit of Mauna Kea. Each dome enclosure would be a maximum of 10.7-m (35-ft) high, 9.1 m (30 ft) in diameter at its widest point and 8 m (26 ft) at its base. These dome enclosures would be made up of two sections: an 8-m (26-ft) diameter ring wall base colored “heritage red” to blend into the surrounding landscape, and a white 9.1-m (30-ft) diameter spherical dome that would rotate along the top of the ring wall on 16 wheels. Each proposed telescope and dome would be mounted on separate concrete piers for the purpose of vibration isolation. The domes would be large enough to accommodate both a telescope and its associated optical equipment and would have a slit width adequate for unobstructed viewing with a 1.8-m (6-ft) diameter primary mirror.

2.1.2.2 Underground Structures and Pipes

Underground Telescope Instrument Rooms and Junction Boxes. Each proposed telescope would be supported by an underground telescope instrument room that would act as a telescope pier and would house the mirror that injects the starlight beams into the underground light pipes. Five new junction boxes (JB-3, JB-4, JB-5, JB-6, and JB-7) would be constructed (see Figure 2-7 and Table 2-1). JB-1 and JB-2 were previously constructed in conjunction with the Temporary Optical Test Sites project. The proposed project would retain them and use them to route the beams from Outrigger Telescope 4 into the existing South Tunnel.

Each newly and previously constructed junction box would house the mirrors that redirect the starlight beams through underground pipes to the basement of the Keck II Telescope building where the interferometer instrumentation would be located (see Table 2-1). Access to JB-3 and JB-6 would be through the South and North tunnels, respectively. An above-grade “roof hatch” would provide access to the inside of JB-2, JB-4, JB-5, and JB-7. The roof hatches would be marked with snow poles to provide a route for snowplows. Figure 2-10 illustrates a proposed Outrigger Telescope and dome enclosure.

Underground Pipes. Light pipes located on the north side of the facility would serve as conduits for the light beams from Outrigger Telescopes 1, 2, 5, and 6 to JB-6. From there a 1.5 by 2.4-m (5 by 8-ft) North tunnel would bring starlight beams into the basement instrumentation room. These pipes would be buried in trenches.

Two existing 1.2-m (4-ft) air pipes may have to be reinstalled 0.6-m (2-ft) deeper if they interfere with the light pipes. The 88.7-m

TABLE 2-1. OUTRIGGER TELESCOPES JUNCTION BOXES

Junction Box	Estimated Exterior Junction Box Dimensions[a] Length x Width x Depth	Associated Outrigger Telescope
2 [b]	3 m x 3 m x 3.7 m (10 ft x 10 ft x 12 ft)	4
3	2.4 m x 3.7 m x 2.7 m (7.9 ft x 12 ft x 9 ft)	3
4	2.2 m x 2.2 m x 2.4 m (7.3 ft x 7.3 ft x 7.9 ft)	1
5	2.2 m x 2.2 m x 2.4 m (7.3 ft x 7.3 ft x 7.9 ft)	2
6	6.1 m x 4.9 m x 2.8 m (20 ft x 16 ft x 9.3 ft)	1, 2, 5, 6
7	2.2 m x 2.2 m x 2.4 m (7.3 ft x 7.3 ft x 7.9 ft)	5

Source: CARA 2000f

Note: The Outrigger Telescopes would not use the existing JB-1.

a. Maximum dimensions.

b. Previously constructed junction box.

(291-ft) long light pipe between JB-5 and JB-6 would be routed under the service road. It would either be installed in a culvert, in a trench covered by cinder, or by some other method that would ensure that the pipe would not be damaged by vehicular traffic.

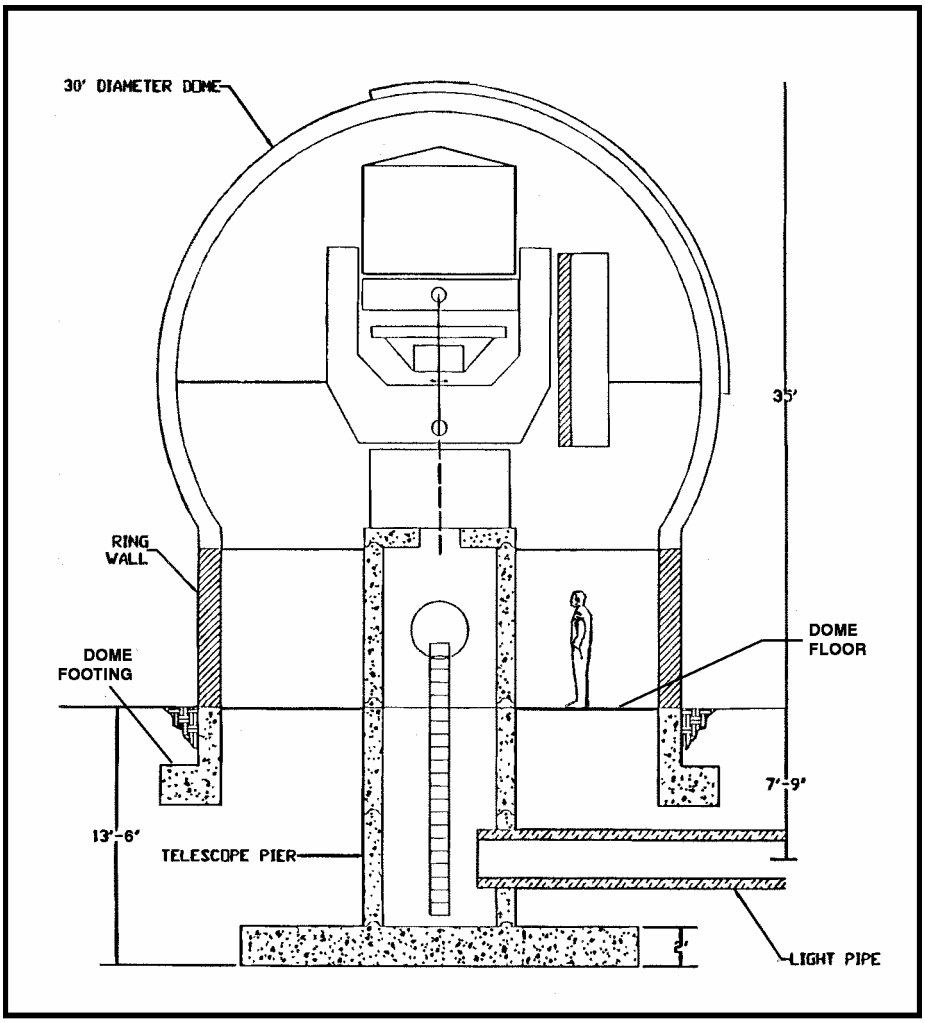
The existing 2.4-m (8-ft) wide by 2.1-m (7-ft) high by 20-m (67-ft) long (interior dimensions) underground tunnel on the south side of the facility and a proposed new junction box (JB-3) would provide a path for the starlight beams from Outrigger Telescopes 3 and 4 and personnel access to JB-3.

The light path from Outrigger Telescope 4 would travel via an existing 0.9-m (3-ft) light pipe from JB-2 to the South tunnel; the light path for Outrigger Telescope 3 would travel via JB-3, which would be attached to the end of the tunnel. With the exception of Outrigger Telescope 2, the air pipes would be routed underground to the edge of the slope as follows: north, about 18.3 m (60 ft), for Outrigger Telescope 1; north, about 15.2 m (50 ft), for Outrigger Telescope 5; northeast, about 15.2 m (50 ft), for Outrigger Telescope 6, south; about 7.6 m (25 ft) for Outrigger Telescope 3; and north, about 7.6 m (25 ft), for Outrigger Telescope 4. The air pipe for Outrigger Telescope 2 would run above ground about 4.6 m (15 ft); its end would be mounted on the top of JB-5. A square pad (1.2 to 1.8 m (4 to 6 ft)) of either precast concrete or hardened-in-place cinder would be installed at the end of each pipe to stabilize the pipes and prevent potential damage from surface water runoff.

2.1.3 On-Site Construction and Installation of the Outrigger Telescopes

2.1.3.1 Schedule

On-site construction work for the Outrigger Telescopes Project would start as soon as



Source: W.M. Keck Observatory

FIGURE 2-10. ILLUSTRATION OF A PROPOSED OUTRIGGER TELESCOPE AND DOME ENCLOSURE

practicable after all permits and approvals have been obtained. It is expected that the site work for all six telescopes and the installation and commissioning of the first four telescopes and their dome enclosures would be completed approximately 24 months after project start. The remaining two telescopes and their enclosures are not funded at this time. If their funding becomes available, it would require an additional six months to install and commission them after the Outrigger Telescopes 1 through 4 have been constructed.

It is anticipated that the first four Outrigger Telescopes would be installed in their domes by 2007 if construction and installation begins in 2005. If funding for Outrigger Telescopes 5 and 6 is obtained, on-site construction and installation would likely begin no earlier than 2007. If the two phases of construction do not occur within three months of each other, all facilities, containers, and equipment used during the first phase would be removed from the site

and the construction staging areas until start of the installation of Outrigger Telescopes 5 and 6.

Because the project is so complex and the conditions surrounding high-altitude construction unique, UH requested that the period for the start of construction after granting of the CDUP be at least two years and that the total time allowed for completion be at least 7 years after granting the CDUP for completion.

Until funding of Outrigger Telescopes 5 and 6 is secured, concrete work for those two telescopes would be limited to structures that are no higher than 18 cm (7 in) above level ground. For reasons of safety, the unfinished underground telescope instrument rooms would be covered with steel plates and the area secured. Each telescope foundation area, including the 18-cm (7-in) high ring wall footing and covered telescope instrument room, would then be covered with cinder from project excavations.

2.1.3.2 Estimated Excavation

Before undertaking underground work in the vicinity of power and communications cables, the construction contractor would install sheet piling, as required by the Hawaii Electric Light Company, to protect the cables from inadvertent disturbance by construction equipment. The sheet piles would be removed and transported off the mountain when this phase of the on-site construction is finished.

As currently proposed, about 918 cubic meters (m^3) (1,200 cubic yards (yd^3)) of cinder would be excavated to install about 274 m (900 ft) of light pipe and air pipe trenches. About 1,835 m^3 (2,400 yd^3) of cinder would be excavated for telescope footings and underground telescope instrument rooms. Approximately 50 percent of the excavated material would be replaced on top of the tunnels and pipes and used for backfill around the telescopes. Excavated material not required for fill would be graded and washed**,** and suitable sized cinder would be used for restoration of the Wēkiu bug habitat. Any excavated cinder not used for backfill or restoration would be placed on the mountain at locations determined after consultation with the State Historic Preservation Division (SHPD) and OMKM.

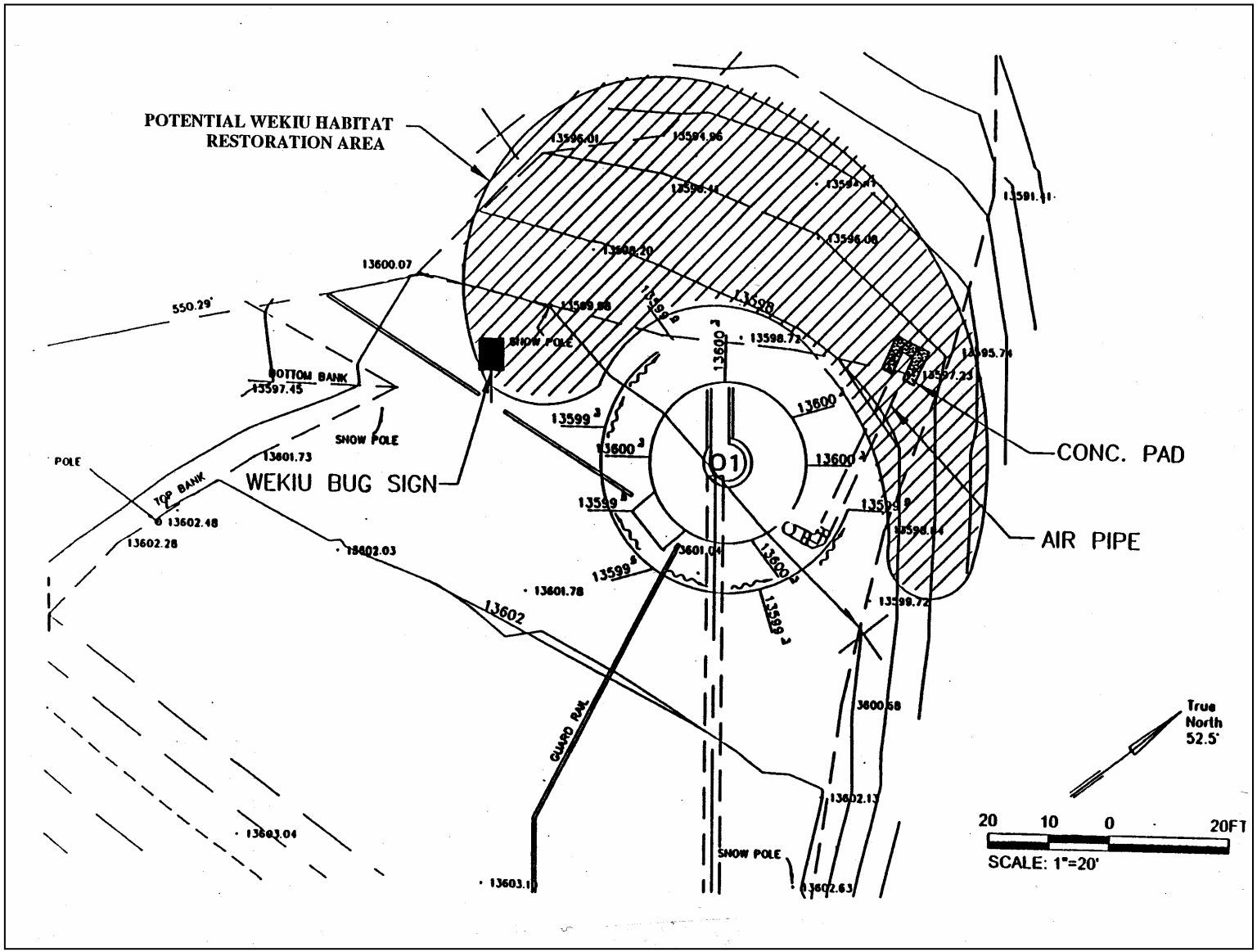
2.1.3.3 Grading Plans for Outrigger Telescope Domes and Junction Boxes

Outrigger Telescope 1. The finished grade elevation outside of the structure would be about 1.1-m (3.5-ft) lower than the existing level grade directly outside the Keck domes. A small swale would divert surface water runoff away from the dome. The finished grade would require about 1.5 m^3 (2 yd^3) of fill.

This grading would not require either a retaining wall or a truck access pad driveway because the slope would be no steeper than about 12 percent. Figure 2-11 provides the proposed site plan for Outrigger Telescope 1. Because of engineering design changes, no additional Wēkiu bug habitat would be disturbed by on-site construction of Outrigger Telescope 1.

As part of on-site construction, Wēkiu bug habitat restoration is being proposed in the graded and sloped area near Outrigger Telescope 1, in an area previously disturbed for the W.M. Keck Observatory site in 1982. Restoration of this area will be given equal priority equal with restoration of the area around JB-5.

A guardrail would be installed to protect Outrigger Telescope 1 and the light pipe. The guardrail would protect the Wēkiu bug habitat in the sloped area from inadvertent s



Source: UH IfA 2001a

FIGURE 2-11. PROPOSED SITE PLAN—OUTRIGGER TELESCOPE 1

damage caused by trucks entering, leaving, and backing up within the dome area. As shown in Figure 2-11, habitat restoration would include filling a semi-circular area (0.032 ha) (0.08 ac) around Outrigger Telescope 1.

Chapter 4 and the Wēkiu Bug Mitigation Plan (see Appendix D of this EIS) provide further details.

Outrigger Telescope 2 and JB-5. The proposed siting area for Outrigger Telescope 2 is on the existing graded pad of the main complex, eliminating the need for extra fill near the slope. The junction box directly northwest of Outrigger Telescope 2 (JB-5), however, would be located close to the edge of the slope and would require structural support. Figure 2-12 shows the proposed site plan for Outrigger Telescope 2 and JB-5.

On-site construction and installation of an air pipe and retaining wall needed for slope stability at JB-5 near Outrigger Telescope 2 would result in the disturbance (0.002 ha (0.005 ac)) of the sloped cinder cone wall that contains Wēkiu bug habitat. The retaining wall would be of solid concrete block construction and would match the color of the existing cinder.

Because JB-5 has been relocated to less than 0.9 m (3 ft) from Outrigger Telescope 2, any disturbance to the crater wall would be minimal.

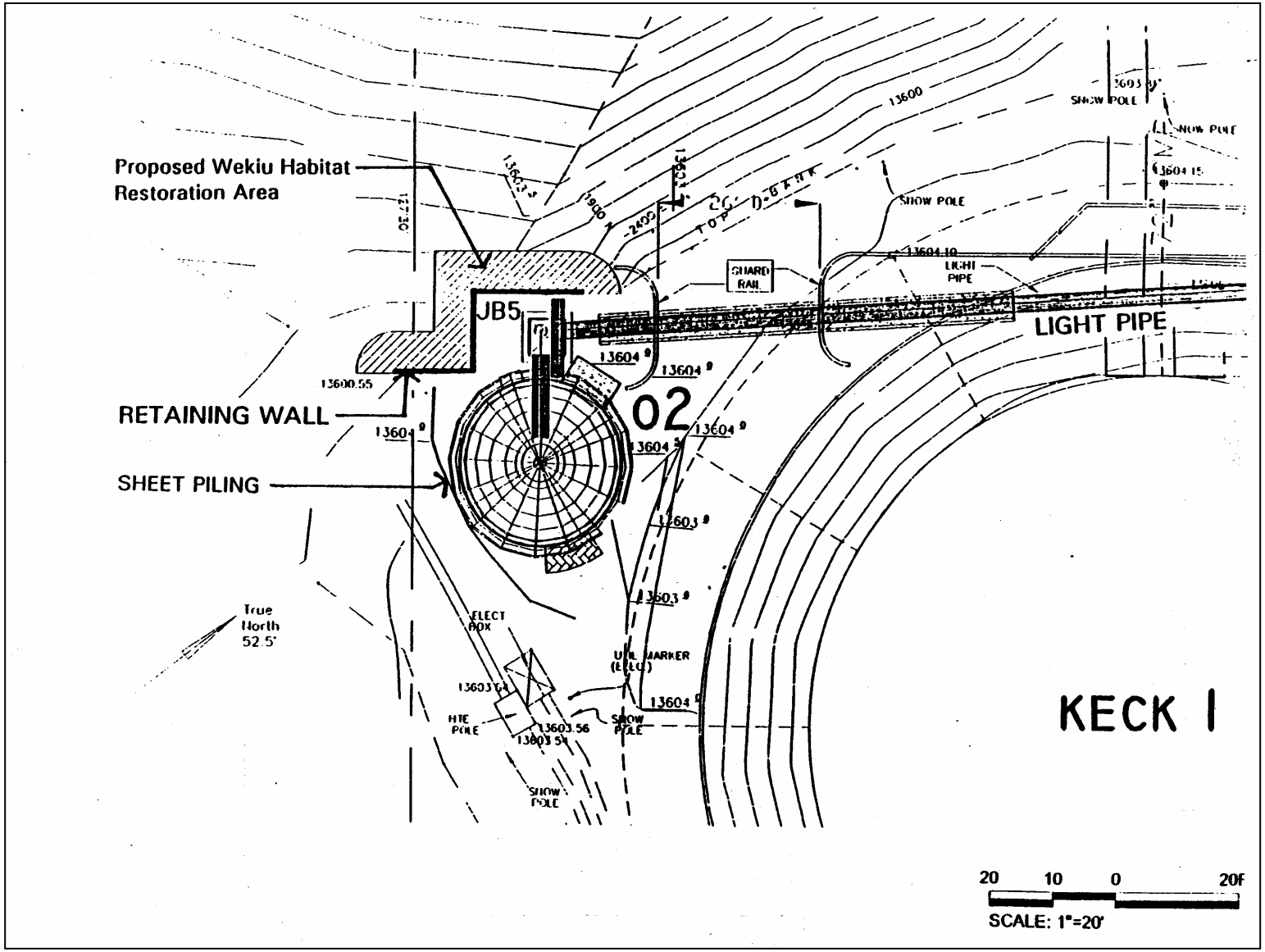
Outrigger Telescope 3. The proposed location for Outrigger Telescope 3 is on the existing graded area near the entrance to the W. M. Keck Observatory site. This area is slightly elevated so that surface water would flow away from the dome. A cinder-colored concrete masonry block retaining wall would be placed about 1.8 m (6 ft) south of Outrigger Telescope 3 to provide slope stability. The retaining wall would be a maximum of about 2.4-m (8-ft) high by about 11-m (36-ft) long. On-site construction and installation of Outrigger Telescope 3 would disturb 0.006 ha (0.014 ac) of Wēkiu bug habitat. However, no Wēkiu bug habitat restoration can occur here because the slope is severe and the cinder necessary to restore the area would spill over onto undisturbed habitat occupied by Wēkiu bugs.

Figure 2-13 shows the proposed site plan for Outrigger Telescope 3.

Outrigger Telescope 4. This Outrigger Telescope is proposed to be located on the previously graded area near the entrance to the W.M. Keck Observatory site. The finished grade outside the structure would be slightly elevated so that surface water would flow away from the dome. About 42 m^3 (55 yd^3) of fill would be added to provide stability to the adjacent slope. The resulting new top of slope would be about 1.8 m (6 ft) from the edge of the Outrigger Telescope dome. On-site construction and installation of Outrigger Telescope 4 would not disturb any Wēkiu bug habitat.

A retaining wall would be built as a barrier to keep the fill from spilling onto the nearby access road. The retaining wall would be constructed of cinder-colored masonry blocks. The wall would be about 13.7-m (45-ft) long and 1.2-m (4-ft) high. A 56-m (185-ft) long retaining wall is already in place to retain the slope underneath the Keck II Telescope. Figure 2-14 shows the proposed site plan for Outrigger Telescope 4.

Outrigger Telescopes 5 and 6. If funded, on-site construction and installation for Outrigger Telescopes 5 and 6 would occur well within the area that was previously graded and leveled for construction of the Keck I and Keck II Telescopes and would require no special engineering design applications (see Figures 2-15 and 2-16).



Source: UH IfA 2001a

FIGURE 2-12. PROPOSED SITE PLAN—OUTRIGGER TELESCOPE 2

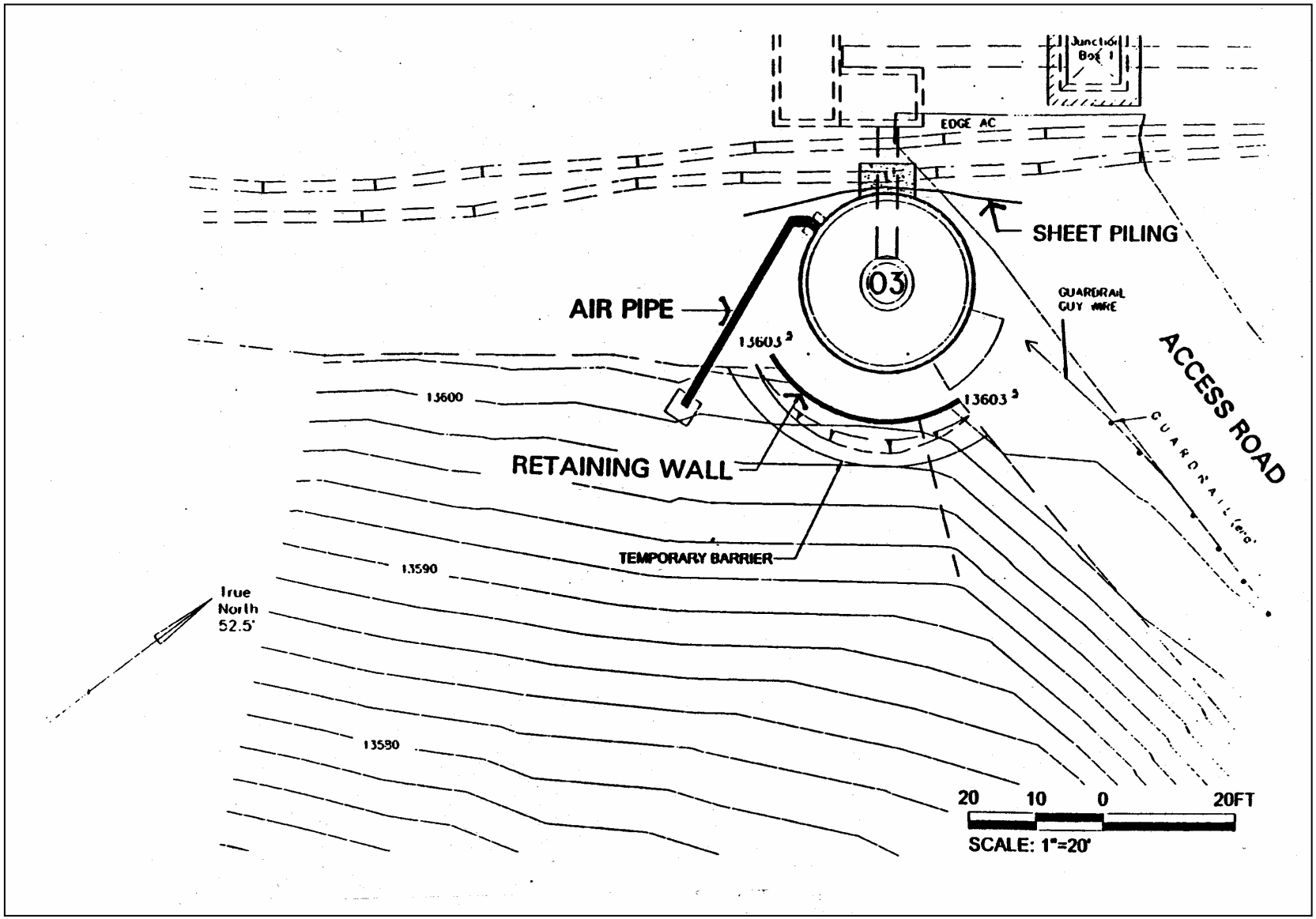


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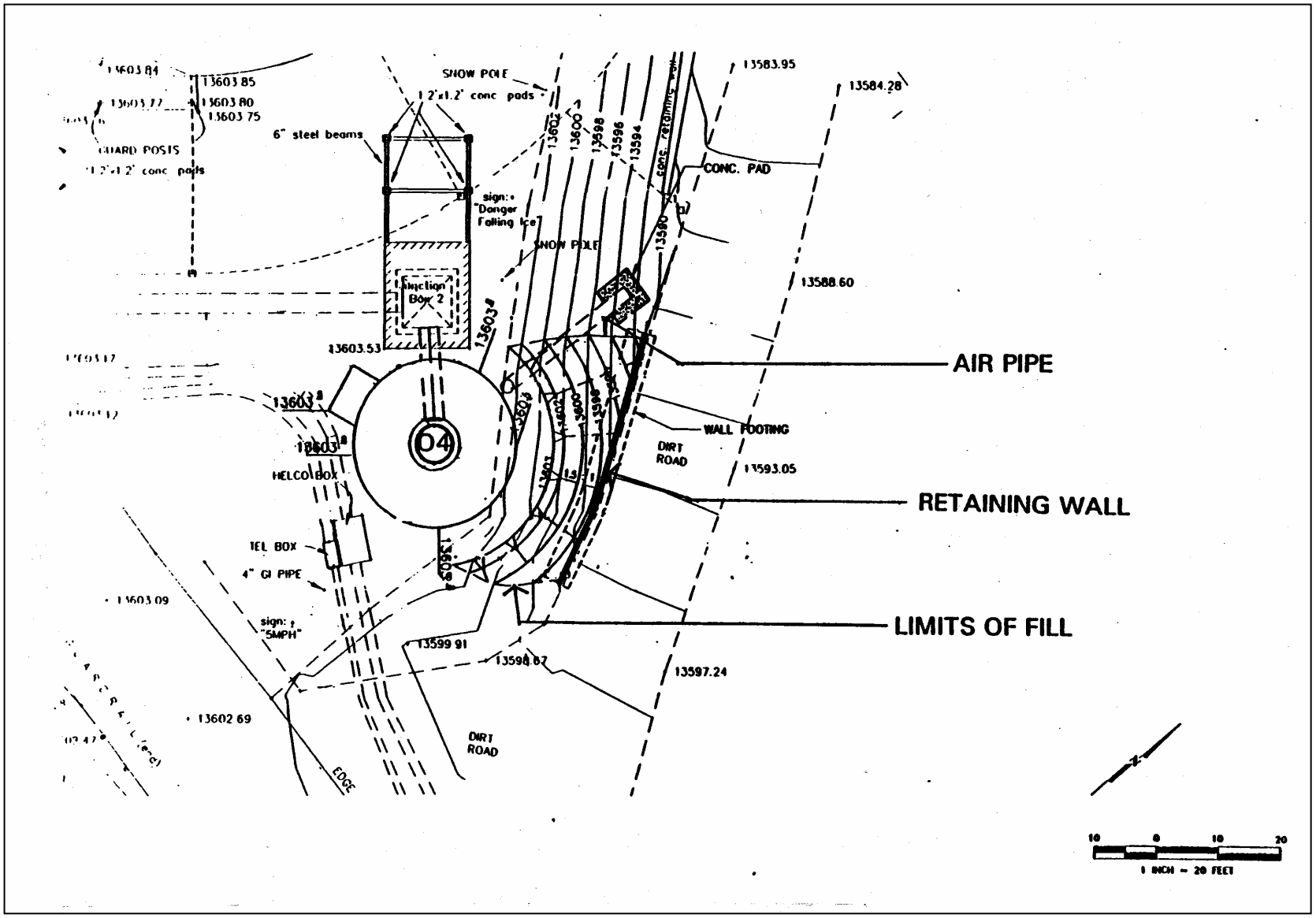
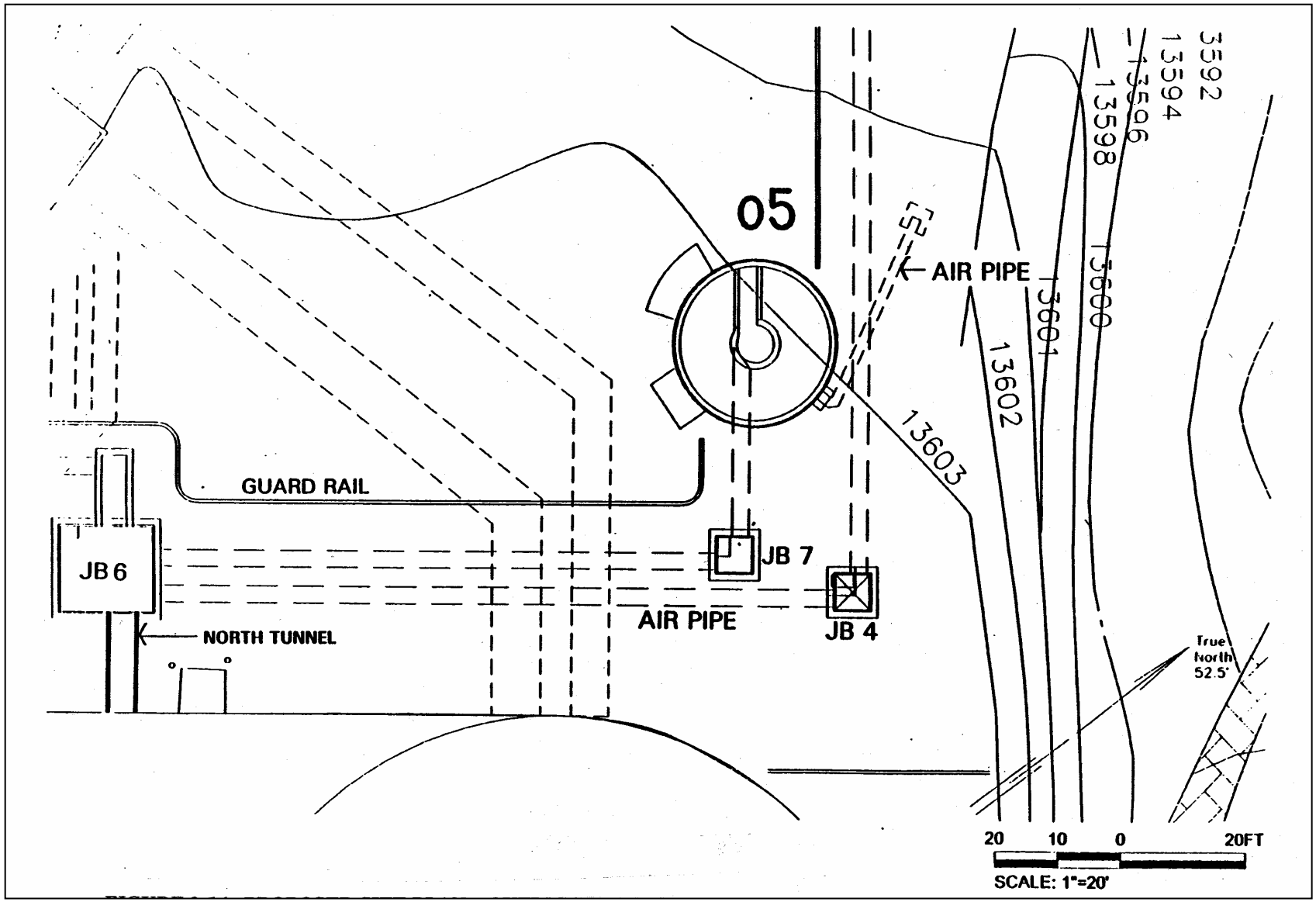
FIGURE 2-13. PROPOSED SITE PLAN—OUTRIGGER TELESCOPE 3



Source: UH IfA 2001a

FIGURE 2-14. PROPOSED SITE PLAN—OUTRIGGER TELESCOPE 4



Source: UH IfA 2001a

FIGURE 2-15. PROPOSED SITE PLAN—OUTRIGGER TELESCOPE 5

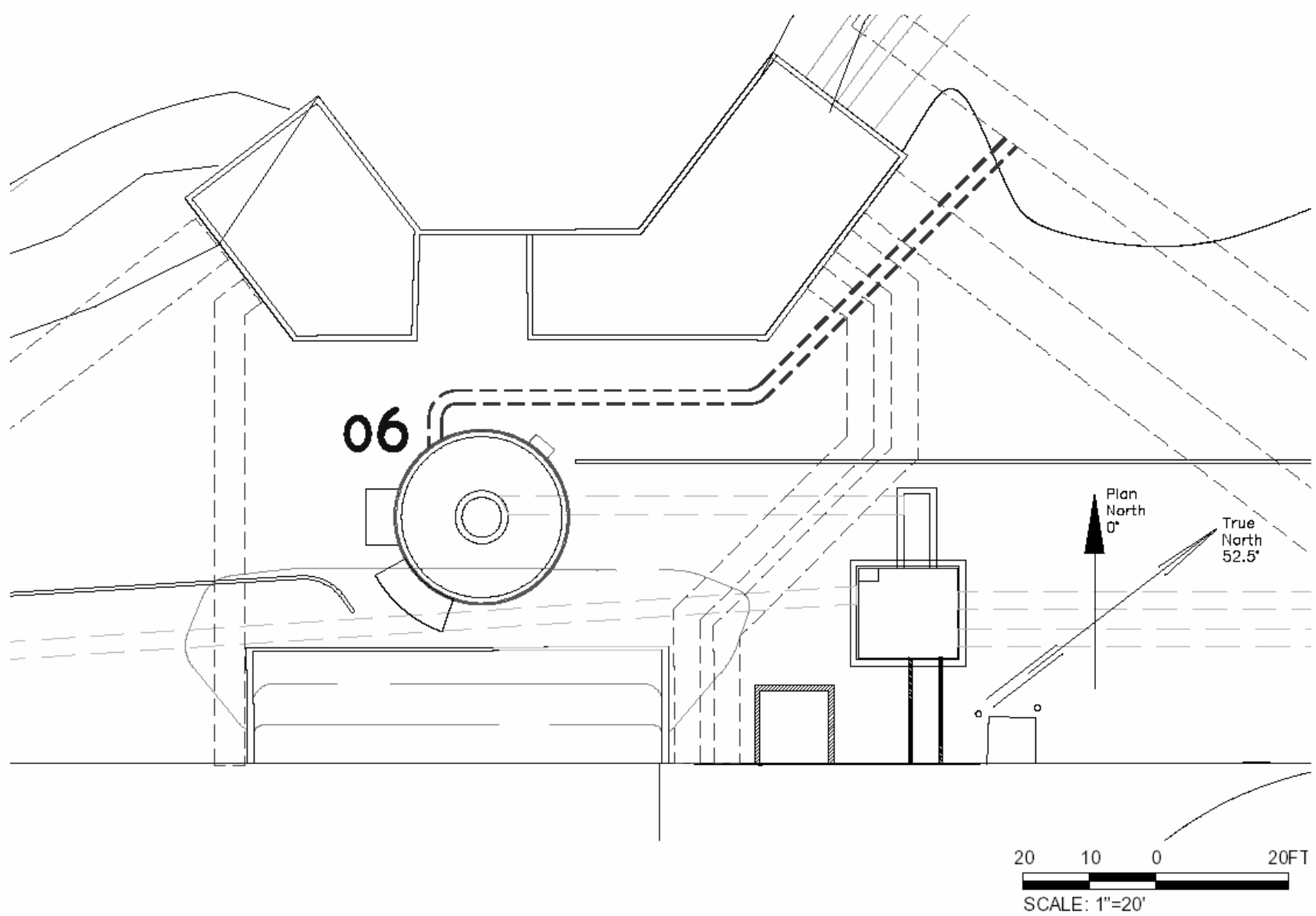


FIGURE 2-16. PROPOSED SITE PLAN—OUTRIGGER TELESCOPE 6

The finished grade around each Outrigger Telescope would be slightly elevated so that surface water would flow away from the enclosures. On-site construction and installation of Outrigger Telescopes 5 and 6 would cause no Wēkiu bug habitat disturbance.

2.1.3.4 History of Engineering Design Changes to Minimize Disturbance of Wēkiu Bug Habitat

There have been several design changes to minimize the disturbance of Wēkiu bug habitat. Originally, the total habitat disturbance area, including setback areas and fills, was estimated at approximately 0.067 ha (0.17 ac).

The first significant engineering design change occurred in 1999. Three engineering designs were considered: (1) moving JB-4 associated with Outrigger Telescope 1 from the crater side of the telescope to just under the telescope, (2) using a retaining wall for JB-5 instead of the slope extension and fill, and (3) continuing with Outrigger Telescope 3's original slope extension and vent pipe plans. The estimated total disturbed Wēkiu bug habitat area was reduced to approximately 0.03 ha (0.08 ac).

In December 1999, CARA outlined three engineering designs to move JB-5 4.6-m (15-ft) closer to Outrigger Telescope 2: (1) building a vertical retaining wall, (2) building a geo-habitat wall, or (3) maintaining the original slope and fill plans at the new location.

CARA proposed an additional design change in August 2000. This involved building a retaining wall at Outrigger Telescope 3 instead of slope extension and fill, further reducing the total disturbed habitat area to approximately 0.02 ha (0.06 ac).

In October 2000, as a result of continuing engineering and design discussions, a proposal was accepted to move Outrigger Telescope 1 4-m (13-ft) closer to the W. M. Keck Observatory building, to bend the vent pipe for Outrigger Telescope 3, and to make the JB-5 retaining wall part of the junction box structure. This reduced the disturbed Wēkiu bug habitat to approximately 0.01 ha (0.03 ac).

Between 2001 and 2003, recommendations were made and approved to move JB-5 closer to Outrigger Telescope 2 and turn the configuration. This adjustment saved an additional 0.001 ha (0.003 ac) of Wēkiu bug habitat, reducing the estimated disturbed area to approximately 0.009 ha (0.024 ac).

In 2004, after reviewing the locations of the air pipes, it was determined that there was a problem with the location of the air pipe for Outrigger Telescope 6. Upon discussion with the entomologist, it was determined that it could bend the air pipe in a direction that would not disturb Wēkiu bug habitat. This saved an additional 0.002 ha (0.005 ac) of disturbance to Wēkiu bug habitat.

All of the combined engineering design changes reduced the total disturbed Wēkiu bug habitat by 0.06 ha (0.15 ac).

2.1.3.5 Foundations and Footings

Based on current engineering design concepts, the total amount of concrete needed for the tunnel, junction boxes, dome, and telescope foundations is estimated to be about 512 m^3 (670 yd^3). Concrete would be mixed in Hilo or Waimea and trucked to the site. When possible, CARA plans to use precast concrete for the junction boxes and telescope foundations.

2.1.3.6 Signs

Up to six permanent signs would be located on the W. M. Keck Observatory site,

primarily along the Pu‘u Hau‘oki crater rim, to inform visitors of the historic and cultural significance of the crater and the need to protect the Wēkiu bug. One sign would be placed near the access point to Pu‘u Hau‘oki crater to protect the Wēkiu bug habitat restoration area.

Design of the signs would be consistent with the guidelines presented in the recently adopted MKSR Master Plan: they would be small, unobtrusive; printed in black, blue, or dark earthtones; and would be no higher than 2.4 m (8 ft) above the finished grade. The signs would conform to criteria specified in HAR 13-5-22: no larger than 1.1 m^2 (12 ft^2) in area. They would not be lighted and would be self-supporting. Before installation, the sign designs and specifications would be submitted to both the DLNR and to the OMKM for approval.

2.1.3.7 Installation of Telescopes and Dome Enclosures

Prior to entry into the MKSR, all construction materials, equipment, crates, and containers carrying materials and equipment, would be inspected by a trained biologist, who would certify that all materials, equipment, and containers are free of any and all flora and fauna that could potentially have an impact on the Mauna Kea summit ecosystem.

The enclosure sections (ring wall base and spherical dome) would be prefabricated off site and shipped to either Hilo or Kawaihae harbor in standard marine 12-m (40-ft) by 2-m (8-ft) containers. From there, the containers would be transported to an approved construction staging area at either Hale Pōhaku or the summit, off-loaded, and unpacked. The enclosure components would then be delivered to the project site on flatbed trucks. Each enclosure section (ring wall and dome) would be assembled on site, the ring walls set on concrete foundations, and the rotating domes placed on top.

The components of each Outrigger Telescope would be packed in up to 10 plywood boxes and shipped to Hawai‘i (Kawaihae or Hilo) on standard marine 12-m (40-ft) by 2-m (8-ft) open flat racks. These racks would be delivered to either the Hale Pōhaku or summit staging area, off-loaded, and unpacked. Flatbed trucks would then bring the telescope components to the W. M. Keck Observatory site.

After the erection of each enclosure, its telescope would be assembled on a previously constructed concrete pier. A crane would lift large components and place them in the enclosure through the enclosure shutter. When complete, the final component—the dual star module—would be hoisted through the dome shutter and installed on the telescope.

2.1.3.8 On-Site Construction Facilities/Equipment

A trailer used as a temporary office for construction management could be on site throughout the construction period. It is estimated that at various times during on-site construction—not necessarily at the same time—the following equipment could also be present on site: two excavators, a grader or bulldozer, two water trucks, two back-hoes, a loader, two or three dump trucks, a forklift, three or four cement trucks, two or three flatbed trucks, a crane of approximately 64-mt (70-ton) capacity, a compactor, and a vibrating hammer rig.

During on-site construction, a total of 20 2 by 12-m (8 by 40-ft) containers, painted brown or green, could be present at the summit at one time. Materials and equipment stored in these containers to the W.M. Keck Observatory site. In addition, two or three flatbed trucks with cranes and

two or three forklifts would be located at the staging area to support these activities.

If possible, all twenty containers would be unloaded at the approved summit staging area. If it were not feasible to store twenty containers at the summit, it would be necessary to unload some of them at the approved materials staging area at Hale Pōhaku (see Figure 2-8). If unloading does take place at Hale Pōhaku, up to ten containers, a forklift, and one or two flatbed trucks would support these activities on site. CDUP HA-1819 approved this staging area.

As stated in Section 2.1.3.7, prior to entry into the MKSR, all construction materials, equipment, crates, and containers carrying materials and equipment would be inspected by a trained biologist, who would certify that all materials, equipment, and containers are free of any and all flora and fauna that could potentially have an impact on the Mauna Kea summit ecosystem.

2.1.3.9 On-Site Construction Employment and Costs

The time to complete the on-site construction is estimated to be about 24 months, including site work for six telescopes, and installation and commissioning for four domes and telescopes. It is estimated that the site work would take 9 months and the installation and commissioning would take 10 months. The installation and commissioning crew 5 workers, would start approximately 3 months before the site work crew, estimated to be 15 workers, completes its work:

The management team—the construction manager, administrative assistant, Wēkiu bug monitor, Cultural Monitor and an Archaeologist—are not included in the above numbers. It is assumed that the construction manager and administrative assistant will be on site full time and that the monitors will not be on site full time.

Construction times could vary due to unfavorable weather conditions. As described above, the site work crew and the enclosure/telescope erection crews would be on site at the same time for about 3 months of the construction period.

Construction workers would either commute from off-mountain locations or use existing facilities at the Hale Pōhaku Construction Camp. Workers involved in dome assembly and telescope installation would probably stay at Hale Pōhaku.

On-site construction and installation of four Outrigger Telescopes are estimated to cost approximately $10 million. The on-site construction and installation of the remaining two Outrigger Telescopes is estimated to cost about $2.5 to $3 million.

2.1.3.10 Cultural Resources Management

Under the National Historic Preservation Act (NHPA) Section 106, NASA, in partnership with its Signatories and Consulting Parties, signed a Memorandum of Agreement (MOA) establishing on-site and off-site mitigation measures for the Outrigger Telescopes Project. Unless terminated, the MOA will be in effect until NASA, in consultation with the other Signatories and Consulting Parties, determines all of its terms have satisfactorily been fulfilled, or June 30, 2009, whichever is earlier. After completion of the on-site construction and installation of Outrigger Telescopes 1 to 4, the MOA will be held in abeyance for on-site activities, pending determination by NASA as to whether Outrigger Telescopes 5 and 6 will be installed at the W.M. Keck Observatory site. If NASA obtains funding for Outrigger Telescopes 5 and 6 the MOA will remain in full force and effect for activities during the period of on-site construction and installation. The MOA shall not apply to

Outrigger Telescopes 5 and 6, if installation of those telescopes were to begin later than December 31, 2007. Should NASA decide to begin on-site installation of Outrigger Telescopes 5 and 6 after December 31, 2007, their installation will be considered a new Undertaking, and NASA will reinitiate the Section 106 process with the Hawai‘i SHPO and the Council.

If NASA is unable to or decides not to install the Outrigger Telescopes on Mauna Kea, the MOA will automatically become null and void.

2.1.3.11 Construction Management

- The contractor would be required to follow an approved construction Best Management Practices Plan (BMP) during all on-site construction and installation activities. BMP provisions would avoid, reduce, or mitigate impacts to cultural resources and the Wēkiu bug habitat. Appendix F includes a draft BMP, which addresses designated lines of authority and responsibility.
- Education and training for construction workers to make them aware of the sensitive environment, historic and cultural significance of the site, and importance of strict adherence to the BMP and all State and Federal regulations regarding burial sites and/or cultural artifacts.
- Precautions and actions before construction begins, including review of grading and site development drawings by the Consulting Parties to help ensure that implementation would be conducted in a manner that minimizes or reduces impacts to cultural and natural resources on the project site.
- Inspections and mitigation to control alien arthropods in accordance with an approved Wēkiu Bug Mitigation Plan (see Appendix D).
- Actions to prevent or minimize disturbance of Wēkiu bug habitat by construction activities including, but not limited to, control of all trash, construction material, and cinder stored at the site.
- A plan, in consultation with SHPD and OMKM, to ensure appropriate disposition of all excavated material not used for backfill or Wēkiu bug habitat restoration.
- Stipulations incorporated in the NHPA Section 106 MOA and relevant conditions attached to the CDUP.

The final BMP would be incorporated into the construction contract.

2.1.3.12 Construction Traffic

Depending on the construction phase, daily construction worker traffic would add about 15 to 17 trips during the morning and afternoon peak periods. The increase in traffic in the summit area during construction would be minimal, except for the assembly enclosure phase, because most heavy construction equipment would be stored on site. Construction activities would generate other traffic originating off the mountain, including service vehicles, water tankers, and fuel trucks.

In addition, at any time as many as six container loads of dome enclosures and/or telescope components would travel from the harbor at either Kawaihae or Hilo to the summit area, and crews would off-load them at the staging area and deliver them to the W.M. Keck Observatory for assembly on the project site. Current plans would be to use standard-size trucks. However, if heavy

trucks were to be used, their trips would be scheduled during off-peak hours to avoid interference with normal traffic flow in Kawaihae, Waimea, or along the Saddle Road. CARA would coordinate with other road users to avoid traffic problems when nonstandard-size loads would be transported from the staging areas to the W.M. Keck Observatory site.

Traffic has two alternative ways to reach the W.M. Keck Observatory site within the summit area: (1) along a continuation of the paved Mauna Kea Access Road, which runs along the summit ridge from the UKIRT to the NASA IRTF and then to the W.M. Keck Observatory site or (2) along the paved road through Submillimeter Valley to its junction with the gravel "detour" road and then to the site. Two roads would serve to minimize conflicts between construction and observatory traffic. Construction traffic would avoid the "detour" road to minimize dust generation.

2.1.4 Operations for the Outrigger Telescopes Project

2.1.4.1 Employment

An estimated eight full-time personnel would be added to the W.M. Keck Observatory staff: four to test the Interferometric Array begins and four more when operations begin. It is expected that almost all of the observing would be done from would take place at the CARA base facilities in Waimea, requiring the addition of one or two people on the mountain at night. The number of people on the mountain during the day would increase by up to three people (UH IfA 2001a).

2.1.4.2 Traffic

It is estimated that new employees would generate two to three two-way vehicle trips per day and about one two-way vehicle trip per night along the Mauna Kea Access Road. The number of vehicle trips by service vehicles, such as water and fuel trucks, would not be expected to increase (UH IfA 2001a).

2.1.4.3 Infrastructure and Utilities

WMKO would provide all utilities—water, power, communications and sewage. The existing water storage tanks (15 and 30 kiloliters (kl) (4,000 and 8,000 gallons (gal)) would accommodate the project's needs. An existing Department of Health (DOH)-approved septic tank and seepage pit would handle wastewater disposal.

The existing 12.47-kV Hawaii Electric Company (HELCO) underground system supplies commercial electric power to W.M. Keck Observatory. Power requirements are estimated to be a maximum of 30 kilowatts (kW) per Outrigger (dome and telescope). Peak electrical demand at the W.M. Keck Observatory site is currently 525 kW; the operation of the six Outrigger Telescopes would increase demand by about 34 percent, to 705 kW. If the Keck Telescopes and all six Outrigger Telescopes were operational, peak demand would be about 70 percent of service capacity (CARA 2004i).

A local vender currently provides voice and fiber-optic data transmission. The existing communication system has adequate capacity to accommodate the addition of the four, and possibly up to six, Outrigger Telescopes.

2.1.4.4 Maintenance

During operations, the Outrigger Telescopes and domes would rotate on wheels that have ball bearings. These bearings would be encapsulated in a sealed track to prevent dust and other contamination from degrading bearing performance and life. The bearings would require periodic lubrication, which would be accomplished

by injecting lubricant directly into the sealed bearing track.

From time to time during operations, Outrigger Telescope mirrors and equipment would require maintenance. Each Outrigger Telescope mirror would require periodic cleaning. Common cleansing solutions would be used to clean the mirror surfaces.

Periodically, the Outrigger Telescope mirrors also would require surface recoating, which uses chemicals and water to remove the aluminum surface. Mirror recoating would take place in an area set aside for this purpose within the existing W.M. Keck Observatory facility. The rinse water from the aluminum removal and recoating process would be collected, removed, and transported off the site.

2.2 DESCRIPTION OF ALTERNATIVES CONSIDERED

NASA's Origins Program, seeks to understand how galaxies, stars and planetary systems form, and whether there are planets orbiting other stars that might be capable of sustaining life. The task of studying planets around other stars is particularly challenging, because even the closest stars are very far away and the planets orbiting them are millions-to-billions of times fainter than the stars themselves. As seen from Earth, the angular separation between a star and its companion planet is exceedingly small—10 times smaller than the angle corresponding to the thickness of a human hair held at arm's length. Observing planets around nearby stars is comparable to studying fireflies buzzing around a lighthouse on a foggy night from hundreds of miles away.

To study planetary systems around other stars, NASA has developed a robust, multifaceted program of space flight missions and ground-based observation initiatives, each designed to complement the others by making a unique measurement, and each revealing a piece of the overall puzzle. The proposed Outrigger Telescopes Project is part of this program.

The Outrigger Telescopes exploit a measurement technique known as interferometry: the light from individual telescopes is combined so that the telescopes function as though they were part of a single, much larger telescope. Because the detail that can be resolved in the sky is proportional to the size of the telescope, interferometry is an extremely powerful technique.

As science enters the 21st century, interferometry involving large telescopes promises to revolutionize astronomy—both on the ground and in space. Leadership in astronomy will increasingly be equated with leadership in this new technology.

2.2.1 Criteria for Locating the Outrigger Telescopes

When evaluating alternative sites for accomplishing the full set of science objectives of the Outrigger Telescopes Project, both technical and programmatic aspects must be considered. Physics (e.g., the physical properties of light and the characteristics of the Earth's atmosphere through which the observed light must pass) and the current state of technology both impose limitations. In addition, NASA must be able to obtain the data in a timely and reliable manner, and to use the data effectively in accomplishing the objectives of the Origins Program.

The screening criteria are arranged in two tiers. The *Tier 1* criteria address whether the Outrigger Array can be built at a particular site and its capability, if built there, to accomplish the Outrigger Telescopes Project's scientific objectives. The *Tier 2* criteria address programmatic and technical

considerations associated with building the Outrigger Array at that site. For the sake of completeness, some sites that failed one or more *Tier 1* screening criteria were nonetheless evaluated against relevant *Tier 2* criteria.

2.2.1.1 Tier 1 Screening Criteria

Northern Hemisphere Location to Maximize Sky Coverage. One of the most compelling long-term goals of the Origins Program is the detection and characterization of Earth-like planets around other stars. NASA envisages space missions in support of this goal, including the Space Interferometer Mission (SIM), scheduled for launch later this decade, and the Terrestrial Planet Finder, whose launch is anticipated around 2015. If these missions are successful in locating Earth-like planets, NASA plans to follow up with missions that would seek to characterize these planets and search for signs of life.

In the near term, NASA is conducting research to determine the conditions that would give rise to habitable planets around other stars, to understand the number and characteristics of these systems, and to characterize stars to be observed with the Terrestrial Planet Finder. Possible target stars extend out to a distance of about 45 light-years (about 1/2000th the diameter of the Milky Way galaxy), and are arranged almost uniformly in space around our solar system. Because the TPF search will concentrate on stars similar to our Sun, only a small fraction of all stars within 45 light-years will be included in the search, perhaps 500 in all. Given this limited number of targets, it is important that supporting observations from the ground include all target stars in both the northern and southern hemispheres.

In the southern hemisphere, a facility in the Andes mountains of Chile called the Very Large Telescope Interferometer (VLTI) is under construction by the European Southern Observatory (ESO). Consisting of four 8.2-m telescopes and four movable 1.8-m (6-ft) auxiliary telescopes, the VLTI will provide the European astronomical community with capability similar to that NASA envisions for the Outrigger Telescopes Project. The VLTI facility is state of the art, and when completed in 2006 will be capable of performing the supporting observations NASA would need in the southern hemisphere.

The European Space Agency (ESA) is also pursuing the goal of detecting Earth-like planets around nearby stars and is formulating a space mission called Darwin, which is similar in many respects to NASA's Terrestrial Planet Finder. Given the technical challenge and associated expense of a mission to find and characterize Earth-like planets around other stars, it is probable that ESA and NASA will ultimately collaborate in this endeavor. In such a potential collaboration, ESA can be expected to provide supporting ground-based observations from ESO. To complement ESO's capability, there is a need for a facility that could view the northern sky and thereby obtain full sky coverage.

In the northern hemisphere, NASA is the only organization that currently has plans to build an interferometer with the capability of meeting these needs. NASA, therefore, considers it programmatically necessary for the Outrigger Telescopes Project to be located in the northern hemisphere.

Existing Telescope of at Least 8-m (26-ft) Aperture. To achieve all of the science objectives of the Outrigger Telescopes Project, at least four 1.8-m (6-ft) telescopes must be linked to a large aperture telescope, which supplies the light-gathering power that enables the interferometer to observe

faint objects. As the size of the large telescope decreases, the area of sky that can be studied also decreases. To determine the minimum size required for the large aperture telescope, science performance metrics were computed for Outrigger Telescopes linked with large telescopes ranging in size from 4 to 10 m (13 to 33 ft) in diameter. The metrics are: 1) relative sensitivity, and 2) relative searchable volume of space.

Relative sensitivity measures how faint an object can be and still be observed with the interferometer. Interferometers with higher sensitivity can see deeper into space (i.e., see objects that are more distant) and search a larger volume. The volume of searchable space is roughly proportional to the number of objects that can be studied.

Table 2-2 compares these metrics for several large telescopes, using the two Keck 10-m (33-ft) telescopes as a baseline. When the aperture of the large telescope falls below about 8 m (26 ft), the searchable volume of space drops by roughly a factor of two.

NASA has determined that an *8-m (26-ft) aperture* is the lower limit for the size of the large telescope needed. A smaller aperture results in an unacceptable loss of capability. In addition, the 8-m (26-ft) or larger telescope must be of a general-purpose design that can observe down to a zenith (or overhead) angle of 60 degrees in most directions.

Adequate Land Available for Outrigger Telescope Baselines. The number of telescopes in an interferometer and their relative separations and orientations are important in determining the quality of the images that the interferometer can form. Each connection between two telescopes in the interferometer array is called a *baseline*, and each baseline has both an orientation relative to the sky and a separation distance between the pair of telescopes. The greater the number of baselines in the array, the higher the quality of the image produced. Moreover, the larger the baseline separation distances, the sharper the detail on the sky that the interferometer can measure.

For the astrometry science objective, NASA must also consider is the ability of the Outrigger Telescopes to simultaneously form two long baselines that are nearly perpendicular to one another. Each baseline measures one component of a star's motion, for example, up-and-down for one baseline, and side-to-side for the other baseline. The longer the baseline, the more accurate the measurement. The minimum baseline separation depends on the measurement of the astrometric signature of Uranus-mass planets around nearby stars. To accomplish this (science objective 3 for ground-based interferometry), the baseline separation for the Outrigger Telescopes must be at least 75 m (246 ft) in two nearly perpendicular directions.

There must also be unobscured views of the sky from each Outrigger Telescope down to a zenith angle of 60 degrees in most directions. The notable exception would be in the direction of the large telescope itself, where some obscuration is inevitable. There would also need to be paths for installing beam lines from each Outrigger Telescope to the beam-combining laboratory to direct the starlight for interferometric combination. The telescope support piers must be on the same level or elevation, so that the starlight beam from each telescope to the combining laboratory is horizontal (i.e., level).

Superior Site Observing Quality. The atmosphere above a ground-based telescope interferes with the light from astronomical objects in several important ways. It is crucial that telescopes be situated to minimize this interference. A very

TABLE 2-2. SCIENTIFIC CAPABILITY OF VARIOUS LARGE TELESCOPES LINKED TO THE OUTRIGGER ARRAY

Instrument	Number x Aperture Size	Relative Sensitivity	Relative Searchable Volume of Space
W.M. Keck Observatory	2x10m	1.00	100 percent
Large Binocular Telescope (LBT)	2x8.4m	0.84	77 percent
Gran Telescopio Canarias	1x10m	0.82	74 percent
Magellan Observatory	2x6.5m	0.65	52 percent
Gemini	1x8.2m	0.67	55 percent
MMT	1x6.5m	0.53	39 percent
Generic 4-m	1x4m	0.33	19 percent

important effect for the Outrigger Telescopes Project is the atmospheric bending of light, which depends on the air's temperature and density along the line-of-sight all the way to the top of the atmosphere. Because the atmosphere is dynamic and is not uniform and is constantly in motion, this bending causes the light arriving at the telescope to travel slightly different paths from moment to moment. It is this effect that causes stars to appear to twinkle. Typically, the more atmosphere the light travels through and the more turbulent the air, the more the light from the star is bent, causing the image in the telescope to blur. This blurring is called atmospheric "seeing"; it is measured in units of angle called *arcseconds* (3,600 arcseconds equal one degree of angle).

Historically, astronomers have mitigated this effect by locating telescopes on mountaintops, above a significant portion of the atmosphere, and by choosing sites where the air flows over the Earth smoothly rather than with turbulence. Typically, mountain peaks, such as Mauna Kea, that are the first landforms encountered by smooth winds coming from the ocean are good candidates for astronomical telescopes.

The telescopes must be carefully arranged relative to other structures and local geographic features so that prevailing winds do not produce turbulent wakes that disrupt the airflow across them, creating "local seeing" disturbances. Building structures with aerodynamic shapes (such as domes rather than boxes) reduce turbulent wakes and mitigate these effects. Placing structures in relation to prevailing winds also reduces wake interference.

Adaptive optics, a technology developed in the past 20 years, uses powerful computers and sophisticated optics to measure and correct some atmospheric distortion in real time. In general, this technology works best when the *seeing* is relatively good and it requires observing a relatively bright object—either the science target itself, or a star very close in angle to the science target (which may not always be available)—so that sufficient light can be gathered every fraction of a second to measure and correct the atmospheric distortion. The requirement for a relatively bright object in close proximity to the target object has the effect of reducing the fraction of the sky that can be observed.

Other important atmospheric effects include scattering of light and absorption at certain wavelengths or "colors"—particularly absorption of infrared light by water vapor. These effects are typically mitigated by siting observatories in dark locations away from city lights, and in dry regions such as deserts or in the thin dry air at the top of a mountain.

A site with superior atmospheric seeing is essential for the Outrigger Array. To support the full set of science objectives, atmospheric seeing better than 1.0 arc second is required, with lower values strongly preferred. For sites where seeing is typically 0.5 arcseconds or better we do not anticipate needing adaptive optics systems on the Outrigger Telescopes. This situation enables the interferometer to reach fainter targets, and thereby search a larger volume of space, and also improves the quality of the astrometry.

2.2.1.2 Tier 2 Screening Criteria

Sites that pass the Tier 1 screening criteria will be evaluated for technical and programmatic considerations.

Technical Considerations. Building an interferometer of the type envisioned for the Outrigger Telescopes Project is a very complex undertaking. Adapting the Outriggers to an existing large telescope is also a formidable task. Such a project must proceed with a reasonable expectation that it can be successfully completed within budget and on a schedule that meets NASA's needs. This requires a technical approach that is feasible and has reasonable implementation risk.

Programmatic Considerations. NASA does not own or operate any 8-m or larger telescopes: they typically are owned and operated by consortia of institutions. It is not NASA's intention to impose itself or its program upon these consortia. Rather, NASA would have to negotiate an agreement permitting the integration of the Outrigger Telescopes with the large telescope, and further negotiate for time at the facility, both for development and scientific observation. NASA must feel confident that access agreements could be negotiated and observing time obtained at an affordable cost and within a time frame that would support its programmatic and scientific needs.

NASA must consider additional factors when the large telescope is foreign owned. Foreign-owned facilities focus on serving the needs of the national constituencies involved, not those of NASA or the U.S. astronomical community. Although NASA frequently negotiates international collaborations, they are always predicated on mutual benefits for all partners. To reasonably expect success in negotiating access to a foreign-owned large telescope for the Outrigger Telescopes Project, NASA would have to be confident that the foreign entities involved saw benefit in reaching such an agreement with NASA.

Other factors, such as cultural and environmental sensitivity, must also be taken into consideration as an integral part of the decision-making process.

2.2.2 Alternative Site Descriptions and Screening Criteria

The following 8-m (26-ft) or larger telescopes are either operational or expected to be operational within the next few years.

- Keck Telescopes, Mauna Kea, Hawaii
- Subaru Telescope, Mauna Kea, Hawaii
- Gemini North Telescope, Mauna Kea, Hawaii
- Very Large Telescope Interferometer, Cerro Paranal, Chile

- Gemini South Telescope, Cerro Pachón, Chile
- Magellan Telescope, Las Campanas, Chile
- Gran Telescopio Canarias, La Palma, Canary Islands, Spain
- Large Binocular Telescope, Mt. Graham, Arizona
- South African Large Telescope, Sutherland, South Africa
- Hobby-Eberly Telescope, Mt. Fowlkes, Texas

Two telescopes, Gemini North and Subaru (which is foreign-owned), are on the summit of Mauna Kea at sites much less suitable than the Keck site. Therefore NASA did not evaluate them further.

Two other telescopes, the Hobby-Eberly and its near twin, the South African Large Telescope, are not general-purpose telescopes. They employ tracking secondary mirrors, which limits the portion of the sky that can be observed. These telescopes cannot be adapted for use as an interferometer with the Outrigger Telescopes and therefore are not evaluated further.

In the following, we describe the remaining large telescope facilities and evaluate them against the screening criteria.

2.2.2.1 Very Large Telescope Interferometer

Description. The European astronomical community has selected Cerro Paranal in northern Chile as the location for this premier astronomical facility, the Very Large Telescope Interferometer (VLTI). It is being developed by the European Southern Observatory, a collaboration of several European organizations. Recognizing the importance of interferometry to the future of astronomy, the European Southern Observatory has designed the facility to provide capability similar to what NASA proposes for the Outrigger Telescopes Project. Combining very high sensitivity with very high angular resolution, VLTI's four 8.2-m (27-ft) telescopes, together with its four 1.8-m (6-ft) movable auxiliary telescopes, can be used in several different modes. These interferometric combinations can ultimately provide an angular resolution equivalent to a 200-m (656-ft) telescope. The facility is nearing completion, with all four main telescopes built and one auxiliary telescope installed.

FIGURE 2-17. AERIAL VIEW OF VLTI SHOWING FOUR 8.2-M TELESCOPES AND VARIOUS STATIONS FOR MOVABLE AUXILIARY TELESCOPES

Image courtesy of European Southern Observatory (ESO).

The VLTI is a fully self-sufficient observatory designed to serve the needs of the European astronomical community.

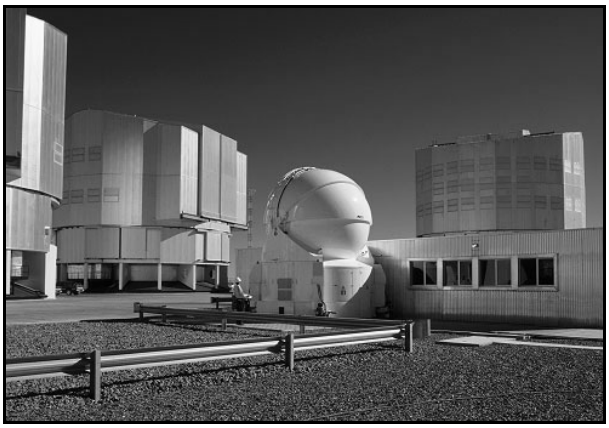


FIGURE 2-18. VIEW OF VLTI SHOWING 8.2-M TELESCOPE ENCLOSURES IN THE BACKGROUND AND MOVABLE AUXIALIARY TELESCOPE IN THE FOREGROUND

Image courtesy of European Southern Observatory (ESO).

Screening Criteria Evaluation. The VLTI, a southern hemisphere facility, fails NASA's Tier 1 northern hemisphere criterion. It also fails the Tier 2 programmatic criteria because NASA would have no reasonable expectation of successfully negotiating access to a facility built in part to compete with the United States in a developing technology. Furthermore, the VLTI includes telescopes equivalent to the Outriggers, which would render the Outriggers redundant and unnecessary at this site.

2.2.2.2 Gemini South Telescope

Description. The Gemini South Telescope is the southern hemisphere element of the Gemini Observatory Project, a multinational effort to build and operate 8-m (26-ft) optical/infrared telescopes on both Cerro Pachón, Chile, and Mauna Kea, Hawai‘i. The Gemini collaboration involves seven astronomical institutions from Europe and the Americas.

FIGURE 2-19. AERIAL VIEW OF GEMINI SOUTH TELESCOPE

Image courtesy of Gemini Observatory Project.

Screening Criteria Evaluation. The Gemini South Telescope is built on the cliff side of the Pachón ridgeline. The Outrigger Telescopes could not be located on this site because of the steep terrain. The site therefore does not meet the Tier 1 criterion that adequate land be available. In addition, a southern hemisphere location does not meet the Tier 1 criterion for maximizing sky coverage.

2.2.2.3 Magellan Telescope

Description. The Magellan Telescope is a collaboration of the Carnegie Institution of Washington, the University of Arizona, Harvard University, the University of Michigan, and the Massachusetts Institute of Technology. The observatory consists of two 6.5-m (21-ft) telescopes on Las Campanas, Chile. If the two telescopes were combined optically, they would have the light gathering power of a single 9-m (30-ft) telescope. The required Outrigger Telescope baseline separations might be achieved at this site if the Outriggers were placed on sufficiently high towers. The

Magellan team has considered the idea of linking the two 6.5-m (21-ft) telescopes as an interferometer, but has not pursued it, in part because the resulting scientific capability would be far less powerful than the European VLTI, which observes the same southern hemisphere sky.

FIGURE 2-20. VIEW OF THE MAGELLAN OBSERVATORY

Photo courtesy of the Carnegie Institution of Washington.

Screening Criteria Evaluation. The southern hemisphere location precludes meeting the Tier 1 criterion for maximizing sky coverage. In addition, linking all of the telescopes and adding the necessary beam-combining laboratory would involve significant engineering challenges and implementation risk.

2.2.2.4 Gran Telescopio Canarias

Description. The Gran Telescopio Canarias (GTC), modeled on the Keck 10-m (33-ft) Telescope design, is currently under construction on the island of La Palma in the Canary Islands, Spain. It is being developed by the Instituto de Astrofísica de Canarias, the Instituto de Astronomía de la Universidad and the Instituto Nacional de Astrofísica, Óptica y Electrónica of Mexico, and the University of Florida (with a 5 percent share). First light is planned for 2006.

FIGURE 2-21. THE GRAN TELESCOPIO CANARIAS UNDER CONSTRUCTION AT LA PALMA

Photo courtesy of Instituto de Astrofisica de Canarias, GTC Project.

Screening Criteria Evaluation

Tier 1 Criteria. The site is a northern hemisphere location.

There appears to be sufficient available land at the GTC site to accommodate the baselines required for the Outrigger Array. The sloping topography of the GTC site poses some challenges, but does not preclude the installation of the Outriggers.

La Palma is generally regarded as having superior observing quality. Atmospheric seeing is estimated to be approximately 0.7 arcseconds, with approximately 79 percent of nights being suitable for observing.

This site meets the Tier 1 criterion.

Tier 2 Criteria. The Tier 2 criteria address the technical and programmatic considerations of implementing the Outrigger Telescopes Project at this site.

Technical Considerations. The 10-m (33-ft) telescope is being implemented with a coudé tunnel beneath the facility that makes it possible to bring the light from the 10-m (33-ft) out to a beam combining facility, where it could be joined with light from the Outrigger Telescopes. This beam

combining facility would be placed adjacent to the 10-m (33-ft) telescope. Ideally, the Outrigger Telescopes would be placed around the 10-m (33-ft) telescope, subject to prevailing wind conditions. The terrain at the GTC site is sloping with a grade of approximately 18 percent. This means that some of the Outriggers would be supported on columns; the vibration aspects of the support columns would require further study. Being above tree line at an elevation of 2,400 m (7,874 ft), boundary layer effects are expected to be minimal.

The owners of the GTC may have future expansion plans for the observatory that might restrict possible locations of the Outrigger Telescopes and beam combining building.

Programmatic Considerations. Discussions with representatives of the Instituto de Astrofisica de Canarias indicate that 70 percent of available observing time on the GTC has been committed to Spain, 5 percent to Mexico, and 5 percent to the University of Florida, leaving approximately 20 percent uncommitted at this time.

Assuming that the GTC collaboration found it in their programmatic interest to host the Outrigger Array, it is possible that NASA could successfully negotiate for a fraction of the uncommitted observing time. It is not known what other financial or programmatic arrangements might be required of NASA in return for access to the GTC. According to sources within the Instituto de Astrofisica de Canarias, Spain has applied to become a member of the European Southern Observatory (ESO). What effect ESO membership might have on available observing time or on NASA's prospects for negotiating access to the GTC is not known.

The best available environmental information for the GTC site suggests there are no known endangered or threatened species. Water supply and disposal appear to be potentially sensitive issues for the site, but are expected to be manageable.

In conclusion, the GTC appears to be a reasonable alternative site for the Outrigger Array, although some programmatic risk does exist.

2.2.2.5 The Large Binocular Telescope

Description. A consortium of 7 U.S. and 10 European institutions, led by the University of Arizona, is developing the Large Binocular Telescope (LBT). Collectively, the U.S. team members have a 50 percent share of the project. The telescope is located in the Coronado National Forest on Mount Graham, near Safford, Arizona, with first light planned for 2004, and full operation expected in 2006.

As its name suggests, the LBT carries two large mirrors, each 8.4 m (28 ft) in diameter, mounted together in a unique arrangement on a single telescope mount. The mirrors are mounted with a center-to-center separation of 14.4 m (47 ft).

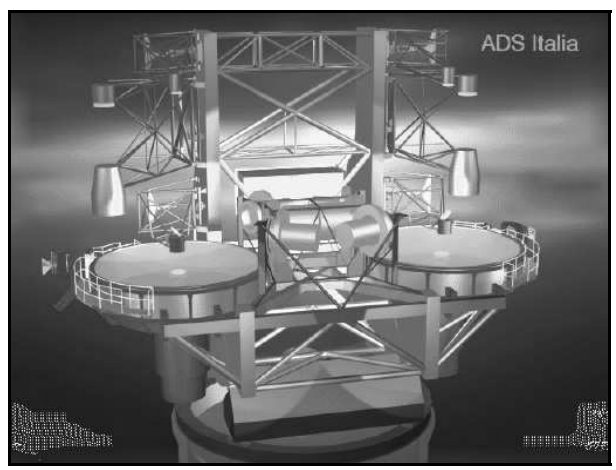


FIGURE 2-22. ARTIST'S RENDERING OF THE LBT SHOWING THE TWO PRIMARY MIRRORS AND THE TELESCOPE MOUNT

Image courtesy of the LBT Project.

Screening Criteria Evaluation

Tier 1 Criteria. Mt. Graham is a northern hemisphere location.

Sufficient terrain exists at the site to locate the Outrigger Telescopes with the necessary baselines. The topography of Mt. Graham poses some challenges, but does not preclude the installation of the Outriggers.

Mt. Graham is generally regarded as having superior observing quality. Based on a survey of the literature, the atmospheric seeing is estimated to be approximately 0.6 arcseconds for telescopes, like the LBT, which are higher than the trees in the surrounding forest. This meets the Tier *1* criterion of 1.0 arcseconds or better. The LBT site at Mt. Graham meets the Tier 1 criteria. The practical issues of locating the Outrigger Telescopes above tree height and of avoiding wake turbulence from structures is discussed under the Tier *2* Technical Considerations criteria.

Tier *2* Criteria. The Tier *2* criteria address the technical and programmatic considerations of implementing the Outrigger Telescopes Project at this site.

The Environmental Assessment prepared by NASA concluded, in reference to the LBT, that "There is no clear engineering solution that would allow the Outrigger Telescopes to be integrated into the overall design." Since that time, the requirements for linking the Outrigger Telescopes to the LBT have been examined more closely. This additional information better enables NASA to assess the technical feasibility and implementation risks associated with such a project.

Background. The LBT design is optimized for observations in the near- and mid-infrared portion of the spectrum. In particular, it minimizes the number of optical reflections required for light to reach the scientific instruments at the focal plane of the telescope. However, this requires that the astronomical instruments used with the LBT be attached directly to the moving portion of the telescope and be carried around with the main (primary) mirrors.

Most astronomical telescopes are designed with the capability to relay light from the primary mirror to an external platform that remains level as the telescope moves. Adaptive optics systems and large spectrographs are commonly located on such a platform or in a coudé room below the telescope. In the latter case, a series of smaller mirrors is used to direct the light from the primary mirror along a coudé path through the rotation axes of the telescope bearings, and eventually outside the telescope itself. Because the LBT has instruments attached directly to the moving portion of the telescope, no coudé path was implemented. Consequently, the LBT does not have a clear path to route an optical beam out of the telescope to a beam-combining facility where it could be combined with light from the Outrigger Telescopes.

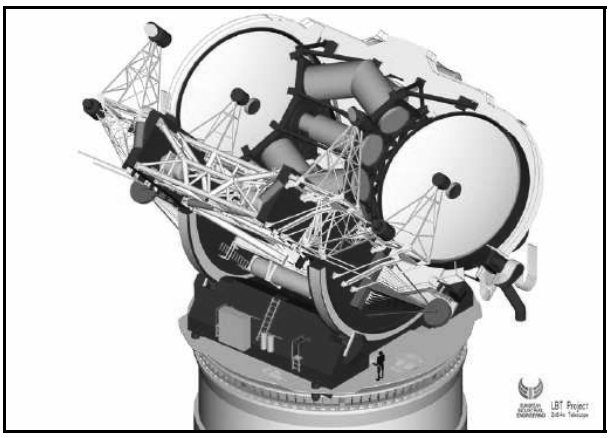


FIGURE 2-23. THIS IMAGE SHOWS THE LBT PRIMARY MIRRORS AS WELL AS THE THREE INSTRUMENT STATIONS (TUBE SHAPED TUNNELS) BETWEEN THE MIRRORS

Image courtesy of the LBT Project.

However, interferometry can be accomplished with the LBT. The consortium is developing the Large Binocular Telescope Interferometer (LBT-I) to take advantage of the unique geometry of the LBT to combine the light from its two 8.4-m (28-ft) mirrors, which are separated by a 14.4-m (47-ft) baseline (i.e., the 14.4-m (47-ft) connection between the two telescopes in the interferometer array). NASA is collaborating on this effort by developing a mid-infrared nulling instrument that will be attached to LBT-I. In some respects the LBT-I is similar to the Keck-Keck Interferometer that combines light from the two Keck 10-m (33-ft) telescopes. However, the Keck Telescopes are separated by an 85-m (279-ft) baseline. The different baselines (14.4 m versus 85 m (47 ft versus 279 ft)) give the two interferometers different (and complementary) scientific capabilities.

For example, NASA plans to use both interferometers to measure the dust believed to be surrounding nearby stars. The thicker this dust is, the greater its interference with attempts to observe Earth-like planets. NASA must know how thick the dust is in order to design the Terrestrial Planet Finder, which is scheduled for launch in the next decade. With its longer baseline, the Keck-Keck interferometer is more sensitive to dust very close to the star, while the LBT, with its shorter baseline, is more sensitive to dust farther away. Together, the two interferometers will map the distribution of dust around nearby stars, indicating to NASA what size the Terrestrial Planet Finder must be in order to see Earth-like planets against this dusty background.

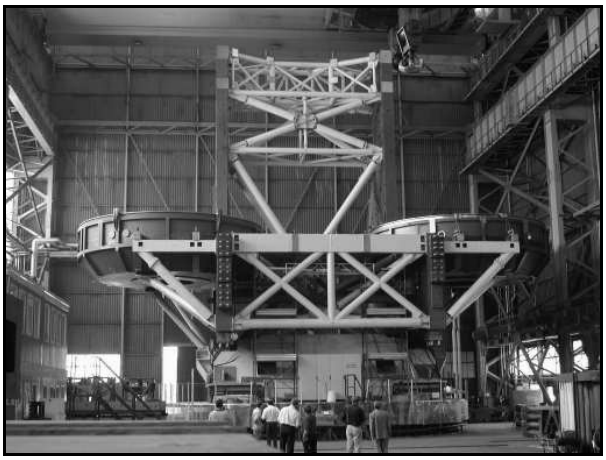


FIGURE 2-24. PHOTOGRAPH OF THE LBT MOUNT STRUCTURE INSIDE THE TELESCOPE ENCLOSURE

Photo courtesy of the LBT Project.

Because the beam-combining optics of the LBT-I are positioned between the two primary mirrors (where they are carried around with the telescope), very few reflections are required to bring the two beams together. This enables the LBT-I to observe exceptionally faint objects in the infrared. However, although this design approach gives LBT-I many advantages, it imposes significant obstacles to combining the LBT with the Outrigger Telescopes.

Technical Considerations. To use the LBT with the Outrigger Telescopes, the light from the two 8.4-m (28-ft) mirrors would have to be collected by optics with a design similar to the optics in the Outrigger Telescopes, relayed down through the support pier of the LBT, and out through the foundation of the building to a new beam-combining facility. The main challenges would be:

- Designing optics (called dual-star optics) for the LBT that would provide the same functionality as optics designed for the Outrigger Telescopes, and installing those optics at a suitable

location within the structure of the LBT.

- Designing a coudé path from the LBT to the beam-combining facility.
- Matching the polarization of light from the LBT with that of light from the Outrigger Telescopes.
- Locating the Outrigger Telescopes and the beam-combining facility relative to the LBT to provide good beam quality for interferometric imaging and narrow-angle astrometry.

These are addressed in turn below.

Dual-Star Optics for the LBT. Linking the LBT to the Outrigger Telescopes as an interferometer would require two sets of dual-star optics—similar to those designed for the Outrigger Telescopes—one for each of the LBT's 8.4-m (28-ft) mirrors. The new optics would have to be located between the two large mirrors near the telescope's focal plane. The LBT has three instrument "stations" that occupy the space between the two 8.4-m (28-ft) mirror cells. The front and rear stations are reserved for other instruments, and would be unsuitable in any case because the light beams from the telescope would be combined at an angle that would introduce excessive polarization effects. The central station is reserved for the re-imaging optics used for the LBT-I beam combiner. This area is also intended to house the nulling instrument for the LBT-I under development by NASA. Two alternative methods of introducing dual-star optics into this central region have been explored:

1. Remove the nulling instrument and replace it with the dual-star optics, thereby using the full space available at the central station. However, in addition to potentially disrupting the observing program for the nulling instrument, this would subject both the nuller and dual-star optics to risk of damage or misalignment each time they were removed or installed.
2. Leave the nulling instrument in place and attempt to build the dual-star optics around it, using mirrors to steer the light to a nearby location, possibly underneath the nuller. This would prevent the need to remove the nulling instrument, but would leave much less space within which to house the dual-star optics. Such volume constraints, together with the circuitous beam path, would greatly complicate the resulting design and introduce significant implementation risk.

Coudé Path from the LBT to the Beam-Combining Facility. Early conceptual plans for the LBT described the possible implementation of a coudé path, whereby light would be sent vertically downward along the azimuth axis of the telescope. As mentioned earlier, such a path was never implemented, perhaps in part because of the unusual approach it would necessitate. Normally, to bring light out of a telescope it is first sent horizontally *along the elevation axis* to a Nasmyth platform. No such platform exists on the LBT because the azimuth turntable sits far below the elevation axis. A "gravity stable" mirror system at the intersection of the azimuth and elevation axes (shown in the following figures) was suggested as a solution. This mirror system would need to be actively controlled to move opposite to the elevation motion of the telescope, so that light being relayed from the telescope would always be sent down the azimuth axis. This path would be complicated to implement, as it would require its own control system and laser metrology for stabilization, and would have to work in concert with the telescope motion control system.

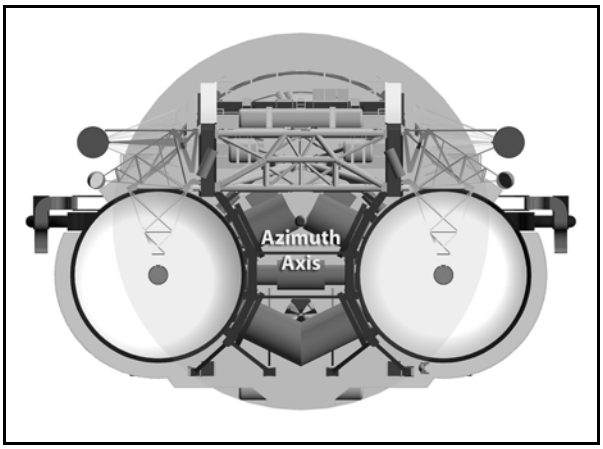


FIGURE 2-25. VIEW LOOKING DOWN THE LINE OF SIGHT OF THE TELESCOPE

Note: The azimuth axis of the mount is indicated.

Image courtesy of the LBT Project.

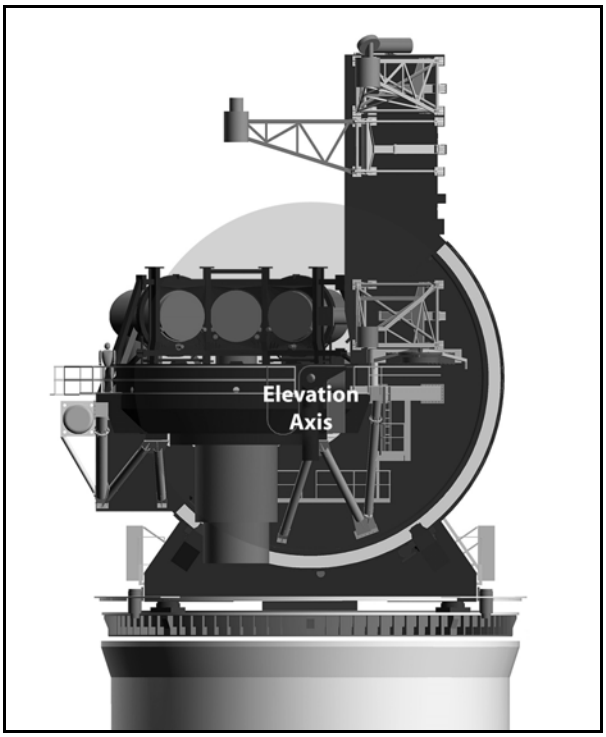


FIGURE 2-26. VIEW LOOKING HORIZONTALLY AT THE TELESCOPE

Note: The elevation axis of the mount is indicated.

Image courtesy of the LBT Project.

In addition, because this approach was not implemented in the telescope, no port is available for the light to exit at its base. Providing this path would require boring through the steel-reinforced concrete of the telescope pedestal.

While it is not impossible to conceive of such a coudé path design, it would entail considerable technical complexity and risk.

Polarization. Each time light is reflected from a mirror its polarization state is altered. To successfully combine light from the LBT and the Outrigger Telescopes as an interferometer, the polarization state of light from each telescope light path must be the same. Because of the unusual nature of the LBT design, additional reflections would have to be introduced into both the *LBT's and the* Outrigger Telescopes' *coudé* paths so that their polarizations match. This further increases complexity and risk.

Locating the Outrigger Telescopes. To provide the best imaging quality for interferometry, the large telescope should be located near the geometric center of the array. Locating the large telescope away from the center would degrade the quality of interferometer images. As mentioned earlier, telescopes should be located to minimize wake-induced turbulence from terrain and other structures and to avoid atmospheric seeing problems that degrade image sharpness.

FIGURE 2-27. AERIAL VIEW OF THE LBT ENCLOSURE

Photo courtesy of the LBT Project.

The LBT is housed in a very large cube-shaped building, approximately 40-m (131-ft) tall and 25-m (82-ft) wide. Unlike a dome, a cube is not an aerodynamic shape, and one could expect wind-induced vortex turbulence downwind of it. Venting air from inside the LBT enclosure could also be problematic. The enclosure is built with large axial vent fans at the four corners of the structure that blow air out of the building slightly above tree height. This vented air is below the LBT but would be slightly above the height of the Outriggers, introducing another potential source of turbulence. Placing the Outriggers around the LBT for best imaging performance would pose possible atmospheric seeing problems for the downwind Outriggers. Alternatively, locating the Outriggers off to one side of the LBT to avoid wind-induced turbulence would result in an inferior array geometry, which would degrade imaging performance.

FIGURE 2-28. THE LBT MOUNT RAISES THE TELESCOPE ABOVE TREE HEIGHT

Note: The enclosure vent ducts can be seen at the four corners of the structure below the open doors.

Photo courtesy of the LBT Project.

Trees cause an atmospheric boundary layer that degrades seeing quality. To avoid this problem, telescopes must either be elevated above tree height or the trees surrounding the telescopes must be removed. The LBT, is well above tree height. The Outrigger Telescopes are relatively small in comparison; elevating them above the trees would require placing them on tall columns. Columns tall enough to support the Outriggers above tree height would be at risk of excessive lateral vibration caused by wind or telescope movement. Furthermore, the terrain surrounding the LBT slopes, while the Outrigger array must to be kept fairly level, so that columns supporting Outriggers at the lower elevation locations would need to be even taller.

Removing trees at Mt. Graham is not a viable option because the summit forest is a designated critical habitat to the red squirrel, a Federally listed endangered species.

The overall approach described may be a credible concept for linking the Outrigger Telescopes and the LBT, but the

implementation is unconventional and complex, and the potential for unforeseen problems is high. In addition to the difficulties of bringing an optical beam out of the LBT, the wake turbulence from the large non-aerodynamic LBT enclosure and the risk of boundary layer effects from tall forest trees introduce other uncertainties. NASA concludes that the implementation risk at the LBT is much higher than at the Keck site.

Programmatic Considerations. As described earlier, NASA's interest in the Outrigger Telescopes Project is related to the need for ground-based science observations that support its Origins Program. The schedule for bringing the Outrigger Array to operational status has been delayed by several years. The important astrometry measurements to be made by the Outriggers will require additional years to compile, making the start of operations increasingly urgent if data are to be available in time to support NASA's future Origins missions.

Unlike the Keck Telescopes, the LBT is not yet a working telescope, and its completion is subject to forces beyond NASA's control. NASA is already supporting the development of one instrument for the LBT-I. If the Outriggers were implemented at the LBT, both NASA projects would be subject to delays. Because the two projects would compete for the same physical space on the telescope, it is likely that they would interfere with each other, and thus delay development schedules. If NASA were unsuccessful in negotiating additional observing time on the LBT, it would have to divide its observing time (both engineering and science) between the two projects. As a result, both completion dates would be delayed and the science return from each would be reduced.

Finally, the issue of environmental and cultural impact must be considered. Like Mauna Kea, Mt. Graham is considered a sacred mountain by some native Americans, and is the home of a Federally listed endangered species. Consequently, it offers no apparent environmental or cultural resource advantage over Mauna Kea.

Because the LBT implementation involves substantially higher technical, cost, and schedule risk, NASA concludes that the LBT is not a reasonable alternative site for the Outrigger Telescopes Project.

2.2.3 Summary of Alternate Sites Comparison

NASA has evaluated all existing or nearly completed large telescope (8-m (26-ft) or larger) facilities against its scientific and national policy objectives for the Outrigger Telescopes Project. No alternate site matches the scientific capability of the Keck Observatory on Mauna Kea, which hosts the world's two largest and most powerful optical telescopes. The existence of the European Southern Observatory (ESO) Very Large Telescope Interferometer (VLTI) in the southern hemisphere provides compelling scientific and programmatic rationale for NASA's facility to be located in the northern hemisphere.

Of the two potential northern hemisphere alternate sites, the GTC in the Canary Islands, Spain, is found to be a reasonable alternate site, although it would offer only a single 10-m (33-ft) telescope, and would carry some residual programmatic risk.

The other northern hemisphere candidate, the Large Binocular Telescope (LBT) on Mt. Graham, Arizona, is considered unsuitable for technical reasons, and to involve unacceptably high technical and programmatic risk.

2.3 DESCRIPTION OF THE CANARY ISLANDS ALTERNATIVE

The Gran Telescopio de Canarias (GTC), a 10-m (33-ft) telescope modeled after the Keck Telescope, is currently under construction on the island of La Palma in the Canary Islands, about 1,800 km (1,100 mi) southwest of Madrid, Spain. Figure 2-29 shows the location of the Canary Islands in relation to Europe and Africa. The GTC site is located within the Roque de Los Muchachos Observatory (ORM) near the northern end of the island. See Figure 2-30 for a map of La Palma, Isla Bonita.

The ORM, in conjunction with the Teide Observatory on the island of Tenerife (100 km (60 mi) to the east), constitute the European Northern Observatory (ENO). The ENO is a consortium of institutions from19 countries including: Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Poland, Portugal, the Republic of Armenia, Russia, Spain, Sweden, Taiwan, Ukraine, the United Kingdom, and the United States. The ENO is administered by the Instituto de Astrofisica de Canarias (IAC) in the city of La Laguna on the island of Tenerife.

The Roque de Los Muchachos Observatory is located at an elevation of approximately 2,400 m (7,900 ft) above mean sea level (AMSL) and occupies the north slope of a large volcanic caldera, the most prominent feature on La Palma. The 189 ha (467 ac) science site supports more than a dozen observatories including the following:

Solar Telescopes

- Swedish Solar Telescope (SST), 1 m (39 in).
- Dutch Open Telescope (DOT), 45 cm (17 in).

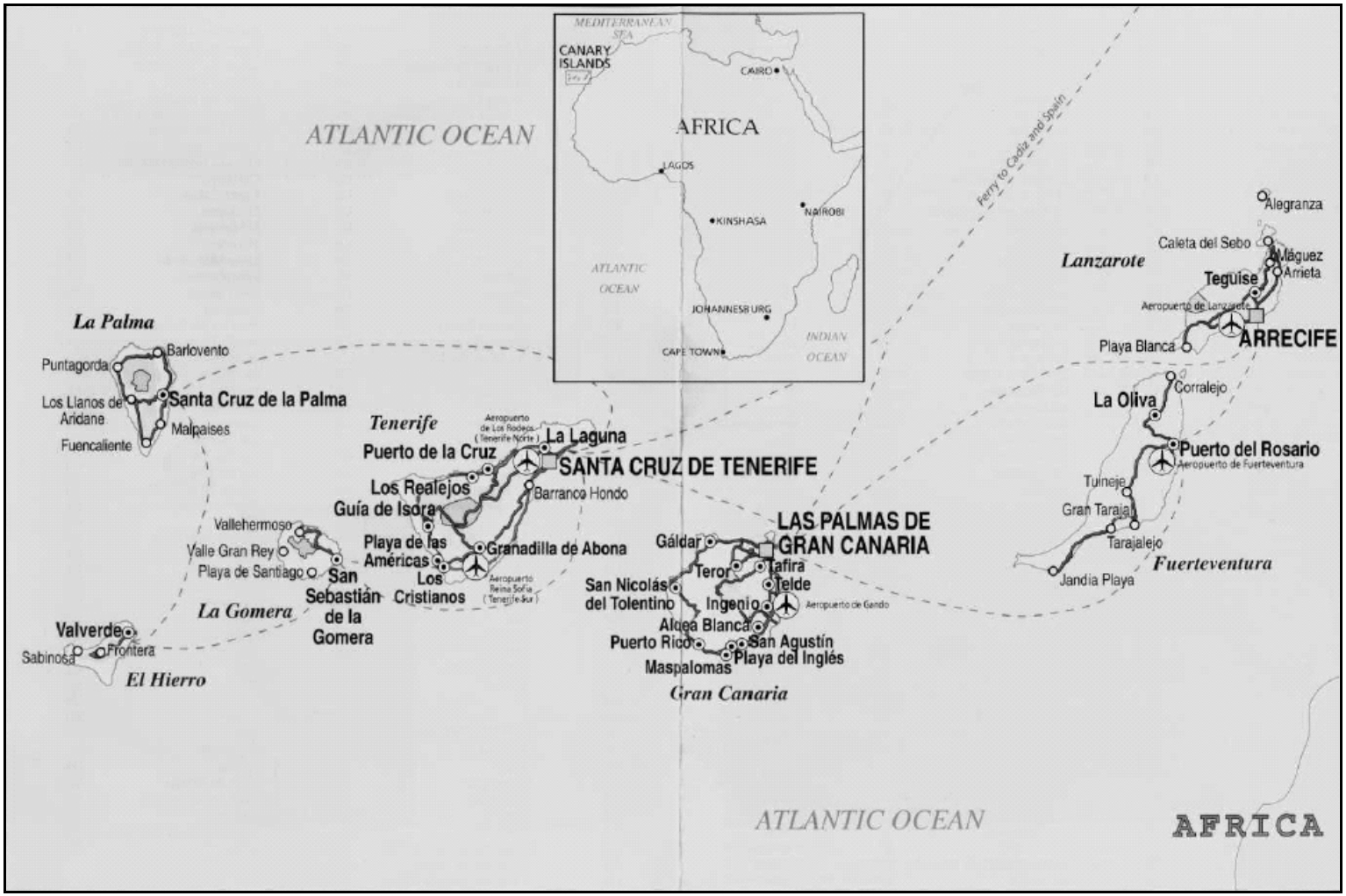
Celestial Telescopes

- Carlsberg Meridian Telescope (CMT), 0.18 m (7 in)
- The Isaac Newton Group of Telescopes (ING):
  - William Herschel Telescope (WHT), 4.2 m (14 ft)
  - Jacobus Kapteyn Telescope (JKT), 1 m (39 in)
  - Isaac Newton Telescope (INT), 2.5 m (8 ft)
  - Nordic Optical Telescope (NOT), 2.56 m (8.4 ft)
  - Telescopio Nazionale Galileo (TNG), 3.5 m (11.4 ft)
- Optical Telescope, 0.6 m (24 in)
- Mercator Telescope, 1.2 m (47 in)
- Liverpool Telescope, 2.0 m (6.5 ft)
- Gran Telescopio Canarias (GTC), 10.35 m (34 ft)

The GTC is a Spanish initiative through the Ministry of Science and Technology and the Regional Government of the Canary Islands. Mexico is a 5 percent participant in the initiative. The University of Florida is also a 5 percent participant. The project is administered through a privately held company GRANTECAN, SA, located on the IAC campus.

2.3.1 Proposed Facilities

Locating the Outrigger Telescopes Project (OTP) at the GTC site would involve the construction of four, and possibly up to six, 1.8-m (6-ft) telescopes together with their enclosures (including domes), light pipes to transport the light from each telescope to a central beam combiner, and a separate structure to house the beam combiner



Source: SeaWest, Inc. 2004b

FIGURE 2-29. CANARY ISLANDS, SPAIN

Source: SeaWest, Inc. 2004b

FIGURE 2-30. LA PALMA, ISLA BONITA

facility. The physical arrangement of the Outrigger Telescopes would be subject to requirements detailed in Section 2.2.1.1.

Figure 2-31 represents one possible layout of four Outrigger Telescopes adjacent to the GTC. The GTC is being constructed with a coudé tunnel beneath the building, which allows light from the 10-m (33-ft) telescope to be brought outside the observatory structure. This light path would feed directly into the beam combiner facility. The light pipes relaying light from the Outrigger Telescopes would also feed into the beam combiner facility, where a complex system of optics would combine the light of the various telescopes together interferometrically. To accomplish the beam combination it is estimated that the beam combiner building would need to be approximately 70 m (230 ft) in length and approximately 10 m (33 ft) in width. An additional 10 m^2 (110 ft^2) of footprint would be required to accommodate the necessary equipment mounting hardware and instrumentation.

2.3.2 On-Site Construction and Installation of the Outrigger Telescopes

2.3.2.1 Schedule

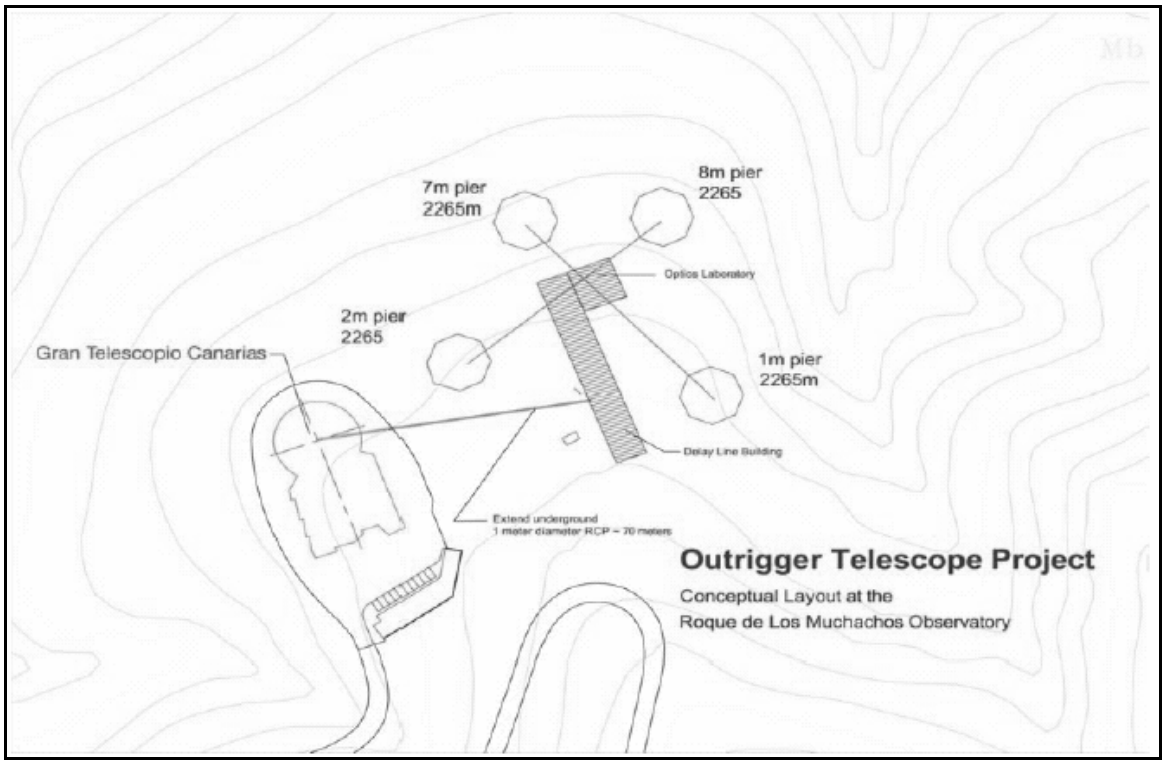
Construction activities at the 2,400-m (7,900-ft) elevation on the island of La Palma are possible on a year round basis, although during the winter months – principally the months of December through March – intermittent periods of inclement weather would be anticipated. Snowfall at the observatory is not expected to represent a significant hindrance to construction progress. Site grading and earthwork activities are anticipated to require several months to complete. The time required for on-site construction and installation would be approximately 24 months. Given the potential for weather related delays, the actual time might be somewhat longer.

2.3.2.2 Estimated Excavation

Construction of the OTP at the GTC site would require building pad earthwork and preparation as well as foundation excavations for each of the four telescopes, the four enclosures, approximately forty light pipe support structures and the beam combiner facility. The overall terrain east of the GTC installation slopes to the north at about 18 percent. This natural slope results in the need to construct level building pads at each location within the interferometer site. The volume of earthwork required to establish pads for four about 93-m^2 (1,000-ft^2) telescope buildings and the about 740-m^2 (8,000-ft^2) beam combiner building is estimated at about 1,900 m^3 (2,500 yd^3). It is anticipated that this project would be engineered with the intent to balance the volume of cut or excavated material with the volume of backfill required. The foundation systems include the enclosure and combiner buildings, as well as the larger mass piers for the telescopes, and the pads for the delay lines, optics tables and combiner instrument stands within the combiner facility. The volume of earth excavation for these elements is anticipated to be approximately 2,140 m^3 (2,800 yd^3).

2.3.2.3 Grading Plans for Outrigger Telescope Domes and Junction Boxes

Proper civil engineering design of the site would ensure proper drainage with minimal potential for erosion arising from or across the proposed construction area. It is important to the function of the interferometer that the Outrigger Telescopes be constructed on a level plane. Consideration of the natural topography, the adjacent GTC facility, and the orientation of the various building elements within the



Source: SeaWest Inc. 2004b

FIGURE 2-31. CONCEPTUAL LAYOUT FOR FOUR OUTRIGGER TELESCOPES AT CANARY ISLANDS SITE

OTP will factor into the final design of the site itself. Where terrain does not naturally permit the telescopes to be built on a level plane, concrete pier structures would be designed to bring the telescopes to the proper elevation.

2.3.2.4 Foundations and Footings

Based on the requirements of four telescope foundation/pier systems, the enclosure foundations, and the integrated foundations and pads for the beam combiner facility, it is expected that cast-in-place concrete would total about 2,400 m^3 (3,200 yd^3). The GTC project made use of dedicated on-site concrete batch facilities approved by the National Park Service and the Municipality of Garafia. A similar temporary on-site concrete/aggregate batch plant could provide the necessary quantity of concrete for the Outrigger Telescopes Project. Alternatively, concrete plants down the mountain near Santa Cruz de La Palma (about 36 km (22 mi)) could provide the material and trucking to accomplish the foundation portion of the construction effort.

2.3.2.5 Signs

Signage required and authorized by the IAC would be used to identify the Outrigger Telescopes Project site within the Roque de Los Muchachos Observatory. It is anticipated that as a result of the "shared site" aspects of the GTC/OTP facility, signage would be provided at designated locations and under guidelines already established for the Gran Telescopio de Canarias.

2.3.2.6 Installation of Telescopes and Enclosures

The prefabricated portions of the telescope enclosures and the telescopes themselves would be shipped to the ORM in standard, steel marine cargo containers and aboard freight flat racks carried by flat bed trucks from the port at Santa Cruz de La Palma to the site. Paved roads to the GTC site provide excellent access for heavy equipment and truck deliveries that would be associated with the construction of a second facility at this location. Ample level staging areas exist adjacent to the proposed site that would permit an orderly time-phased delivery of components and equipment. Following delivery and offloading of the materials, packing debris and cargo containers would be transported down the mountain for disposal and returned to the docks. Individual telescopes would be uncrated and assembled only after completion of the respective enclosure and dome.

2.3.2.7 On-Site Construction Facilities/Equipment

A temporary construction office could be set up on site for the duration of the construction effort. It is anticipated that rubber mounted backhoes, articulated loaders, track mounted excavators and drill rigs would likely be among the earth removal/moving equipment involved in this type of project. During the earthwork, transport vehicles, including 26,000 GVW bobtail trucks, and 25-ton capacity truck-and-trailer combination rigs would be used for the transport, handling, delivery, and disposal of soil and aggregate as required. Vibratory compaction equipment could also be present as a part of engineered backfill efforts. Concrete delivery and placement activities would necessitate the presence of up to six concrete trucks, and at times the use of either high lift or hose type concrete pumping equipment.

During the structural assembly of the enclosures, beam combining building, light pipes, and the installation of the telescopes, a crane of approximately 85-ton capacity along with forklifts and flatbed trucks would constitute the majority of the construction related equipment. All equipment would be required to have up-to-date exhaust systems and mufflers and be inspected regularly to minimize the potential of hydraulic, lubricant or fuel leaks.

2.3.2.8 On-Site Construction Employment and Costs

The construction period for the OTP at the Roque de Los Muchachos Observatory could require approximately two years from the initiation of site works through the installation of the telescopes.

The workforce anticipated for this project varies from an average of between 15 and 25 workers to a peak of perhaps 40 workers. During the initial phases, including site preparation and grading, the number of onsite personnel would likely be limited to 15 or less. The nature of the project suggests a sequential rather than parallel scheduling of construction activities. Throughout the concrete/foundation portions of the project and into the rough construction of the buildings and enclosures, available space to stage structural components, construction tools and equipment and delivered materials is the limiting factor for crew size. Once the building “shells” are complete it is possible that additional specialty contractors and technicians would give rise to a short-term peak crew on the order of 30 to 40 individuals. Final installation of building facilities and telescope/delay line systems would require a smaller effort and result in a substantially reduced personnel requirement. It is estimated that once the building shells

are complete, installation of the telescopes would require approximately 9 months.

While subcontractors and general laborers are available on the island of La Palma, particularly around the city of Santa Cruz, it is anticipated that much of the labor force would come from the islands of Tenerife and Gran Canaria.

On-site construction of the telescope enclosures and the beam combination facility is estimated to cost about $12 to $13 million dollars. This effort would include the installation of four 1.8-m (6-ft) telescopes and the fabrication/installation of light pipes from the individual telescopes to the combiner facility. A portion of this project cost reflects shipping requirements for structural steel, specialized building materials, and major electric/mechanical equipment, most likely obtained from the Iberian peninsula or elsewhere in Europe. This cost does not reflect any permit or agency fees associated with construction authorization, or programmatic costs relative to modifications or contributions to the GTC.

2.3.2.9 Construction Management

Prior to the initiation of any work at the ORM site the Contractor would be required to agree to follow all processes, procedures and authorizations as specified by the Instituto de Astrofisica de Canarias for construction projects within the Roque de Los Muchachos Observatory. Additionally, project construction scheduling and logistics would be submitted to and approved by GRANTECAN prior to mobilization. Care would be taken during all construction activities to minimize the impact on adjacent terrain and operational observatories. Guidelines and procedures for such issues as dust abatement, minimizing terrain disturbance, and the removal/disposal of construction debris during the construction/assembly process could be included within prerequisites to OTP construction at this site. Following review and approval of OTP environmental and construction related documents by jurisdictional agencies, including but not limited to, the Municipality of Garafia and the Parque Nacional de la Caldera de Taburiente, additional compliance requirements may be imposed.

2.3.2.10 Construction Traffic

During construction of the OTP at the ORM it is anticipated that construction related daily vehicular roundtrips might vary from 25 to 35 (work force size equipment/material delivery dependent). These counts reflect an average crew size of approximately 20 persons. Material and construction product deliveries may account for between 5 and 10 daily trips included within this estimate. For short duration peak periods of activity the traffic could reasonably exceed 50 roundtrips per day.

2.3.3 Operations for the Outrigger Telescopes Project

During the commissioning phase of the interferometer, efforts would typically focus on calibration and integration activities associated with the Outrigger and GTC telescopes, pointing and tracking tests, and engineering verification of the beam combination facility. These activities require the participation of engineers and scientists in a intensive effort to achieve fully operational status. Once operational status is achieved, periodic recalibration and troubleshooting would be required. Commissioning activities require personnel to move between the control room, combiner facility and the individual telescope locations in order to conduct the necessary installations and testing. It is anticipated that these activities would not require the use of heavy equipment or

generate noise above normal operating levels associated with pedestrian traffic at the site and occasional vehicular arrivals and departures from the mountain. Once completed, it is anticipated that the level of activity in and around each of the telescope sites, as well as within the beam combiner facility, would decrease dramatically. The interferometer is intended to be operated via a high-speed data connection, both from an on-site control facility and from a remote control location.

Ongoing activities during the lifetime of the Outrigger Telescopes Project would include scheduled equipment and facility maintenance, re-instrumentation/calibration, periodic optics recoating activities and system monitoring.

2.3.3.1 Employment

The Outrigger interferometer is intended to be both locally and remotely controlled during its multiyear science mission. The primary on-site activities would require a daytime staff of between 6 to 8 individuals for maintenance, and a nighttime staff of about 3 specialists.

The OTP staff may be housed during some portion of the time at the ORM dormitory near the entrance to the facility. These accommodations are available on a rental basis along with food services, offices, computer laboratories and conference areas. It is assumed that the OTP staff would live in Santa Cruz de La Palma or the northern island communities, and commute the 36 km (22 mi) to and from the ORM. The current population at the ORM is estimated at approximately 100 persons at any given time.

2.3.3.2 Traffic

It is estimated that operations at the OTP interferometer would generate between 3 to 16 daily round trips along route LP-1032 from Santa Cruz de La Palma and/or route LP-113 from Santo Domingo de Garafia. The number of service related vehicles trips such as water and fuel trucks would be expected to increase incrementally as well.

2.3.3.3 Infrastructure and Utilities

Electrical power to the ORM/IAC is supplied by UNELCO. The mountaintop site currently has a 4 megawatt capacity at the main substation located near the IAC residence and shop compound at the foot of the observatory. The Gran Telescopio Canarias site is supplied with approximately 1,000 kW from this point. Anticipated loads of the GTC, once online, do not exceed 850 kW. OTP power requirement estimates result in an anticipated load for the interferometer site of approximately 120 kW for four and 180 kW for six Outrigger Telescopes. At this level, the current power distribution scheme may be sufficient to support the OTP without upgrade. An emergency generator capacity of 969 kW (full load for 24 hours) is installed as a part of the GTC facility.

The GTC is constructed with fiber optic connectivity facility-wide. The observatory is patched into a main fiber bundle connecting the ORM to Santo Domingo de Garafia and on into Santa Cruz de La Palma. The island of La Palma is connected via undersea fiber cable to Tenerife and the Instituto de Astrofisica in La Laguna.

The Roque de Los Muchachos Observatory relies on water from off mountain supplies for both potable and non-potable use. The GTC facility maintains a non-potable 2,000-l (530-gal) subterranean water supply for sanitation and utility purposes. In addition, the fire suppression system routed throughout the facility is connected to a 30,000-l (7,900-gal) cistern with a 1 ½ hour capacity at full flow. Both of these storage systems are maintained via weekly water

truck deliveries. All potable water is brought to the site in bottles.

2.3.3.4 Maintenance

Maintenance of the OTP telescopes, domes and facilities would require periodic inspections and repair. Bearings associated with moving parts on both the telescopes and the encoded domes would also require periodic lubrication and adjustment. Cleaning of facilities and equipment would involve common cleansing solutions. Periodic mirror resurfacing would require the use of chemicals and water to remove the aluminum surface. This work would be conducted in an area within the GTC designed to contain the wash products. The rinse water and byproducts from the cleaning and recoating process would be containerized and transported off the site.

2.4 DESCRIPTION OF THE NO-ACTION ALTERNATIVE

Under the No-Action Alternative NASA would not fund on-site construction, installation, or future operation of the Outrigger Telescopes Project. The potential environmental impacts described for the Outrigger Telescopes Project in this EIS would not occur. If NASA does not fund the on-site construction and installation of the Outrigger Telescopes at the W.M. Keck Observatory site on Mauna Kea, the facilities at the W.M. Keck Observatory site would consist of the two existing 10-m (33-ft) Keck Telescopes, which also function as the Keck-Keck Interferometer. NASA would be unable to meet any of the four science objectives of the Outrigger Telescopes Project discussed in Section 1.2. In addition, the No-Action Alternative would result in economic losses to the State of Hawai‘i of the estimated $10 to $13 million for the on-site construction and installation of the six Outrigger Telescopes. Further, the State would lose the incremental revenues associated with operation of the Outrigger Telescopes Project. NASA would not fund the Wēkiu bug on-site mitigation, the autecology study, and the Wēkiu bug monitoring activities. NASA also would not fund the on- and off-site mitigation activities provided for in the NHPA Section 106 MOA also would not occur.

2.5 SUMMARY COMPARISON OF PROPOSED ACTION AND THE NO–ACTION ALTERNATIVE

Table 2-3 compares the potential environmental impacts of the Proposed Action, the GTC site, and the No-Action Alternative. Details summarized in this section can be found in Chapter 4 of this EIS.

TABLE 2-3. SUMMARY COMPARISON OF THE PROPOSED ACTION, REASONABLE ALTERNATIVES TO THE PROPOSED ACTION AND THE NO-ACTION ALTERNATIVES

Impact Area	Proposed Action Hawai'i, Mauna Kea	Canary Islands La Palma	No-Action
Meets Purpose and Need	Yes	Yes	No
Cultural Resources	On-site construction and installation—The project would have short-term small-to-moderate and adverse effects to cultural practices due to noise, dust, and construction materials and equipment. Operation—There would be a small adverse effect on traditional cultural practices through visual impacts.	On-site construction, installation—No group considers the area of the ORM to be sacred or of religious importance. There are a number of discovered archeological sites within the ORM. Minor impacts are expected. Operation—No impact on traditional cultural practices. No potential for adverse effects on archeological resources.	No change in baseline condition. NASA would not fund on-site or off-site mitigation activities proposed through the Section 106 consultation process.
Biological Resources	On-site construction and installation—Displacement of Wēkiu bug habitat would be about 0.008 ha (0.019 ac). Project proposes a minimum habitat restoration at a ratio of about 3:1. Very small adverse impact to habitat may be more than counterbalanced by habitat restoration, monitoring, and autecology study. Operation—No impact.	On-site construction and installation—Impact on flora and fauna would be minor. Major portion of the site already disturbed by GTC construction. Impacts on fauna would be temporary, while it could take some period of time for flora to reestablish itself; no sensitive species impacts. Operation—No impact	No change in baseline condition. NASA would not fund Wēkiu bug mitigation, monitoring or restoration activities.
Hydrology, Water Quality, and Waste Water	On-site construction and installation—No impacts would be expected to occur to hydrology and/or water quality. No impacts to Lake Waiau. Operation—No impact.	On-site construction and installation—Construction activities may affect precipitation run-off from the site. Impacts to hydrology and water quality would be small. No water channels or drainages cross the site. Operation—The overall impact would be zero.	No change in baseline condition.

TABLE 2-3. SUMMARY COMPARISON OF THE PROPOSED ACTION, REASONABLE ALTERNATIVES TO THE PROPOSED ACTION AND THE NO-ACTION ALTERNATIVES (CONTINUED)

Impact Area	Proposed Action Mauna Kea	Canary Islands	No-Action
Solid Waste and Hazardous Materials Management	On-site construction and installation—With appropriate handling of solid waste and hazardous materials, no impacts are anticipated. Operation—No impact.	On-site construction and installation—With appropriate handling of solid waste and hazardous materials, there would be effectively no impacts arising from solid waste and hazardous materials. Operation—No impact.	No change in baseline condition.
Geology, Soils, and Slope Stability	On-site construction and installation—Small adverse impacts to soils and slope stability, minimized through best management practices and use of retaining walls. Operation—No impact.	On-site construction and installation—The site is on an 18 percent slope. With available mitigation methods the adverse impacts are anticipated to be small. Operation—No adverse impact.	No change in baseline condition.
Land Use and Existing Activities	On-site construction and installation—*Land Use.* Consistent with the current designation. No impact. *Existing Activities.* No long-term conflict or substantial impact. Operation—*Land Use*. Consistent with the current designation. No impact. *Existing Activities.* The incremental impact would be small.	On-site construction and installation—Consistent with designated uses within the ORM. No impact Operation—Consistent with the only use of any note, astronomy, in and in the vicinity of the ORM. Visitors travel to ORM primarily to see observatories. No impact.	No change in baseline condition.
Transportation	On-site construction and installation—Short-term minor impacts. Operation—Slight increase in traffic would create a very small impact.	On-site construction and installation—Overall adverse transportation impact would be small and less than at Mauna Kea. Operation—Nearly zero impact.	No change in baseline condition.

TABLE 2-3. SUMMARY COMPARISON OF THE PROPOSED ACTION, REASONABLE ALTERNATIVES TO THE PROPOSED ACTION AND THE NO-ACTION ALTERNATIVES (CONTINUED)

Impact Area	Proposed Action Mauna Kea	Canary Islands	No-Action
Utilities and Services	On-site construction and installation—Small increases would be accommodated by existing utilities and services. Operation—Minimal increases would be accommodated by existing facilities and services.	On-site construction and installation—Small increases would be accommodated by existing utilities and services. Operation—Except for electric utilities, increases would be minimal and would be accommodated by existing facilities and services. Substantial impacts to electric power supply unless facilities are upgraded; with upgrades adverse impacts would be small.	No change in baseline condition.
Socioeconomics	On-site construction and installation—Small increases in job opportunities and increased revenues to the State and County economies. Operation—Small positive impact on the State and County economies.	On-site construction and installation—Moderate benefit to La Palma and small benefit to the Canary Islands Operation— Small additional revenues to La Palma and the Canary Islands.	No change in job opportunities and revenues to the State and County economies.
Air Quality	On-site construction and installation—The expected emissions from these activities, including localized fugitive dust and exhaust emissions, would remain below the significance threshold for particulate and combustion emissions. Overall, adverse impact would be small. Operation—No impact.	On-site construction and installation—Adverse environmental impacts on air quality are expected to be small and slightly less than for the W.M. Keck Observatory site. Operation—Adverse impacts would be zero.	No change in baseline condition.
Noise	On-site construction and installation— Intermittent, short-term noise increases would create a moderate impact. Operation—No impact.	On-site construction and installation—Impacts would be small and less than at Mauna Kea. Operation—No impact.	No change in baseline condition.

TABLE 2-3. SUMMARY COMPARISON OF THE PROPOSED ACTION, REASONABLE ALTERNATIVES TO THE PROPOSED ACTION AND THE NO-ACTION ALTERNATIVES (CONTINUED)

Impact Area	Proposed Action Mauna Kea	Canary Islands	No-Action
Visual/Aesthetics	On-site construction and installation—Temporary visual intrusion to the cultural landscape due to construction activities and presence of heavy equipment and materials. Visual impact would be greatest within the Astronomy Precinct, but at times would be visible from certain off-mountain areas. Operation—Outrigger Telescopes would be visible from most locations within Astronomy Precinct. Below the summit area, the mountain topography would determine visual impacts. Where visible, the visual impact would be small compared to the impact of the much larger Keck Telescopes domes.	On-site construction, installation, and operation—No impact.	No change in baseline condition.

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

Standing 4,205 m (13,796 ft) above sea level, the volcanic mountain 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 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 (Hawaii Admin. Rules § 13-5-13). Astronomy facilities are a permitted use in this subzone (Hawaii Admin. Rules § 13-5-24). Astronomy facilities in the resource subzone require a board permit and an approved management plan (Hawaii Admin. Rules § 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.

Astronomical Research. 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).

Other Scientific Research. 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.

Recreational Activities. 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. Visitor 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, visitors are requested to spend time at the Visitor Information Station (VIS) at Hale Pōhaku to view exhibits and acclimatize to prevent altitude sickness.

Sightseeing. Residents and visitors alike visit Mauna Kea to experience a place that is unlike any other location in the world. Many are drawn to the mountain to view the 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

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.

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 Pu‘u 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 National Area Reserve and along existing roads. Individuals typically drive up the mountain for a distance before parking and hiking. The Humu‘ula-Mauna Kea trail, located on the Hilo side of the mountain, runs from the Humu‘ula sheep station to Lake Waiau (UH 1999). Humu‘ula 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 Hawai‘i. 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 Hawai‘i. 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, and 4 student helpers (MKSS 2004a).

Technological advances have made remote observing a practical alternative to working at the summit and astronomers do not necessarily need to be at the summit to analyze data collected at some of the observatories. The WMKO, for example, has designed its Waimea headquarters with control rooms linked by data and video lines to the observatory on Mauna Kea. Astronomers using the Keck facility typically reside in the Keck dorms in

Waimea and perform their work without traveling to the summit.

3.1.2 Cultural Resources

3.1.2.1 Resource Definition

Cultural resources include both historic properties and cultural values or traditional cultural practices.

As defined in the National Historic Preservation Act (NHPA), historic properties are any prehistoric or historic districts, sites, buildings, structures, or objects, significant in American history, architecture, archaeology, engineering, or culture that are included in, or eligible for inclusion on, the National Register of Historic Places (NRHP). Historic properties include archaeological sites (locations where human activity has altered the earth or left deposits of physical remains), historic buildings and structures, historic districts (groups of significant archaeological, architectural, or landscape features), and other evidence of human activity, as well as artifacts, remains, and records related to and located within such properties.

Historic properties also include places of traditional religious and cultural importance to an Indian tribe or a Native Hawaiian organization. These traditional cultural properties are places associated with the practices and beliefs of a living community, are rooted in its history, and are important in maintaining the continuing cultural identity of the community (Parker and King 1998).

Historic properties are protected under the NHPA.

Cultural values or traditional cultural practices include contemporary cultural practices or beliefs of particular ethnic or cultural groups. These values and practices are identified in ethnographic studies and other personal accounts (refer to Section 3.1.2.4). The American Indian Religious Freedom Act of 1978 makes it Federal policy to protect and preserve the rights of indigenous groups, including Native Hawaiians, to practice their traditional religion, access sites, and conduct ceremonials and traditional rites.

3.1.2.2 Previous Cultural Resources Investigations

Figure 3-1 shows the location of archaeological surveys that have been conducted on Mauna Kea. Early archaeological work was confined to brief visits and general recording of sites in the Mauna Kea quarry complex. These led to designation of the quarry complex as a National Historic Landmark in 1962. In 1975 Bishop Museum initiated an intensive study of the quarry, which resulted in the recording of over 264 workshops, 45 shrines, and numerous rock overhangs used as shelters by the Hawaiians quarrying stone (McCoy 1977a; McCoy 1977b; McCoy 1978; McCoy 1990).

The first archaeological surface survey in the MKSR, conducted in preparation for California Institute of Technology telescope construction (McCoy 1982b), covered a large section of the summit, including the Kūkahauʻula summit cones. Included within the area of this reconnaissance survey is Puʻu Hauʻoki, 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 Kūkahauʻula 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

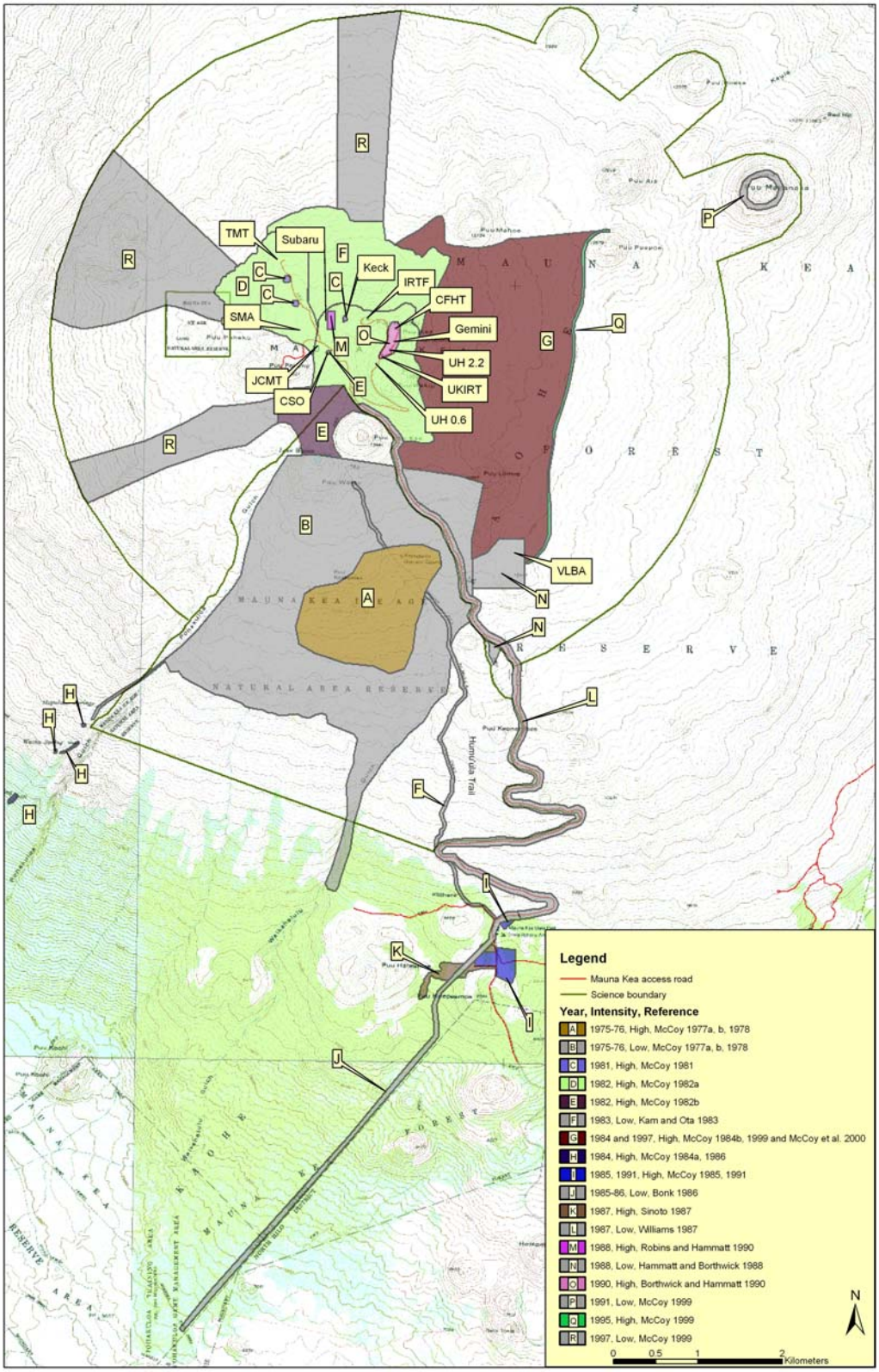


FIGURE 3-1. ARCHAEOLOGICAL SURVEY FOR MAUNA KEA

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 Hawai‘i, 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 Hawai‘i. 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 Hawai‘i, 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 Pu‘u Kūkahau‘ula, 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 *pu‘u* (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 Hawai‘i, 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 Hawai‘i (c. 1860-1900); nineteenth century writings of native historians – Malo (1951), I‘i (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 (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 Hawai'i 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 Hawai'i (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,
'Ōpu'u a'e ka mauna a Kea.
'O Wākea ke kāne, 'o Papa,
'o Walinu'u ka wahine.
Hānau Ho'ohoku he wahine,
Hānau Hāloa he ali'i,
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
Walinu'u was the wife.
Born was Ho'ohoku, 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 (Hibbard 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.

Puʻu Hauʻoki 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 Puʻu Hauʻoki. 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.

Shrines. 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).

Adze Quarrying and Manufacturing Workshops. Although most of the sites associated with the Keanakākoʻi 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).

Burials. Within MKSR, one burial site has been identified on the summit of Puʻu Mākanaka (McCoy 1999). Four other possible burial sites also have been noted: one on the rim of Puʻu 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).

Markers. 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-Humuʻula 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 *kūpuna* familiar with the mountain and traditional 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. Cultural values and traditional cultural practices include intangible resources that are important to a culture. Contemporary or neo-traditional 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; subsistence and recreational hunting; and collection of stone from quarry sites within the Mauna Kea Adze Quarry (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. Pu'u Poli'ahu and Pu'u 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. Pu'u 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 Hawai'i. According to Kanahele and Kanahele (1997), the three *pu'u* are named for three sister goddesses of water: Poli'ahu (snow); Līlīnoe (mist); and Waiau (lake). Poli'ahu 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.

3.1.3 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, Puʻu Hauʻoki, Puʻu Wēkiu, and Puʻu Kea. This landscape feature is also known as Kūkahauʻula (Maly 1998; Maly 1999). The W.M. Keck Observatory site, the proposed location of the Outrigger Telescopes, is on Puʻu Hauʻoki 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).

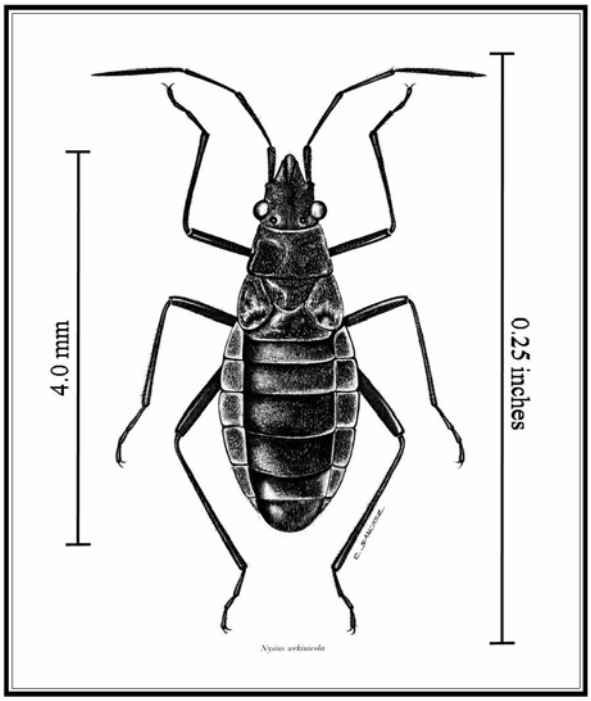


FIGURE 3-2. WĒKIU BUG

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 Hawai‘i, 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 Pu‘u Māhoe and Pu‘u 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).

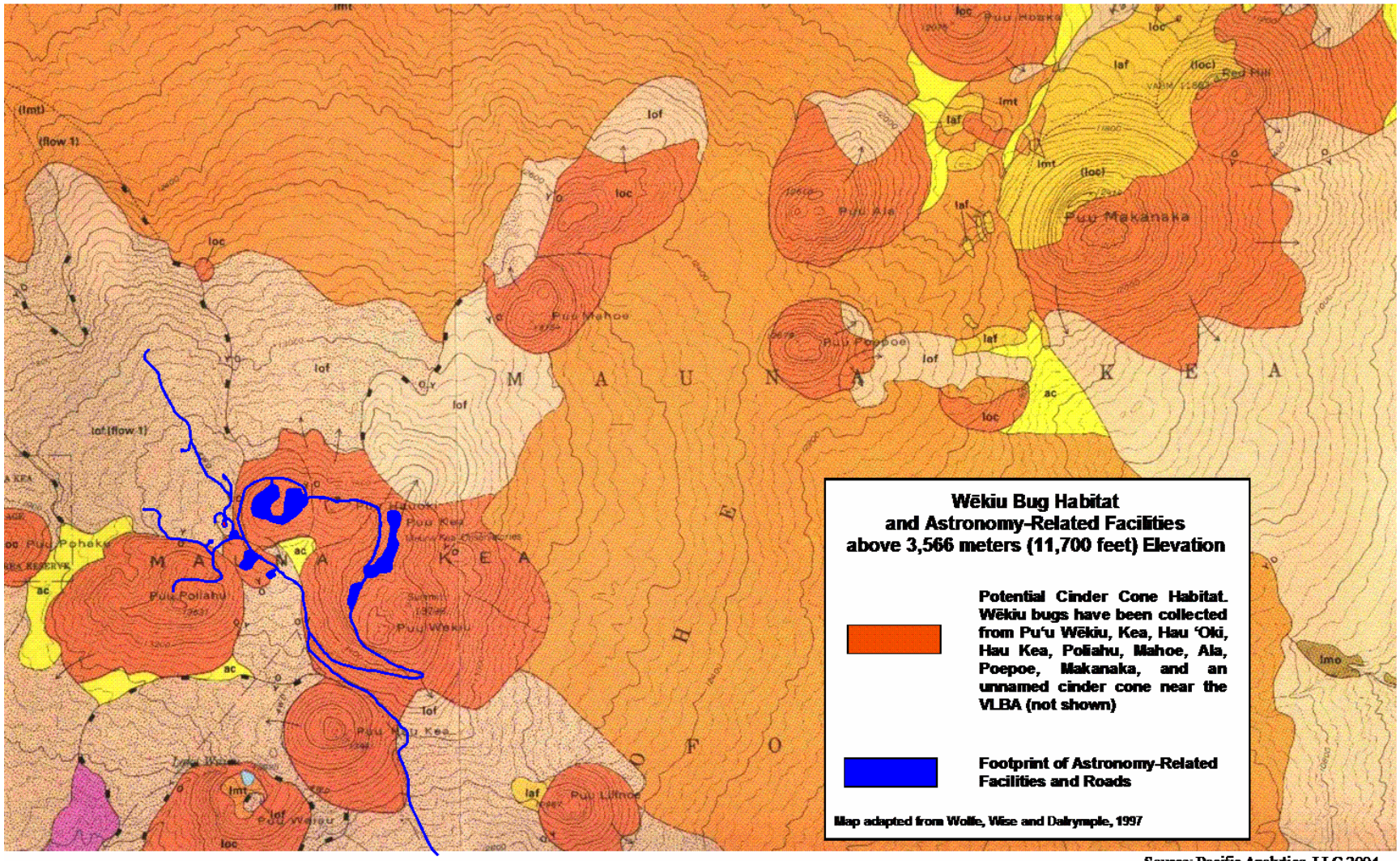
In 1982, Howarth and Stone mapped about 232 ha (573 ac) of Wēkiu bug habitat above 3,900 m (12,800 ft) elevation including some habitat below the *Summit Area Cinder Cones*. It is very likely that Wēkiu bugs occurred elsewhere above 3,900 m (12,800 ft) elevation in unsampled areas. The 1997/98 total 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, 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 is returning to near 1982 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 3rd quarter 2003 monitoring session, Wēkiu bug trap capture rates averaged 90.6 bugs/trap/3-days (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). Increasing trap capture rates measured during quarterly Baseline Monitoring indicate that Wēkiu bug populations have apparently grown since 1998 (Pacific Analytics, LLC 2002a - 2003b).

The Wēkiu bug range may also be expanding. 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).

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).



Source: Pacific Analytics, LLC 2004

FIGURE 3-3. WĒKIU BUG HABITAT AND ASTRONOMY-RELATED FACILITIES

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 zone. Weather conditions are similar to those found on the summit. Under these harsh conditions, only hardy lichens, mosses, and scattered grasses, shrubs, and ferns can survive (Cuddihy 1989).

Twenty-six species of lichens have been found below the summit in the *Area Below the Summit Area Cinder Cones*. Apparently all are indigenous to Hawaiʻi, but about half are not unique to Hawaiʻi, occurring naturally in other areas of the world (Smith and others 1982; Char 1999). Lichens reach their highest density and greatest diversity on the north and west facing rocks sheltered from long periods of direct exposure to the sun. The most abundant lichen, *Lecanora muralis*, is distributed throughout the *Area Below the Summit Area Cinder Cones*. *Candelariella vitellina* and *Lecidea skottsbergii* occur less frequently, and are found on small rocks and cobbles in cinder and colluvial material (Char 1999). Three special interest areas of high lichen concentrations occur along the northwest four-wheel drive road (Smith and others 1982). The proposed Outrigger Telescopes site is not located within or adjacent to any of these sensitive areas.

Twelve species of mosses have been collected within the *Area Below the Summit Area Cinder Cones* (Smith and others 1982; Char 1999). These mosses occur in shaded caves and crevices, and are usually associated with areas moistened by melting snow. Mosses have not been observed on the loose cinder of summit cones (Char 1999). The most abundant mosses in the *Area Below the Summit Area Cinder Cones* are species of the genus *Grimmia*. These silvery-gray species grow in semi-exposed snow run-off channels at the base of rocks. The bright green *Pohlia cruda* is the second most abundant moss. It occurs in deeply shaded and well-protected sites hidden from direct sunlight (Bartram 1933; Char 1999). None have been found above approximately 4,084 m (13,400 ft) (Smith and others 1982).

Only six species of vascular plants grow in the lava plateau in the *Area Below the Summit Area Cinder Cones* extending from an elevation of about 4,084 m (13,400 ft) to near 3,960 m (13,000 ft) (Char 1999). Two are the common, cosmopolitan, introduced weeds, gosmore (*Hypochoeris radicata*) and dandelion (*Taraxacum officinale*). Neither are abundant in this habitat. Two native grasses occur in the *Area Below the Summit Area Cinder Cones*, *Agrostis sandwicensis* and *pili uka* (*Trisetum glomeratum*). They are abundant at lower elevations, but are found only infrequently above 3,200 m (10,500 ft). None have been recorded above 4,084 m (13,400 ft) (Smith and others 1982).

Two ferns also are found in the *Area Below the Summit Area Cinder Cones*. *ʻIwaʻiwa* (*Asplenium adiantum-nigrum*) is the more abundant of the two indigenous species, and grows on cinder plains, lava flows, and in dry forests as low as 610 m (2,000 ft) (Valier 1995). *Cystoperis douglasii* grows in open, exposed areas, typically on weathered rocks exposed to wind (Char 1999). This delicate fern is very rare, and is considered a species of concern by the U.S. Fish and Wildlife Service (USFWS) (1999) but is not a candidate species for listing (USFWS 2002). It does not occur above 4,084 m (13,400 ft) (Smith and others 1982).

The endangered Hawaiian dark-rumped petrel, *ʻuaʻu* (*Pterodroma phaeopygia sandwichensis*), formerly nested on Mauna Kea (Day and others 2003). This Federally listed pelagic seabird once nested in the mountains of all the main Hawaiʻi islands, and reportedly was abundant in the saddle area between Mauna Loa and Mauna Kea. Recent studies have found a few *ʻuaʻu* in Kilauea crater, and colonies are suspected along the Mauna Loa summit trail, and on Mauna Kea above 3,002 m (9,850 ft) near Puʻu 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, most 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 *ma'ohi'ohi* (*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 Hawai‘i. 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 Hawai‘i, 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, *‘ōpe‘ape‘a* (*Lasiurus cinereus*) is the only native land mammal living in Hawai‘i today. This federally listed bat roosts in trees, and feeds on a broad range of insects. *‘Ōpe‘ape‘a* 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 Hawai‘i (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 *‘ōhi‘a* forests on Mauna Loa occur only in dry forests (Gagne 1979). More than 3000 species of invertebrates have been introduced into Hawai‘i, 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 Hawai‘i (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 official state insect of Hawai‘i, can often be spotted flying over the canopy, and showy koa bugs (*Coleotichus blackburniae*) feed on seeds of the *‘a‘ali‘i* (*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 and Water Quality

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, Pu‘u Hau‘oki is nominally at the upper end of a drainage basin, which ultimately empties into Ku‘upaha‘a 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 Pu‘u Hau‘oki, it does not appear that any surface runoff from the W.M. Keck Observatory facility moves down the north side of the *pu‘u.*

On the south side, Pu‘u Hau‘oki 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 Pu‘u Hau‘oki 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 Pu‘u Hau‘oki.

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 Pu‘u 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 Pu‘u Hau‘oki. 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 3-2).
- 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

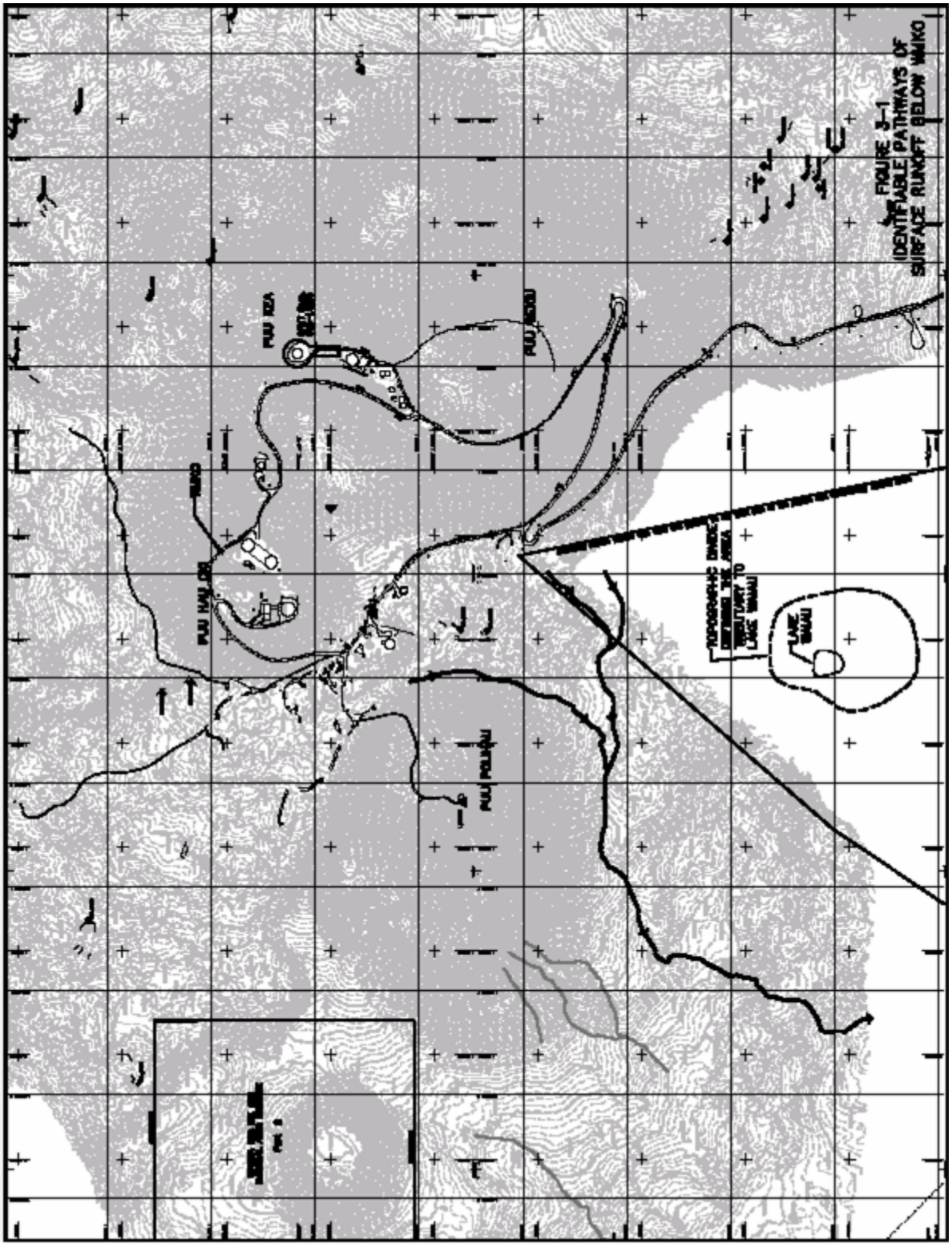


FIGURE 3-5. SURFACE RUNOFF PATHWAYS

TABLE 3-2. 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

that the lake's source of water is limited to precipitation on its 14.2-ha (35-ac) watershed, that seepage loss 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 3-3. Data of two other samples taken in January 2003 are listed in Table 3-4. 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 3-5). 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 3-5).

Laboratory analyses of December 2002 samples from the two upper Hopukani Springs are presented in Table 3-4. As with Lake Waiau water, dissolved constituent levels are very low.

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

Constituent	Units	Month of Sampling					
		August	May	June	July	August	September
		1976	1977	1977	1977	1977	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 3-4. 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 3-4. 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 3-5. 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.

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 3-6. None of these wells are 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

TABLE 3-6. 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).

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 (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 3-6, are: 460 m (1,510 ft) (20.3 km (12.6 mi)) to the west at Waikiʻi (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 Hawaiʻi, 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 Hawaiʻi (Hawaiʻi Administrative Rules 11-62). The Hawaiʻi 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 Hawai‘i 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 3-7 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

TABLE 3-7. 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

from any receptacle that might lead to the septic system (CARA 2004c).

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).

Instrument Cooling. 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.

Lubrication of Ball Bearings. 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).

Laser Dye. 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 at Lawrence Livermore (LLNL - California) and shipped to Keck for additional mixing with ethyl alcohol for use in the lasing process. The R2 perchlorate product (not yet mixed with ethyl alcohol) 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 is then combined with 100 percent ethyl alcohol in a 50:50 mixture 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 3-8 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

TABLE 3-8. 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.

reporting under Section 304 of EPCRA. CERCLA hazardous substances, and their reportable quantities, are listed in Title 40, 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 Hawaii. 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 (Pu'u Wēkiu, Pu'u Kea, Pu'u Hau'oki, and Pu'u 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 Pu‘u 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 Pu‘u 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 Pu‘u Kea, north of Pu‘u Wēkiu are also covered by these coarse-grained, loose spatter deposits.

Pu‘u Hau‘oki 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 Pu‘u Wēkiu and Pu‘u 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 Pu‘u 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).

This apparent difference in the texture of the deposits underlying Pu‘u Hau‘oki and the higher summit cones to the southeast (Pu‘u Wēkiu and Pu‘u Kea) may have significant impact on the distribution of native arthropods on these cones. It has been noted that "Wēkiu bugs appear to prefer habitat made of loose cinder 1 cm (0.5 in) in size or larger". In past studies (Howarth and Stone 1982; Howarth and others 1999), the highest concentration of Wēkiu bugs were collected in habitat consisting of loose accumulations of 1 cm (0.5 in) size or larger cinders (Section 4.1.6), and thus may be that that the Pu‘u Hau‘oki cones were never as suitable a habitat for Wēkiu bugs as are the loose cinders of the higher cones to the southeast.

Because of the potential biological significance of tephra size differences, an attempt was made to quantify the grain size differences between Pu‘u Wēkiu, Pu‘u Haukea and the Pu‘u Hau‘oki 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

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.

variability within each pu‘u and that overall differences between Pu‘u Wēkiu/Kea and Pu‘u Hau‘oki 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 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 4.1.6) 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 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

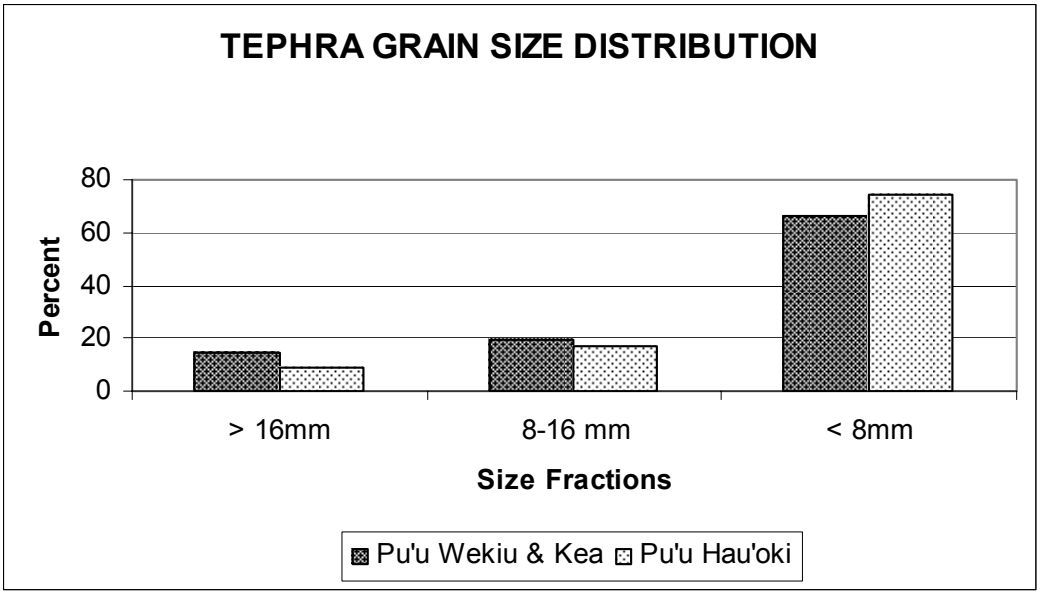


FIGURE 3-8. DISTRIBUTION OF AVERAGE TEPHRA GRAIN SIZE IN SAMPLES FROM THE FLANKS OF PU'U WĒKIU, PU'U KEA, AND PU'U HAU'OKI

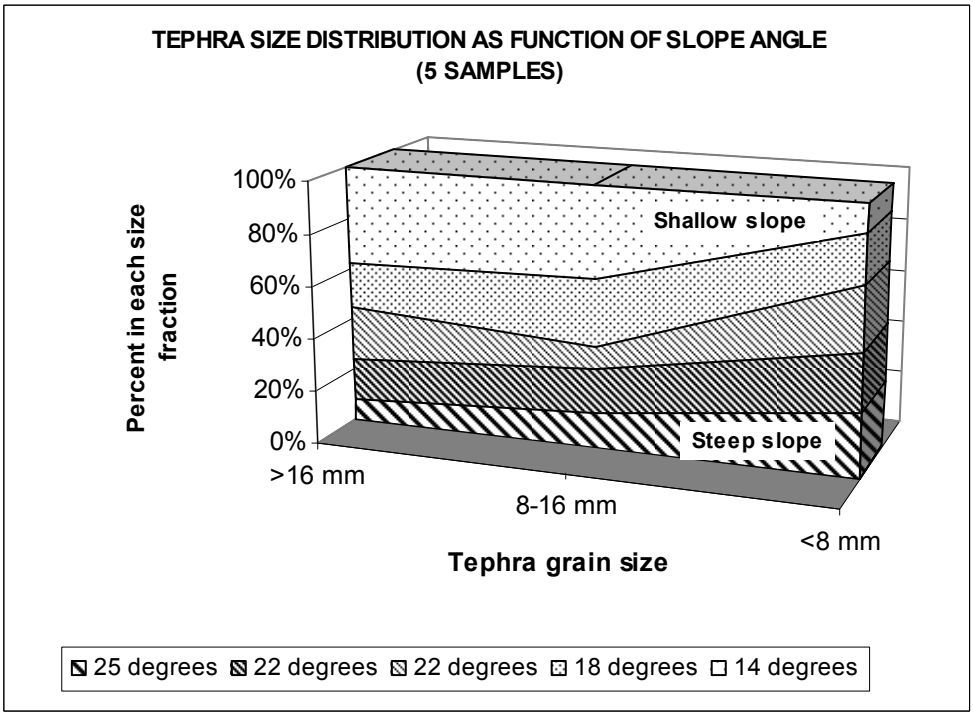


FIGURE 3-9. EFFECT OF SLOPE ANGLE ON TEPHRA GRAIN SIZE DISTRIBUTION

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

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

Earthquake Categories. Earthquakes on the island of Hawai‘i 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. This 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

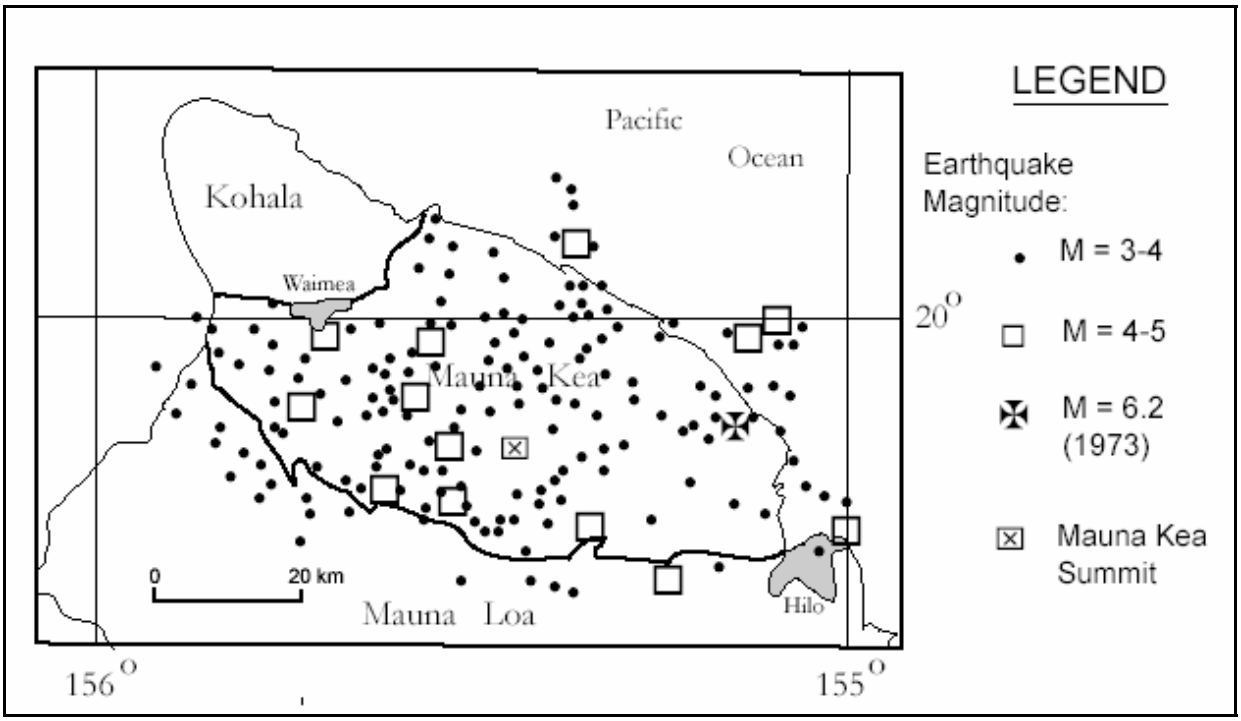


FIGURE 3-10. EARTHQUAKE MAGNITUDES

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 6 have occurred on Hawaii 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 Pu‘u 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 3-9 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 4-19 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

TABLE 3-9. 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

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 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 54 percent of the capacity at the substation (CARA 2004j). Table 4-19 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 Hawai‘i 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 Hawai‘i 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 (CO2) 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 Hawai‘i and in particular on the island of Hawai‘i 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 Hawai‘i (e.g., urban lighting) that could affect astronomical observations.

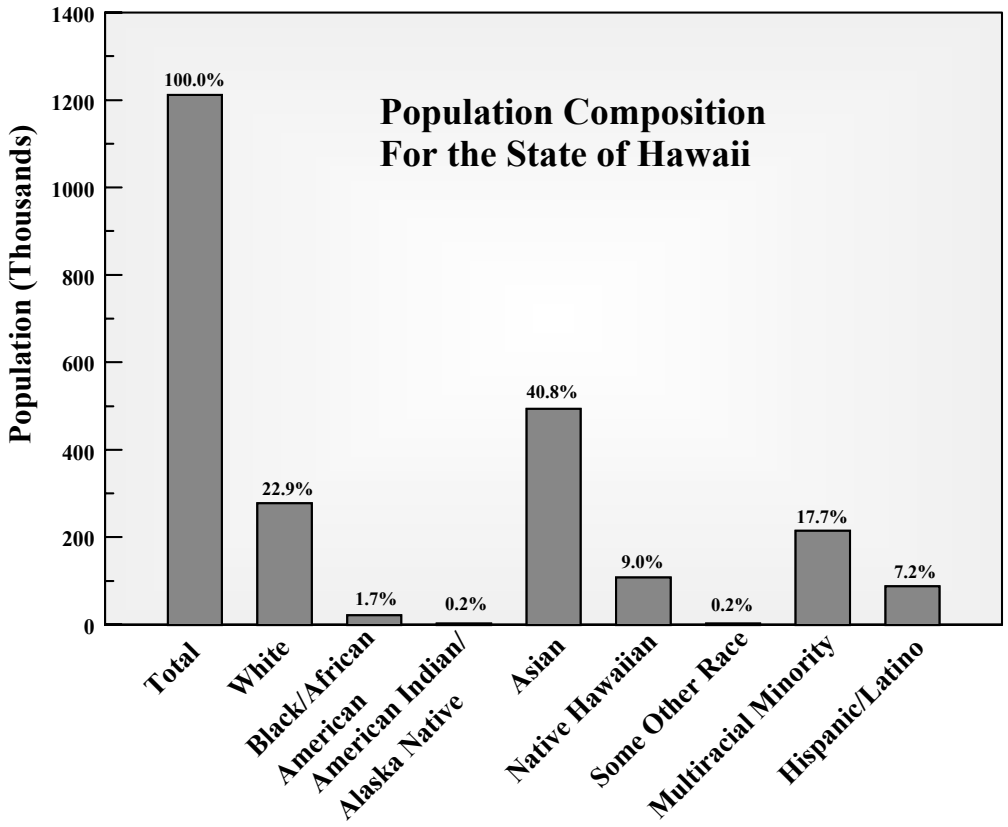
Astronomers and scientific organizations throughout the world have responded by investing in observatories on the summit. In addition, UH has developed an undergraduate program in astronomy at Hilo and a graduate program at Manoa with the ability to create scientific instruments for astronomical observations.

Demographics. Figure 3-11 shows the resident population for the State of Hawai‘i 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 Hawai‘i. 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 Hawai‘i.

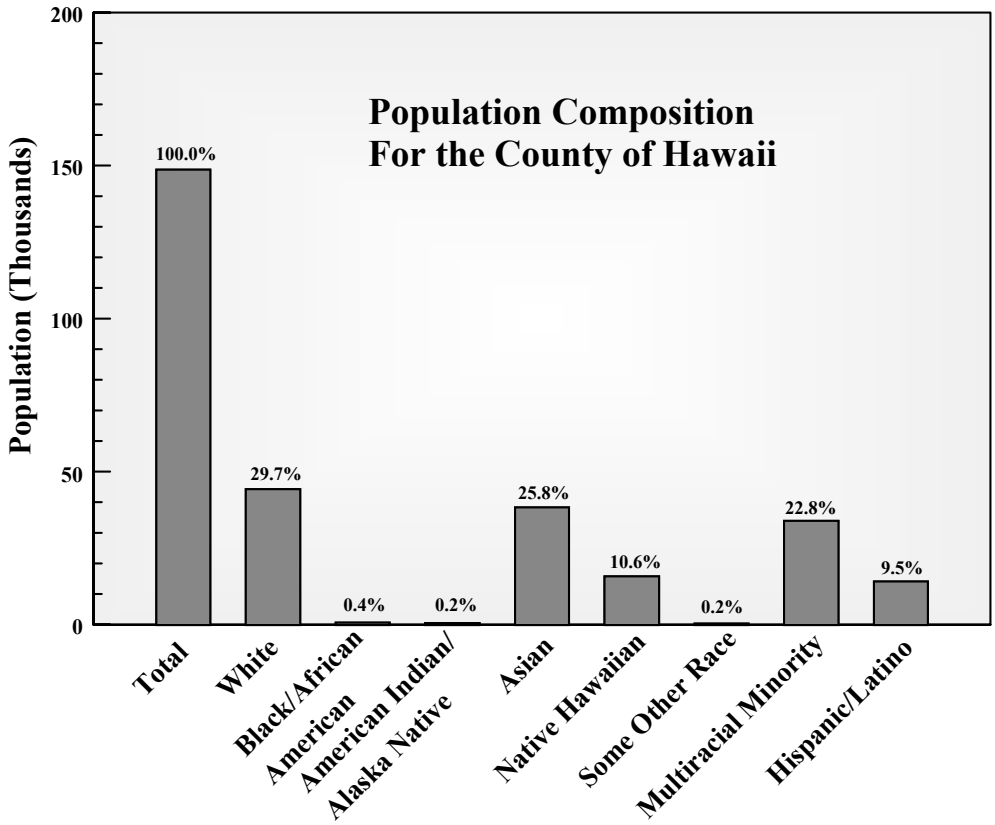
The area surrounding MKSR is relatively unpopulated. Figure 3-13 shows the population residing within 50 km (31 mi) of the reserve. Moving outward from the reserve, resident populations show relatively large increases as one approaches population centers in Waimea and Hilo.

As shown in Table 3-10, population centers in Hilo and Waimea both experienced an overall increase in population during the decade between 1990 and 2000. During that



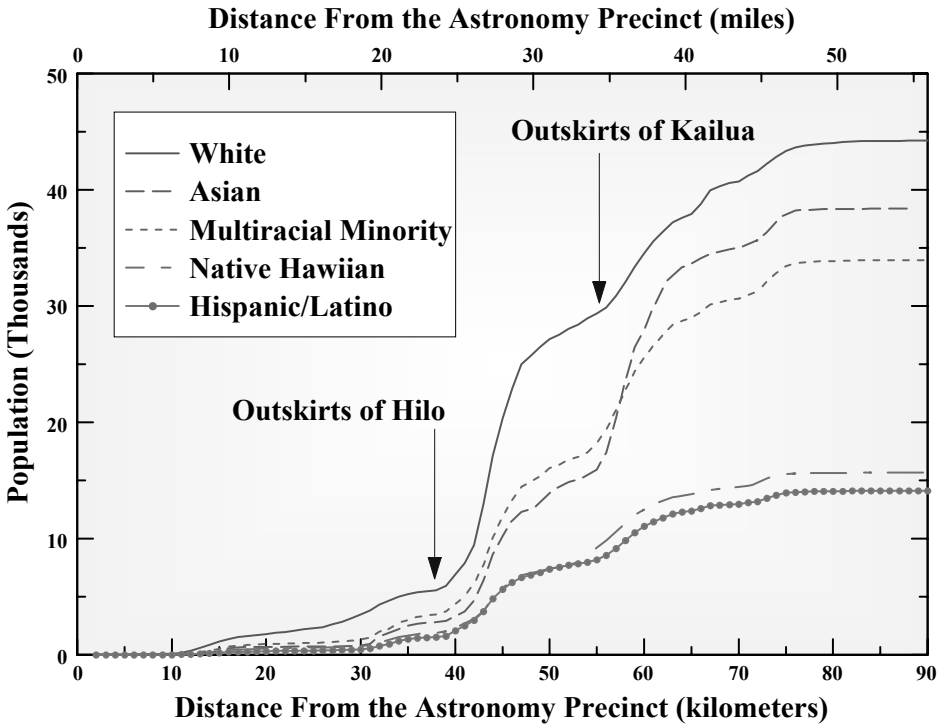
Source: USDOC 2000

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



Source: USDOC 2000

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



Source: USDOC 2000

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

TABLE 3-10. 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

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 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 3-9).

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 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 and Hilo (see Table 3-11). 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.

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

TABLE 3-11. 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	1.3	8	1970
Canada-France-Hawai‘i 3.6-m (Optical/Infrared)	30	6.2	50	1979
NASA IRTF 3.0-m (Infrared)	10	3.2	16	1979
United Kingdom 3.8-m (Infrared)	5	3.0	31	1979
James Clerk Maxwell 15-m Submillimeter	32	5.0	39	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	77	1999
Mauna Kea Observatories Support Services	Not applicable	2.4[b]	28	N/A
Total	611	61.6	483	—

Source: adopted from UH IfA 2002a

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

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

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 3-11 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 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 Hawai‘i 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 3-12.

Air Quality Monitoring. The DOH has been monitoring ambient air quality in the State of Hawai‘i since 1957. Before 1971, there was only one air monitoring station located on O‘ahu. Today the air-monitoring network has expanded to include twelve national, State, and local air quality monitoring stations on O‘ahu, Kaua‘i and Maui. A number of non-DOH air quality monitoring programs have been undertaken on the island of Hawai‘i, 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:

Ozone. 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.

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.

TABLE 3-12. 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.

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 Pu‘u Hau‘oki is presently occupied by the two 10-m (33-ft) Keck Telescopes and associated domes and support structures. 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, Honoka‘a, 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 ISLAND 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 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,

FIGURE 3-14. EXISTING VIEW

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 of 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 UNESCO 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 ground water reserves.

3.2.5 Solid Waste and Hazardous Materials Management

3.2.5.1 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 HCL; Concentration of 4 percent.
- 1 l (0.26 gal) of Cu So4; Concentration of 4 percent.
- 2 l (0.53 gal) of K OH; Concentration of 10 percent.
- 1 l (0.26 gal) of Isopropyl alcohol.
- 200 l (53 gal) of HÒ.

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 Observatorio Del Roque de Los Muchachos, 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 8000volt/400amp 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 Gran Telescopio de Canarias 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 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.

4 ENVIRONMENTAL IMPACTS

This Chapter presents information on the potential environmental impacts of the Proposed Action and reasonable alternatives. The environmental impacts are examined for (1) on-site construction and installation, and (2) operation of the Outrigger Telescopes. In addition, this chapter addresses the cumulative impacts of past, present, and reasonably foreseeable future activities when combined with the impacts of the Outrigger Telescopes Project.

4.1 POTENTIAL ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

The National Aeronautics and Space Administration's (NASA) Proposed Action is to fund the on-site construction, installation, and operation of four, and possibly up to six, Outrigger Telescopes at the W.M. Keck Observatory site. It is anticipated that the on-site construction and installation of four of the six Outrigger Telescopes, along with on-site construction of the underground structures for Outrigger Telescopes 5 and 6, would begin in 2005 (upon issuance of all State and local permits and approvals), with start of operations anticipated no earlier than 2007. If funding becomes available, NASA intends to complete the installation and operation of Outrigger Telescopes 5 and 6, with on-site construction and installation likely to begin no earlier than 2007.

This section presents information on the potential environmental impacts of the Proposed Action and the No-Action Alternative, discussed in Chapter 2. The environmental impacts are examined for (1) on-site construction and installation, and (2) operation of the Outrigger Telescopes.

Each environmental resource section addresses the region of influence (ROI), that is, is the physical area that bounds the environmental, economic, or cultural feature of interest for the purpose of this analysis. Each subsection defines the ROI for that area, and then discusses the impacts directly related to it. Section 4.1 addresses the impacts directly related to the on-site construction, installation, and operation of the Outrigger Telescopes. Section 4.2 addresses the impacts of the Outrigger Telescopes Project when combined with past, present, and reasonably foreseeable activities.

4.1.1 Cultural Resources

4.1.1.1 ROI for Cultural Resources

Cultural resources include historic properties, cultural values, and traditional cultural practices. The ROI for cultural resources includes the summit and slopes above the Mauna Kea Saddle, from about 1,830 meters (m) (6,000 feet (ft)) above sea level (asl) to the highest summit cone, an area of special importance to Native Hawaiians. This assessment focuses primarily on the area that the Outrigger Telescopes Project would directly impact, the land around the W.M. Keck Observatory where the telescopes would be built and the construction staging areas at the summit south of the W.M. Keck Observatory site and at Hale Pōhaku.

4.1.1.2 Impacts of the Outrigger Telescopes Project on Cultural Resources

Impact Assessment Process. This section identifies the impact assessment process for archaeological and traditional cultural resources. This cultural impact evaluation

includes information on the practices and beliefs of Native Hawaiians. Information has been obtained through background research, the Environmental Impact Statement (EIS) scoping process and scoping meetings held in January 2004, town hall meetings held for NASA's earlier Environmental Assessment (EA), and Section 106 consultation meetings, supplemented with existing ethnographic interviews and oral histories (see Section 3.1.2.3)

On-Site Construction and Installation Impacts. Potential impacts of construction and installation of the Outrigger Telescopes on archaeological sites, traditional cultural properties, and traditional cultural practices are addressed for the summit installation site and summit staging areas, and Hale Pōhaku staging area.

Historic Properties. In a letter to the University of Hawaii (UH) dated May 3, 1999, the State Historic Preservation Division (SHPD) stated for the first time that, "…we have come to believe that the cluster of cinder cones which merge and collectively form the summit of Mauna Kea is an historic property and that this single landscape feature probably bore the name Kūkahauʻula. This single landscape feature is now called Puʻu Hauʻoki, Puʻu Kea, and Puʻu Wēkiu. Several lines of evidence lead to the conclusion that the cluster of cones is an historic property …Given our conclusion that Puʻu Hauʻoki is part of an historic property, we believe the proposed construction of four to six outrigger telescopes on the site of the W.M. Keck Observatory will have an "adverse effect" both on this historic property and on the summit region that we believe is eligible for inclusion in the National Register as an historic district. …We believe, however, that these "adverse effects" can be mitigated if appropriate measures are adopted…" (see Appendix B of this EIS) (SHPD 1999).

SHPD concludes that the summit region is eligible for inclusion on the National Register of Historic Places (NRHP) 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; DLNR 2002). Puʻu Hauʻoki is a culturally significant landscape feature within the district. SHPD recommended that the boundaries of the district 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).

In response to the May 3, 1999, letter, NASA contacted and solicited comments from Native Hawaiian organizations and other interested parties. NASA used input from the SHPD and the State of Hawaiʻi Office of Hawaiian Affairs (OHA) to help identify Native Hawaiian organizations that might be interested in providing their input on the proposed project. NASA participated in several meetings hosted by Native Hawaiian organizations, receiving comments at those forums not only from the host organizations, but also from representatives of other Native Hawaiian organizations and individuals.

On the basis of information in the SHPD's letter and comments from Native Hawaiian organizations and individuals, NASA concurred with the SHPD that the cluster of cinder cones of which Puʻu Hauʻoki is a component should be considered an historic property and that the summit region of Mauna Kea should be considered an historic district eligible for listing on the NRHP.

NASA concluded that the proposed Outrigger Telescopes Project would have an adverse effect on the cluster of three cinder cones and summit region that are eligible for listing in the NRHP.

NHPA Section 106 Consultation Process. Pursuant to regulations under the National Historic Preservation Act (NHPA), NASA proceeded with the Section 106 process. Initially, NASA formally invited four Native Hawaiian organizations to act as Consulting Parties:

- Hui Mālama I Nā Kūpuna o Hawai‘i Nei (this organization is referenced in the NHPA)
- Hawai‘i Island Burial Council
- OHA (also referenced in the NHPA)
- The Royal Order of Kamehameha I.

The Advisory Council on Historic Preservation (ACHP) also agreed, at NASA's invitation, to participate in the Section 106 process. Two more Native Hawaiian organizations later requested and were given Consulting Party status: Ahahui Ku Mauna and Mauna Kea Anaina Hou.

NASA has also consulted with and invited the Office of Mauna Kea Management (OMKM), the Mauna Kea Management Board, and Kahu Kū Mauna to participate in the development of mitigation measures under the Section 106 process.

A formal Section 106 meeting was held on February 1, 2001, in Hilo. NASA held a second formal Section 106 meeting in Hilo on January 16 and 17, 2002. Table 4-1 lists these consultations and other formal meetings that have taken place in connection with the Outrigger Telescopes Project since 1999.

NASA also held informal meetings in Hilo, Kona, and Waimea that were attended by individuals and organizations who stated their position, asked questions, expressed concerns, and received additional information about the Outrigger Telescopes Project. Many of the issues raised in these meetings concerned historic/cultural resources.

On the basis of these formal and informal meetings, and as part of the Section 106 consultation process, NASA prepared proposals for on-site and off-site mitigation of potential impacts to cultural resources for consideration by the SHPD, ACHP, and the other Consulting Parties.

In preparing and developing cultural resource mitigation measures pursuant to the Section 106 process, NASA took into account a wide variety of impacts that may arise during on-site construction, installation, and operation of the Outrigger Telescopes Project. Such impacts included, but were not necessarily limited to, those on biota, the visual landscape, soils and groundwater arising from solid waste and accidental release of hazardous substances, and noise levels. On-site mitigation measures proposed included, but were not limited to, stabilizing the cinder cone slopes, preventing accidental dispersal of debris during and after on-site construction, disposing of excavated material, and reducing noise during on-site construction and operation of the Outrigger Telescopes. Monitoring and other measures that would prevent or minimize deterioration of the visual integrity (i.e., shape and contour) of the cinder cone and its crater were also included. One such measure is the commitment to provide the Consulting Parties with the opportunity to review and comment on the grading and site development drawings and the construction Best Management Practices plan for the proposed project.

TABLE 4-1. OUTRIGGER TELESCOPES PROJECT FORMAL MEETINGS WITH INTERESTED PARTIES

Date	Organization	Location	Type
10/01/99	Hawai‘i Island Burial Council	Kailua-Kona, Hawai‘i	Scheduled meeting
03/28/00	Office of Hawaiian Affairs (OHA) staff	Honolulu, Hawai‘i	Special meeting
03/28/00	OHA Board of Trustees	Honolulu, Hawai‘i	Scheduled meeting
03/28/00	Department of Land and Natural Resources (DLNR) and State Historic Preservation Division (SHPD)	Honolulu, Hawai‘i	Special meeting
03/28/00	Royal Order of Kamehameha I	Hilo, Hawai‘i	Special meeting
03/29/00	Hawaiian Civic Clubs - Kona Chapter	Kailua-Kona, Hawai‘i	Scheduled meeting
03/30/00	Hawai‘i Island Burial Council	Hilo, Hawai‘i	Scheduled meeting
01/30/01	Delegation meets with U.S. Fish and Wildlife Service (USFWS)	Honolulu, Hawai‘i	Special meeting
01/31/01	Delegation meets DLNR and SHPD	Honolulu, Hawai‘i	Special meeting
01/31/01	Delegation meets with Hawai‘i Office of Environmental Quality Control (OEQC)	Honolulu, Hawai‘i	Special meeting
02/01/01	Advisory Council on Historic Preservation (ACHP), Department of Hawaiian Home Lands, Hawai‘i Island Burial Council, OHA, SHPD, W.M. Keck Observatory, Kumu Pono Associates, (Royal Order of Kamehameha I appeared at the start of the meeting)	Hawai‘i Naniloa Hotel, Hilo, Hawai‘i	Section 106 Meeting
02/05/01	Office of Mauna Kea Management (OMKM)	Hilo, Hawai‘i	Special meeting
02/05/01	W.M. Keck Observatory, Public	Hilo, Hawai‘i	Open House Meetings
02/06/01	Mauna Kea Management Board (MKMB)	Hilo, Hawai‘i	Scheduled meeting
02/07/01	W.M. Keck Observatory, Public	Kailua-Kona, Hawai‘i	Open House Meetings
09/27/01	SHPD	Honolulu, Hawai‘i	Special meeting
10/01/01	W.M. Keck Observatory, Public	Kona Outdoor Circle, Kailua-Kona, Hawai‘i	Town Hall Meeting*

TABLE 4-1. OUTRIGGER TELESCOPES PROJECT FORMAL MEETINGS WITH INTERESTED PARTIES (CONTINUED)

Date	Organization	Location	Type
10/02/01	W.M. Keck Observatory, Public	Waimea Community Center, Waimea, Hawai‘i	Town Hall Meeting*
10/03/01	W.M. Keck Observatory, Public	University of Hawai‘i at Hilo, Hilo, Hawai‘i	Town Hall Meeting*
10/04/01	W.M. Keck Observatory, Public	University of Hawai‘i at Hilo, Hilo, Hawai‘i	Town Hall Meeting*
01/16/02	All Consulting Parties	Hilo, Hawai‘i	Section 106 Meeting
01/17/02	All Consulting Parties	Hilo, Hawai‘i	Section 106 Meeting

* The following organizations either appeared or sent a representative to at least one of the Town Hall Meetings.

Ahahui Ku Mauna
Association of Hawaiian Civic Clubs
Conservation Council for Hawai‘i
Department of Land and Natural Resources
Hawai‘i Island Burial Council
Kahu Kū Mauna members
Ka Pae Aina Hawai‘i
Mauna Kea Anaina Hou
Office of Hawaiian Affairs
Office of Mauna Kea Management member
Royal Order of Kamehameha I

Mitigation measures have been specified in a Memorandum of Agreement (MOA) (see Appendix B of this EIS) and are restated in each environmental resource section where applicable. Signatories to the MOA included NASA, the Advisory Council on Historic Preservation, the Hawai‘i State Historic Preservation Officer, UH,the California Association for Astronomy (CARA), the California Institute for Technology (Caltech), and Ahahui Ku Mauna (with caveat). Consulting Parties who did not sign the MOA included the Hawaii Island Burial Council, Hui Mālama I Nā Kūpuna o Hawai‘i Nei, Mauna Kea Anaina Hou, the Office of Hawaiian Affairs, and the The Royal Order of Kamehameha I.

CARA will ensure that any of the MOA provisions relating to on-site construction and installation of the Outrigger Telescopes will be included as provisions in any contracts for on-site construction and installation.

Archaeological Resources. Most of the archaeological resources identified within the Mauna Kea Science Reserve (MKSR) fall into three categories: shrines, adze quarrying and manufacturing localities, and burial sites, as described in Section 3.1.2. No archaeological sites have been identified on Pu‘u Hau‘oki.Nonetheless, no area at or near the summit is assumed to be devoid of archaeological resources. This is true even for the proposed site of the Outrigger Telescopes Project, land that was previously disturbed and leveled for construction of the Keck Telescopes. For example, the slope edges could be effectively undisturbed at a shallow depth below the surface and could contain archaeological deposits.

NASA has, therefore, proposed mitigation measures that assume that archaeological resources could be found anywhere on the site. A Draft Burial Treatment Plan has been prepared that stipulates procedures to be followed if burial remains are found during construction. This draft has been submitted for review to the Hawai‘i Island Burial Council and is provided in Appendix C of this EIS.

If an archaeological resource is discovered during excavation for the Outrigger Telescopes, the mitigation measures as described in the MOA will prevent or reduce adverse effects.

Summit Staging and StockpileAreas. An archaeological survey has been conducted of the summit construction staging and stockpile areas. There are no known historic properties within the area of the Proposed Action. The nearest documented shrine is located more than 250 m (820 ft) from these areas. The summit staging and stockpile areas lie outside the boundary of the Kūkahau‘ula historic property.

Hale Pōhaku. An archaeological survey of the construction staging area at Hale Pōhaku has been conducted. There are no known historic properties within the area of the Proposed Action. However, there are archaeological sites and historical architectural resources in the vicinity of the staging area. NASA is aware two shrines located to the south and west at Hale Pōhaku, outside the UH-leased area, about 30.5 m (100 ft) and 48.8 m (160 ft) away from the staging area boundary, respectively. The shrine closest to the proposed use is located on an *aa* wall, which is separated from the staging area by a drainage swale. It would be extremely unlikely for staging area activities to adversely affect either of these shrines. NASA is also aware that archaeological deposits (e.g., lithic artifact clusters) are present throughout the area around Hale Pōhaku. In addition, two stone cabins built in 1936 and 1939 by the Civilian Conservation Corps at Hale Pōhaku under L.W. Bryan’s direction are historic

architectural resources that may be eligible for the NRHP.

Traditional Cultural Properties. The SHPD has designated Kūkahau‘ula, the area of the three summit cones of Mauna Kea, to be a traditional cultural property. Some Native Hawaiians have identified the larger area of Mauna Kea, from the 1,829-m (6,000-ft) elevation to the summit, as a sacred landscape valued for its spiritual significance (Maly 1998; Maly 1999).

The Outrigger Telescopes would be built within the boundaries of the Kūkahau‘ula traditional cultural property. The placement of the telescopes on Pu‘u Hau‘oki would modify this traditional place, which forms a portion of the landscape regarded as especially sacred by the Native Hawaiian community. Because the Outrigger Telescopes would be placed on ground that has already been disturbed and would be located next to the much larger Keck I and II structures, their impact would be a small increment to the impact that has already occurred.

Traditional Cultural Resources. Traditional cultural resources can be intangible (e.g., traditional gathering practices, ritual observances, burial rites). They are not directly under the purview of the NHPA, but they are included in Section 106 evaluation procedures to the extent that they relate to the significance of specific traditional cultural properties. The American Indian Religious Freedom Act of 1978 protects and preserves the rights of indigenous groups, including Native Hawaiians, to practice their traditional religion, access sites, and conduct ceremonies and traditional rites. Native Hawaiian groups have identified potential impacts to their traditional cultural practices that would result from the on-site construction, installation, and operation of the Outrigger Telescopes Project.

Studies addressing Mauna Kea have identified the following Native Hawaiian concerns regarding the summit area:

- Maintaining the integrity of the spiritual and sacred quality of the summit landscape
- Lack of respect on the part of the astronomy program for Native Hawaiian cultural practices, features, and beliefs
- The effect of increased public use on the summit landscape.

Most Native Hawaiians consulted for Maly’s (1999) study expressed the desire that no further development of astronomy facilities occur on Mauna Kea. Potential visual and physical impacts on the *pu‘u* (summit cones) were identified as important concerns.

Contemporary Cultural Practices. Contemporary Hawaiian cultural practices identified for the summit area of Mauna Kea include the release of cremated remains and possibly the burial of such remains; prayer and ritual observances, including the construction of new altars; and use of the mountain as a repository of *piko* (umbilical cords) (Maly 1999). Contemporary cultural practices are generally a continuation of traditional practices (with modifications), and impacts on them are similar to impacts identified for traditional cultural practices and values. Concerns include the importance of maintaining access to the summit area for spiritual purposes and maintaining the integrity of the spiritual and sacred quality of the summit landscape.

Native Hawaiian groups have expressed concerns to ACHP that the proposed facilities would limit their access to the summit area (ACHP 2000). Implementation of the Outrigger Telescopes Project would not result in any additional restrictions on

accessibility of the summit area to Native Hawaiians.

The presence of large construction equipment, materials, and telescope components at the observatory site and staging area would temporarily increase noise and dust levels and alter the viewscape. These impacts would be short term, restricted to the construction period. They will be mitigated and therefore would have no long-term impact on cultural practices.

Operations Impacts. Operation of the telescopes would not affect archaeological or historic architectural resources, but would have an effect on traditional cultural properties and practices in the summit region. Some of the concerns of Native Hawaiian groups, discussed above in relation to construction and installation impacts, are also relevant during operation of the telescopes. The primary impact would be the continued visual presence of the telescope structures within the Kūkahau‘ula traditional cultural property. The visual presence of observatories in general impacts the cultural bond that many Native Hawaiians associate with this historic property. Viewscapes at some locations in the summit region, already impacted by the presence of observatories, would be further altered by the presence of the Outrigger Telescopes. However, because the Outrigger Telescopes would be located next to the much larger Keck I and II structures, their impact would be a small increment to the impact that has already occurred. The operation of the telescopes would not in any way restrict access of Native Hawaiians to the summit region.

Some Native Hawaiians have expressed concern over the possibility of a potential impact to the spiritual and sacred quality of the summit landscape from the disposal of wastewater in sacred areas. The Outrigger Telescopes would use the disposal system now in place for the Keck Telescopes, in which wastewater reaches groundwater beneath the summit and travels to the southwest flank of the mountain without any physical effect on the summit plateau or Lake Waiau (see Section 4.1.3.2).

The project’s presence within Kūkahau‘ula would indirectly affect the other two traditional cultural properties on the summit plateau, Pu‘u Līlīnoe and Waiau, by affecting their view planes. During cultural practices at locations with clear views of the Keck Observatory site, views of the summit area would be further altered to a small extent by the Outrigger Telescopes. This could diminish these practices. The view planes from some areas below the summit would also be altered, but the Outrigger Telescopes would not be visible from many locations below the summit or from the summit itself.

Operation of the Outrigger Telescopes would have no effect on archaeological resources, but would have a small adverse effect on traditional cultural practices associated with the mountain.

On-Site Mitigation Measures. Mitigation measures for cultural impacts associated with the Outrigger Telescopes Project are those set forth in the MOA, including cultural and archaeological monitoring of the construction area, education of workers on the site, mandatory adherence to the construction Best Management Practices Plan, adhering to the Burial Treatment Plan developed for this project, and general historic property protection measures (see Appendix B of this EIS).

Detailed mitigation measures address the need to protect cultural resources in the proposed on-site construction project area, the construction staging area at the summit, at Hale Pōhaku, and at the construction

stockpiling area. On-site mitigation measures include, but are not limited to, those described below.

Archaeological Monitoring. CARA will hire a qualified archaeologist, in consultation with the SHPD and OMKM, to monitor all excavation activities; keep a log and map notes of every visit; and to ensure that all project excavation activities follow SHPD Hawaii Administrative Rules for Archaeological Monitoring Studies and Reports. The archaeologist will have the authority to halt work in the vicinity of an inadvertent discovery of human remains or archaeological properties.

Cultural Monitoring. In consultation with NASA and the Consulting Parties, CARA will develop criteria for and select an individual to be the project's Cultural Monitor. This individual will be knowledgeable about Mauna Kea's cultural landscape and the traditions, practices, beliefs, and customs associated with Mauna Kea. The Cultural Monitor will provide cultural orientation to individuals who are associated with the on-site construction and installation of the Outrigger Telescopes. The Cultural Monitor will have unrestricted access for monitoring activities during excavation, other on-site construction, and telescope installation. The Cultural Monitor will keep a log and map notes of every visit. A monitoring plan will be prepared that stipulates the responsibilities of the Cultural Monitor and the procedures to be followed if on-site supervisory or construction personnel act in culturally insensitive ways. The Consulting Parties will be given an opportunity to review the monitoring plan before finalization.

Education. Prior to on-site construction, the contractor(s), supervisors, and all construction workers involved with the Outrigger Telescopes Project will be required to watch a videotape reviewing the historic and sacred qualities of Mauna Kea. They will also be advised that CARA could demand their removal from the project if they fail to comply with the commitments made by NASA and other project participants.

Cultural Interpretation. During on-site construction and installation of the Outrigger Telescopes, OMKM, in consultation with the Hawaii State Historic Preservation Officer (SHPO), will develop and provide interpretive materials on the cultural significance of Mauna Kea. The Consulting Parties will be given an opportunity to review and comment on these materials during their development.

Off-Site Mitigation Measures. Under the terms of the MOA, and as part of its budget for the Outrigger Telescopes Project, NASA will fund an initiative that addresses preservation and protection of historic/cultural resources on Mauna Kea and the educational needs of Hawaiians. This initiative is recorded in the MOA (Appendix B of this EIS).

The mitigation measures developed for the Outrigger Telescopes Project and stipulated in the Section 106 MOA would minimize the impact of the Outrigger Telescopes Project, insuring avoidance of damage to archaeological and traditional cultural resources during construction. Archaeological monitoring and analysis will insure preservation of historic information from any cultural remains that are found, and these remains will then be properly curated. Measures that are part of the Burial Treatment Plan will insure that steps will be taken for proper and respectful retrieval, reburial, and protection of any human remains inadvertently disturbed during construction. There will be no further impact on these types of cultural resources following construction. After construction and mitigation, the presence of the Outrigger

Telescopes will have a small incremental adverse impact to Native Hawaiian cultural practices and the quality of sacredness Native Hawaiians associate with the summit. These impacts cannot be completely mitigated; however, NASA and CARA will attempt to offset this adverse impact by educational programs that will benefit Native Hawaiians.

4.1.2 Biological Resources and Threatened and Endangered Species

4.1.2.1 ROI for Biological Resources and Threatened and Endangered Species

For purposes of this evaluation, the potential impacts to biological resources as a result of implementing the Outrigger Telescopes Project would occur primarily in the four ecological zones described in Section 3.1.3. The boundaries of the ROI would be from the summit of Mauna Kea down to the elevation of the intersection of the Mauna Kea Access Road and Saddle Road.

4.1.2.2 Impacts of the Outrigger Telescopes Project on Biological Resources

On-Site Construction and Installation Impacts.

<u>*Summit Area Cinder Cones*</u>

<u>Flora</u>. As noted in Section 3.1.3, no floral species have been found on the *Summit Area Cinder Cones*. Lichens, the only botanical resource that inhabit this zone, occur in low abundance adjacent to the W.M. Keck Observatory site, and only the most common lichen species can be found there (Smith and others 1982). Construction of the Outrigger Telescopes would disturb 0.008 hectares (ha) (0.019 acres (ac)) of habitat on the sloped portion of Puʻu Hauʻoki. This represents a very small fraction of the available lichen habitat on Mauna Kea. Consequently, on-site construction and installation of four, and possibly up to six, Outrigger Telescopes would have no adverse impact to the floral component of the natural environment of the *Summit Area Cinder Cones*. There would be no significant impact on the flora of the *Summit Area Cinder Cones* as a result of the construction and installation of the Outrigger Telescopes.

<u>Fauna</u>. There are at least 11 species of indigenous Hawaiian arthropods that inhabit the *Summit Area Cinder Cones* (Howarth and others 1999). The area of the W.M. Keck Observatory site that was leveled for construction of the Keck I and Keck II Telescopes is subject to daily activities such as vehicle parking and foot traffic, and therefore harbors no substantial populations of any of the 11 Hawaiian arthropod species known to inhabit the *Summit Area Cinder Cones* (see Section 3.1.3). Almost all on-site activities would be confined to this previously leveled area.

There is concern that some construction activities could harm Wēkiu bugs that live in cinder habitats adjacent to the proposed construction site. On-site construction and installation of Outrigger Telescope 1 would occur on a gradually sloped portion of the leveled area that was previously graded and disturbed during construction of the Keck I and Keck II Telescopes (see Figure 2-6). No Wēkiu bugs were found in that leveled area during the 1997/98 sampling effort (Howarth and others 1999) (see Section 3.1.3). Wēkiu bugs do inhabit the cinder adjacent to this site. While this habitat and its porous structure are fairly stable, it is possible that disturbance can degrade it. Side-casting of unsorted materials during construction of Outrigger Telescope 1 could bury Wēkiu bug habitat and the resident

population. However, habitat protection procedures outlined in the Wēkiu Bug Mitigation Plan, such as protective barriers and educational signage, would minimize side-casting of materials into Wēkiu bug habitat, and thus minimize habitat disturbance.

On-site construction and installation of Outrigger Telescopes 2, 3, and 4, would involve activities on the previously disturbed sloped wall area of the cinder cone immediately adjacent to the leveled area of the W.M. Keck Observatory site. The sloped areas of the cinder cone wall adjacent to the W.M. Keck Observatory site received substantial side-cast material during the construction of the Keck I and Keck II Telescopes. The surface structure on these slopes has recovered to some degree, and some of these slopes were the locations of the densest populations of Wēkiu bugs measured during the 1997/98 Mauna Kea arthropod assessment (Howarth and others 1999).

On-site construction and installation of air pipes and retaining walls necessary for slope stability at Junction Box 5 (JB-5) and at Outrigger Telescope 3 would displace 0.008 ha (0.019 ac) of this previously disturbed habitat. Table 4-2 summarizes these displacements.

Specifically, at JB-5, the air pipe and retaining wall would extend into and displace about 0.002 ha (0.005 ac) of the sloped area habitat (CARA 2001g) (see Figure 2-12). At Outrigger Telescope 3 the air pipe and retaining wall would displace about 0.006 ha (0.014 ac) of the sloped outer wall area that is Wēkiu bug habitat (see Figure 2-13). Outrigger Telescope 4 would require placement of its air pipe and a retaining wall within a steeply sloped portion of previously disturbed outer cinder wall area on the northeastern side of the W.M. Keck site (see Figure 2-14). However, the 1997/98 arthropod assessment found no Wēkiu bugs in this area.

Displacement and disturbance of habitat by construction of the Outrigger Telescopes has the potential for a small to moderate impacts on local populations of Wēkiu bugs. Proposed restoration efforts would encompass an area of at least 0.024 ha (0.057 ac), resulting in a habitat restoration ratio of at least 3:1 when compared to the amount of habitat area that would be displaced by on-site construction and installation of Outrigger Telescope 3 and JB-5. If successful, the net result of habitat restoration would be an increase in the amount of Wēkiu bug habitat on Pu‘u Hau‘oki.

Except for the habitat displacement described above, almost all of the on-site construction and installation activity for Outrigger Telescopes1 through 4, and all of those activities for Outrigger Telescopes 5 and 6, would occur within the leveled area that was previously graded and disturbed during construction of the Keck I and Keck II Telescopes (see Figure 2-6). That activity will not directly disturb Wēkiu bugs, but impacts could occur as a result of some construction related activities. Construction materials, trash, and other substances that migrate onto the slopes of Pu‘u Hau‘oki would have a small impact on Wēkiu bug habitat. The Wēkiu Bug Mitigation Plan requires that construction trash containers be tightly covered and that construction materials stored at the site be covered with tarps, or anchored in place to prevent materials from being dispersed by wind.

Construction of the proposed Outrigger Telescopes would involve excavations for dome and junction box foundations, and trenching for air and light pipes. This activity has the potential for creating dust.

TABLE 4-2. LOCATION AND AREA OF WĒKIU BUG HABITAT DISTURBANCE

Location	Area of Wēkiu Bug Habitat Disturbance
Junction Box 5	0.002 ha (0.006 ac)
Outrigger Telescope 3	0.006 ha (0.014 ac)
Total	0.008 ha (0.019 ac)

Summit wind velocity usually ranges between 16 and 24 km per hour (10 and 15 miles per hour) with speeds exceeding 160 km/h (100 mph) during severe storms. Dust, ash, and cinder disturbed during excavation can be carried by wind and deposited on adjacent slopes. Excessive dust could have a substantial impact on Wēkiu bug habitat. The Wēkiu Bug Mitigation Plan provides for dust control by: applying water to excavation sites and cinder stockpiles; suspending dust-generating activities during high winds; and using environmentally friendly soil-binding stabilizers. Thus, only a small amount of dust would be generated from on-site construction activities, with only small impacts to Wēkiu bug habitat.

Hazardous substances may be required during on-site construction of the Outrigger Telescopes. Paints, thinners, solvents, and fuel may be transported to the site for specific construction activities. The Wēkiu Bug Mitigation Plan and its provisions incorporated into the Best Management Practices Plan (Appendix F) requires contractors to minimize the amount of on-site paints, thinners, and solvents, and to clean painting and construction equipment off-site in order to reduce the potential for spills. This would reduce the likelihood of accidental spills and minimize potential impacts to Wēkiu bug habitat.

Arthropod species introduced outside their natural range represent a threat to natural systems because they can deplete native arthropod food resources and prey on native species, sometimes driving them to extinction. Alien species that successfully establish populations within the Mauna Kea Science Reserve (MKSR) could out-compete or exclude native species, such as the Wēkiu bug, lycosid wolf spider, and other native resident arthropods. Alien arthropods can arrive at the summit by two general pathways. First, alien species already on the island can spread to new localities. Second, alien species can arrive with shipping crates and containers. Earthmoving equipment, large vehicles and trailers often sit at storage sites for several days or weeks between jobs. Most of these storage sites are located in industrial areas and usually support colonies of ants and other alien arthropods. These species often use stored equipment as refuges from rain, heat, and cold. Ants will colonize mud and dirt stuck to earthmoving equipment and could then be transported to uninfested areas. Spiders occupy stored equipment, looking for food or escaping predation by hiding in protected niches. Once transported to the summit, these species could migrate to Wēkiu bug habitat. The probability for the introduction of a serious predator is small, but the establishment of just one alien species could have substantial impacts on native arthropods. Earthmoving equipment, large trucks, tractors and other heavy equipment, containers, and construction materials would be pressure washed and inspected for invasive alien arthropods before proceeding up the Mauna Kea Access Road. A qualified entomologist will monitor the construction site for alien species, and if any are found appropriate measures would

be taken. The pressure washing, inspections, and monitoring would reduce the probability for invasive alien arthropod introductions that could result from the construction of the Outrigger Telescopes, and thus the probability for impacts is small.

In summary, mitigation measures associated with on- site construction and installation of the Outrigger Telescopes would make potential impacts to Wēkiu bugs and their habitat small. Because other species of Hawaiian arthropods known to inhabit the *Summit Area Cinder Cones* occur in equal abundance on other summit area cinder cones, the impact to any of these would likely be small and not significant.

Below the Summit Area Cinder Cones - There are three off-site activities that would occur away from the W.M. Keck Observatory site that could potentially impact the flora and fauna *Below the Summit Area Cinder Cones*:

- Storage of construction materials and equipment at the summit staging area,
- Cinder screening and washing at the summit staging area, and
- An increase in vehicle traffic on the Puʻu Hauʻoki Detour Road.

Flora. Vegetation is sparse within the elevations of the Mauna Kea Science Reserve *Below the Summit Area Cinder Cones*. Construction and installation activities of the Outrigger Telescopes *Below the Summit Area Cinder Cones* would be confined to approved construction lay down and storage areas largely uninhabited by floral species, lichens, or mosses. Habitats for the fern, *Cystoperis douglasii,* regarded as a species of concern by the USFWS, lichens, and mosses occur adjacent to the summit staging area. Ferns, lichens and mosses that inhabit these areas could potentially be impacted if excessive dust is generated from activities at the staging area. Dust generation from cinder screening would be minimized because washing would happen concurrently. Other dust generation from vehicle traffic would be small. In addition, ferns are not abundant there and fern populations *Below the Summit Area Cinder Cones* are not expected to be affected by Outrigger Telescopes construction and installation activities. Lichens and mosses are more abundant elsewhere. Thus, Outrigger Telescopes construction and installation activities would have a small, localized impact on the vegetation, but no significant impact on the overall flora *Below the Summit Area Cinder Cones.*

Fauna. The staging area near the summit is not located in Wēkiu bug habitat, but there may be Wēkiu bug habitat nearby. The use of the staging area should not impact Wēkiu bugs *Below the Summit Area Cinder Cones* when the mitigation measures are followed (e.g., trash control, dust control, material control, inspections for alien arthropods, monitoring). For example, vehicles generating dust on the unpaved portion of the Puʻu Hauʻoki Detour Road could impact adjacent habitat, but when the vehicles follow the recommended speed limit of 8 km (5 mi) per hour, only a small amount of dust would be generated that would have no impact on Wēkiu bug habitat. Cinder screening and washing would happen concurrently and therefore, should not generate excessive dust. Overall, there would be no impact on Wēkiu bugs or their habitat *Below the Summit Area Cinder Cones* from construction and installation of the Outrigger Telescopes. The mitigation measures in the Wēkiu Bug Mitigation Plan would also protect the habitat of the other resident species. The construction and installation of the Outrigger Telescopes would therefore have no impact on the fauna *Below the Summit Area Cinder Cones.*

Silversword/Alpine Shrub Zone

Flora. Traffic along the Mauna Kea Access Road in the lower elevation areas, particularly the heavy truck traffic that would be associated with the Outrigger Telescopes Project, could result in some dust deposition on roadside vegetation in the *Silversword/Alpine Shrub Zone*. This is expected to be short-term and temporary given that the increase in daily traffic would amount to only about 15 round trips each day, and heavy vehicle traffic would be confined largely to the mobilization and demobilization periods of the on-site construction and installation phase. The Mauna Kea silverswords (*Argyroxiphium sandwicense)*, is the only Federally-endangered plant species known to inhabit Mauna Kea above 3,132 m (9,000 ft). One plant located next to the road in the switchback area could be impacted by dust generated from vehicle traffic. The only other known population of this species occurs at the Wailuku river basin outside of the MKSR, 4-km (2.5-mi) away from the Mauna Kea Access Road and is unlikely to be disturbed by dust. No other plant species are likely to be impacted by vehicle traffic on the road. Consequently, vegetation in the *Silversword/Alpine Shrub Zone* would not be impacted by construction and installation of the Outrigger Telescopes.

Fauna. The endangered Hawaiian seabird, *ʻuaʻu*, is suspected to occur at mid-elevations on Mauna Kea, near Puʻu Kanakaleonui, more than 4.8 km (3 miles) from the unpaved portion of the Mauna Kea Access Road. It is unlikely that there would be any adverse impacts to this species or its habitat as a result of the construction and installation of the Outrigger Telescopes. There are no other species known to inhabit the *Silversword/Alpine Shrub Zone* that could be impacted by vehicle traffic. There would be no adverse impacts to the fauna at lower elevations within the MKSR.

Māmane/Subalpine Forest Zone

Flora. Construction activities for the Outrigger Telescopes in the *Māmane/Subalpine Forest Zone* would be limited to the Hale Pōhaku staging area. The area would be used only for storing construction equipment and materials and activities would be limited to the gravel-covered staging area. No indigenous plants inhabit the staging area and there would be no impact on native flora at this site.

Fauna. Two federally endangered bird species, the *palila* and the *ʻakiapolaʻau,* inhabiting the *māmane* subalpine forest near the Hale Pōhaku staging area. There are no food resources on the site and it is unlikely that these birds would visit there. However, the *māmane* forest surrounding the construction staging area is dry and susceptible to fire, and once started, a fire could be difficult to control. Fire prevention and suppression measures that are part of the Best Management Practices would make this potential for fire damage small.

Although several hundred arthropod species inhabit the *māmane* subalpine forest, none are known to occur exclusively near the Hale Pōhaku staging area. Because of increased vehicle traffic and storage of equipment and construction materials, it is possible that nonindigenous species could be introduced to the surrounding *māmane* subalpine forest. To mitigate this possibility, earthmoving equipment, large trucks, tractors and other heavy equipment, containers, and construction materials would be inspected for invasive alien arthropods before proceeding up the Mauna Kea Access Road. The inspections would reduce the probability for invasive alien arthropod introductions as a result of the construction

activity of the Outrigger Telescopes, and thus make the potential for impacts small.

Summary of the Impacts of the On-Site Construction and Installation of the Outrigger Telescopes Project on Biological Resources. Construction and installation of four, and possibly up to six, Outrigger Telescopes would have no significant impacts on the biological resources of the four ecological zones.

Operation Impacts.

All Ecological Zones

Flora and Fauna. CARA has already begun to implement some of the protection measures outlined in the Wēkiu Bug Mitigation Plan for current Observatory activities. These will continue to be followed, and would make the potential impacts from Outrigger Telescope operations small.

The small amount of additional traffic to the summit that would be associated with Outrigger Telescopes would generate negligible amounts of dust, reducing the potential for adverse impacts. Housekeeping and trash management can increase disturbance to habitats. Retrieving debris from sensitive areas can destroy the fragile structure of the cinder habitat. Shipments to the W.M. Keck Observatory site increase the potential introduction of alien arthropods to the summit area that may prey on native resident species thereby reducing their populations. Spills of toxic materials could spread into adjacent habitats, making them unsuitable for resident species.

Summary of the Impacts of the Operation of the Outrigger Telescopes Project on Biological Resources. Operation of the Outrigger Telescopes would have no foreseeable adverse effects on species on the *Summit Area Cinder Cones* and *Below the Summit Area Cinder Cones*. Operation impacts below these two areas are likely to be small and would also not adversely affect plant or animal resources within the lower elevations of the MKSR. No Federally listed threatened or endangered species of or animals would be adversely affected by operation of the Outrigger Telescopes.

Mitigation Measures.

Given that on-site construction and installation of the Outrigger Telescopes would displace about 0.008 ha (0.019 ac) Wēkiu bug habitat; and (2) other on-site construction, installation, and operation activities could also impact the Wēkiu bug, a Wēkiu Bug Mitigation Plan (see Appendix D of this EIS) has been developed to reduce or avoid those impacts. This plan includes measures to minimize habitat disturbance by: a) erecting temporary barriers to prevent loose material from being sidecast and impacting Wēkiu bug habitat downslope during on-site construction and installation activities at JB-5 and Outrigger Telescopes 1 and 3; b) controlling dust, hazardous materials, and trash; and c) reducing the potential for introduction of alien arthropods during on- site construction and installation by inspecting vehicles, equipment and materials before they proceed up the Mauna Kea Access Road, and by monitoring for and controlling alien species. The Wēkiu Bug Mitigation Plan addresses all of the potential stresses to the natural ecosystem on the summit of Mauna Kea from the proposed Outrigger Telescopes Project and would reduce potential impacts on all the native Hawaiian arthropods known to inhabit the summit area. When all the protection measures are implemented, the magnitude and significance of the changes as a result of the project would be extremely small.

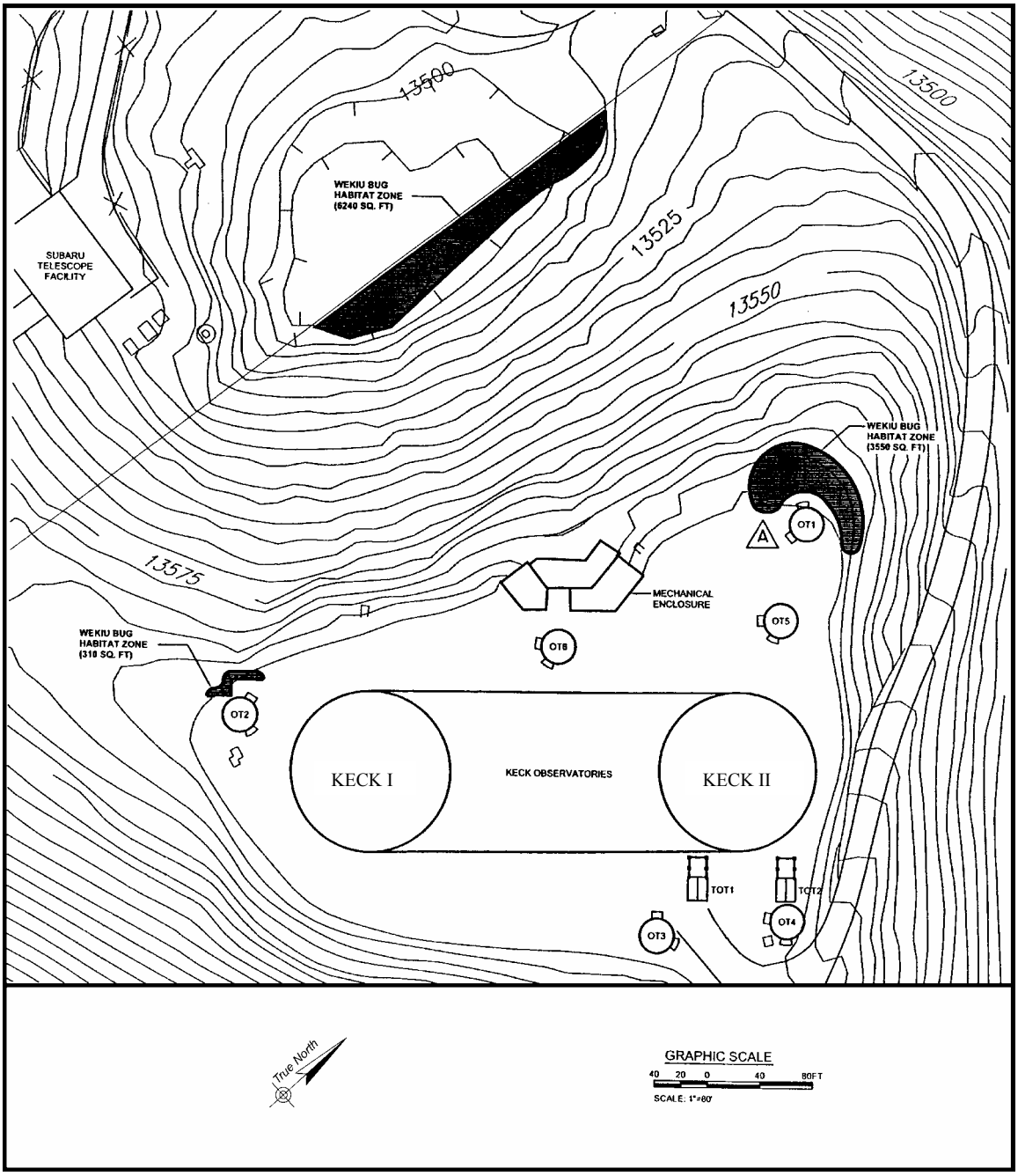
In addition to habitat protection, the plan calls for Wēkiu bug habitat restoration as mitigation, to replace the habitat that would be displaced by on-site construction and installation of Outrigger Telescope 3 and JB-5. At least 0.024 ha (0.057 ac) of habitat would be restored in areas disturbed by previous construction activities. The overall habitat displacement of the Outrigger Telescopes Project would be very small (an increase of about 0.06 percent), and there is potential to increase the amount of available habitat through restoration.

The Wēkiu Bug Mitigation Plan and its requirements will be incorporated into Outrigger Telescopes on-site construction and installation contracts. That plan includes a comprehensive Wēkiu Bug Monitoring Plan (see Appendix E of this EIS) that calls for monitoring contractor compliance to the mitigation plan. CARA will implement the monitoring plan, and enforce compliance with the mitigation plan. In addition, a qualified entomologist would be on-site monthly to monitor implementation of the proposed mitigation measures and measure the effectiveness of habitat protection and restoration efforts.

Development of the Wēkiu Bug Mitigation Plan resulted in design changes that prevent or reduce the disturbance of Wēkiu bug habitat. Outrigger Telescope 1 has been relocated about 4-m (13.2-ft) closer to the Keck II Telescope than originally proposed and removed from Wēkiu bug habitat. JB-5 has been relocated to less than 0.9 m (3 ft) from Outrigger 2, minimizing disturbance to the inner crater wall. Retaining walls would be used at Outrigger Telescope 3 and JB-5 to further minimize habitat displacement. The retaining walls would be constructed of cinder- colored masonry or reinforced concrete to blend with the surrounding land. See Section 2.1.3.4 for a history of the engineering design changes. As a result of the Mitigation Plan and the Project's concern for the Wēkiu bug habitat, the original plans, in which 0.067 ha (0.17 ac) were displaced, have been changed so that only 0.008 ha (0.019 ac) are displaced.

A key element of the Wēkiu Bug Mitigation Plan is restoration of Wēkiu bug habitat. The habitat restoration portion of this plan has been developed in conjunction with the USFWS and other scientists familiar with Wēkiu bug ecology, and would restore habitat adjacent to the W.M. Keck Observatory site and at the bottom of the Pu‘u Hau‘oki crater (see Figure 4-1). The proposed restoration effort would encompass an area of at least 0.024 ha (0.057 ac). The intent is to make it possible for Wēkiu bugs to establish resident populations within the restored areas.

The proposed restoration activity would use cinder excavated for the Outrigger Telescopes as the habitat restoration medium. All cinder not used for backfill or site grading would be screened to obtain suitably sized cinder and washed to remove excess dust. Cinder screening and washing would occur at the summit staging area. The screened and washed cinder would be spread at proposed restoration areas in a layer about 30-cm to 46-cm (12- in to 18-in) deep to accomplish the 3:1 restoration commitment. This is believed to be within the desired depth range for Wēkiu bug habitation (Pacific Analytics, LLC 2000). Cinder on the margins of the restored areas would be placed to ensure that contact with the existing habitat would be established. Restoration of the areas adjacent to Outrigger Telescope 1 and JB-5 would be given greater priority than restoration of the area on the floor of Pu‘u Hau‘oki crater (Figure 4-1). Since the size of the restoration area would be limited by the amount of available cinder excavated during construction of the Outrigger Telescopes,



Source: W.M. Keck Observatory 2001

FIGURE 4-1. PROPOSED WĒKIU BUG RESTORATION HABITAT FOR THE OUTRIGGER TELESCOPES PROJECT

the size of the restoration area on the floor of Pu‘u Hau‘oki crater may be reduced in order for areas adjacent to Outrigger Telescope 1 and JB-5 to be restored.

Restoration would continue until the supply of suitable- sized cinder is exhausted, or the restoration of all three areas is complete.

The habitat restoration protocol has been based on all of the scientific information available about the habitat needs of the Wēkiu bug. The protocol considered the following information.

1. Wēkiu bugs appear to prefer habitat made of loose accumulations of cinder 1 centimeter (cm) (½ in) in size or larger (Howarth and Stone 1982). Studies have found the highest concentration of Wēkiu bugs in this type of habitat (Howarth and Stone 1982; Howarth and others 1999, Polhemus 2001, Englund and others 2002). This information leads to a conclusion that restored habitat consisting of 30 to 46 cm (12 to 18 in) of loose 1 cm (½ in) size or larger cinder will be acceptable to Wēkiu bugs.

2. Wēkiu bug habitat occurs on portions of crater floors and on sloped crater walls in summit cinder cones (Howarth and Stone 1982; Howarth and others 1999). In 1982, 6,230 Wēkiu bugs were collected on the crater floor of Pu‘u Wēkiu and 430 Wēkiu bugs were collected on the crater floor of Pu‘u Hau‘oki. During the 1997/98 arthropod assessment, Wēkiu bugs were found on the crater floor of Pu‘u Wēkiu and Pu‘u Hau‘oki, and on the inner slopes of Pu‘u Hau‘oki adjacent to the crater floor. Since suitable habitat does not currently exist on the crater floor of Pu‘u Hau‘oki, Wēkiu bugs from the adjacent inner slopes apparently migrate to the crater floor. This information leads to a conclusion that Wēkiu bugs would likely find and occupy restored habitat on the crater floor of Pu‘u Hau‘oki.

3. Given sufficient time, Wēkiu bug habitat appears to recover from disturbance. Of all sites sampled during the 1997/98 arthropod assessment, habitat on the slopes below the W.M. Keck Observatory site that was presumably disturbed during site preparation and construction contained the highest concentration of Wēkiu bugs. This information leads to a conclusion that Wēkiu bugs would eventually occupy restored habitat.

Given the information above, it is believed that habitat restoration will succeed in expanding the current Wēkiu bug population. At NASA's initiative, consultations were conducted with the USFWS and biologists familiar with Wēkiu bug ecology to determine an appropriate experimental design to test the effectiveness of habitat restoration. As a result of those consultations the habitat restoration protocol was modified to include another component. In addition to monitoring restored areas, unrestored control sites adjacent to restored areas will also be monitored to better determine if restoration was successful.

CARA would implement the Wēkiu Bug Mitigation and Monitoring Plans and habitat restoration. The restored habitat would be monitored quarterly by a qualified entomologist for 18 months following completion of the proposed habitat restoration to determine if the Wēkiu bug reestablishes in those areas. Monitoring of Wēkiu bug populations would continue semiannually for no less than five years following completion of the construction of the Outrigger Telescopes, and on an annual basis thereafter for the term of the CDUP.

Baseline monitoring of Wēkiu bugs in Pu‘u Hau‘oki and Pu‘u Wēkiu was started in February 2002, and has continued quarterly since then. As a result of that effort, modifications to the trapping system have reduced mortality to near 2 percnet, a

substantial reduction from the 40 percent average mortality before modifications were made, and much less than the 100 percent mortality experienced with ethylene-glycol traps used prior to 1997. On-going efforts are being made to further reduce mortality in live-traps. Progress reports on the monitoring results will be submitted semiannually to the DLNR, OMKM, and the Bishop Museum for no less than five years following completion of construction of the Outrigger Telescopes, and on an annual basis thereafter for the term of the CDUP. During the habitat monitoring, efforts would be made to gather weather data related to Wēkiu bug monitoring from a location near the area of monitoring.

The Wēkiu Bug Monitoring Plan specifies methods for measuring the results of actions undertaken in accordance with the Wēkiu Bug Mitigation Plan and the subsequent changes in the Wēkiu bug population and habitat. Two types of monitoring will be implemented: compliance monitoring and effectiveness monitoring. Compliance monitoring investigates the extent to which contractors, operators, managers, and visitors comply with Wēkiu bug protection guidelines and rules. Effectiveness monitoring investigates the changes in Wēkiu bug habitat and population that happen concurrent with and subsequent to construction of the Outrigger Telescopes. This includes monitoring of habitat restoration efforts. The Wēkiu Bug Monitoring Plan specifies tasks, schedules, and sampling protocols for both types of monitoring.

The compliance monitoring section is based on the commitments made in the Wēkiu Bug Mitigation Plan to protect Wēkiu bugs and their habitat. Compliance monitoring would measure adherence to guidelines set for: slope stability and habitat protection; habitat restoration; control of dust and trash; avoiding spills of hazardous materials; and cleaning and inspecting construction equipment and material before transport to the summit. Monitoring for compliance will give the operators, oversight agencies, and the public the information necessary to ensure that natural resources are protected during the Outrigger Telescopes Project.

Effectiveness monitoring would investigate the changes in the Wēkiu bug population and habitat that happen concurrent with construction and operation of the Outrigger Telescopes. Effectiveness monitoring measures the success of the environmental controls adopted and mitigation treatments undertaken in conserving the Wēkiu bug.

As part of the Outrigger Telescopes Project implementation and mitigation, NASA will fund a Wēkiu bug autecology study, to gather more information about habitat requirements, life cycle, nutritional requirements, and breeding behaviors of this unique bug. New information could be used to modify the habitat restoration protocol to increase its effectiveness.

Where applicable, all participants in the proposed Outrigger Telescopes Project will comply with the Wēkiu Bug Mitigation Plan, the Wēkiu Bug Monitoring Plan, the NHPA Section 106 MOA, the Construction Best Management Practices Plan and all other existing plans and agreements designed to protect the natural resources of Mauna Kea.

<u>Summary of the Impacts of the Outrigger Telescopes Project on Biological Resources</u>. When the Wēkiu Bug Mitigation Plan and the Wēkiu Bug Monitoring Plan are implemented, the anticipated adverse impacts to the biological resources within the ROI as a result of the Outrigger Telescopes Project would be small. Through restoration, the amount of Wēkiu bug habitat adjacent to the W. M. Keck Observatory

would increase. The Outrigger Telescopes Project would have no significant impacts on the biological resources within the ROI.

4.1.3 Hydrology, Water Quality, and Wastewater

4.1.3.1 ROI for Hydrology, Water Quality, and Wastewater

For purposes of this evaluation, the potential impacts to hydrology, water quality, and wastewater as a result of implementing the Outrigger Telescopes Project are the pathways for the flow of surface and subsurface water. The routes and extent of pathways of surface runoff are identifiable by topography. The subsurface pathways, including travel downward through unsaturated lava and then lateral travel in groundwater, extend all the way to the island's shorelines.

4.1.3.2 Impacts of the Outrigger Telescopes Project on Hydrology, Water Quality, and Wastewater

On-Site Construction and Installation Impacts. Activities with the potential to affect hydrology, water quality, and wastewater would occur during the on-site construction and installation phases of the Project. Three principal activities could potentially have environmental impact during construction: (1) the process of washing cinder for Wēkiu bug habitat restoration in Submillimeter Valley directly south of Pu'u Hau'oki, (2) using water to control dust, and (3) accommodating the water supply and wastewater treatment and disposal needs of construction workers. Each of these is addressed in the following sections.

<u>Cinder Washing for Wēkiu Bug Habitat Restoration</u>. An estimated 2,752 cubic meters (m^3) (3,600 cubic yards (yd^3) or 97,200 cubic feet (ft^3)) of material at the W.M. Keck Observatory site would be excavated for the installation of pipes, junction boxes, foundations and instrument enclosures for the Outrigger Telescopes. About one-half of this material would be used as backfill for the trenches and the remainder transported to Submillimeter Valley for screening and washing cinders for use in the Wēkiu bug habitat restoration. It is anticipated that 18 percent (249 m^3 (8,800 ft^3)) of the screened and washed cinder would be suitable for habitat restoration. Washing this cinder would require about one gallon per cubic foot, meaning that the total washwater used would be less than 38 kiloliters (kl) (10,000 gal). Only potable water would be used and it would be trucked to the screening site on the mountain. Some of this wash water would evaporate during washing and drying. The remainder would percolate downward beneath the washing area. This percolating water would contain suspended particulates from the washing process, which would be removed by natural filtration in the downward travel of the water and retained in the unsaturated rock mass.

From a hydrologic perspective, the total volume of water used in the washing process would be inconsequential: the entire 38 kl (10,000 gal) of wash water would represent less than 0.014 percent of the 13 cm (5 in) of average annual rainfall in the 212-ha (525 ac) area of the Astronomy Precinct on the summit area of Mauna Kea. Considering the small volume of wash water and the natural filtration that would occur as it percolates through the cinder removing particulates, no significant hydrologic or water quality impacts would occur.

<u>Water Use for Dust Control</u>. Water would be used to control dust during excavation for trenches and foundations. It would be trucked by the contractor to W.M. Keck Observatory and applied as needed. As an

order of magnitude estimate, it is assumed that this water use would amount to 2 kiloliters per day (klpd) (500 gal per day (gpd)) for 3 days a week through the first 6 months of the 24-month construction period. It is estimated that the total water volume would amount to 148 kl (39,000 gal). This volume would be equivalent to 0.055 percent of the average annual rainfall of 13 cm (5 in) in the Astronomy Precinct.

Some of the water applied for dust control would evaporate. The remainder would percolate downward, initially carrying with it suspended particulates created during the excavation process. During this downward subsurface movement, these suspended solids would be intercepted and retained in the unsaturated rock mass; the naturally clarified water would continue downward, ultimately reaching the underlying groundwater body. As with the cinder washing for the Wēkiu bug habitat restoration, there would be no significant hydrologic or water quality impact from this process.

Water Use and Wastewater Treatment and Disposal for Construction Workers. Two work crews would be required for on-site construction and installation of the Outrigger Telescopes Project: a work crew of up to 15 individuals would be on site for the full 24-month construction period at the W.M. Keck Observatory site for installation of the Outrigger Telescopes and an integration and testing crew of up to 15 individuals would be on site for the final 5 months. To assess the impact of water use by these workers over the 24-month construction period, the following assumptions have been made:

- All workers would be housed at Hale Pōhaku
- Water supply and wastewater collection and disposal for workers at the summit would be handled by portable facilities provided by the contractor. Since these portable facilities would be self-contained, they would create no hydrologic or water quality impacts
- The construction contractor would retain a licensed waste hauler to pump out the portable toilets periodically for off-site disposal at an approved treatment facility (see Appendix F).

Under these assumptions, hydrologic, water quality, and wastewater impacts during construction would be limited to water use and wastewater disposal for construction workers staying at Hale Pōhaku. The number of individuals staying at Hale Pōhaku at present varies substantially, but averages 38 per day. Based on water delivery records, water use at Hale Pōhaku averages about 379 liters per day (lpd) (100 gpd) per person or 14.4 klpd (3,800 gpd) per year. As a first order approximation, it is reasonable to assume that essentially all of this water becomes wastewater disposed of among Hale Pōhaku's seven cesspools and two septic systems. Relative to the average number of Hale Pōhaku residents, construction workers for the Outrigger Telescopes Project would increase the resident population, water use, and wastewater generation as shown in Table 4-3. The additional water supply for construction workers would be trucked to Hale Pōhaku.

The impacts of the subsurface discharge of wastewater can be approximated using the following conservative assumptions:

- Raw wastewater disposed in the facility's cesspools and septic systems would have a total nitrogen concentration of 40 milligrams per liter

TABLE 4-3. WATER USE AND WASTEWATER GENERATION DURING CONSTRUCTION OF THE OUTRIGGER TELESCOPES

Period of Construction	Number of Construction Workers	Total Residing at Hale Pōhaku	Percent Increase	Water Use and Wastewater Generation	
				Addition Due to Construction Workers (gpd)	Total Flow (gpd)
First 15 months	15	53	39	1,500	5,300
Final 5 months	27	65	71	270	6,500

(mg/l) and total phosphorus of 15 mg/l. Nutrients, such as nitrogen and phosphorus, in wastewater are the primary concern for groundwater contamination and are a good indicator of such contamination. The concentrations assumed herein are typical for domestic wastewater.

- No removal of these nutrients would occur in either the cesspools or the septic systems; that is, all of the nutrients in the wastewater would percolate downward toward groundwater in the otherwise clarified wastewater. Depending on the bedding material of the cesspools and leach fields, actual nutrient removal rates are likely to be in the range of 20 to 50 percent.
- Since there is no evidence of shallow (perched) groundwater beneath and/or downslope of Hale Pōhaku, the percolating wastewater would travel downward to the groundwater at depth (refer to Section 3.1.4.4 for a description of this occurrence).
- The drop in elevation of the percolating wastewater through the vadose zone to the underlying groundwater could be on the order of 914 to 2,134 m (3,000 to 7,000 ft), which could take from several months to several years. Such movement through cracks and clinker zones would act as a natural "trickling filter" treatment process to break down and/or adsorb nutrients. Actual nutrient reductions would likely be more than 90 percent. However, for this conservative assessment, no nutrient removal is assumed to occur.
- Given Hale Pōhaku's location relative to Mauna Kea's south rift zone, once the wastewater reaches the underlying groundwater, it would move in an easterly (downgradient) direction generally toward Hilo Bay. Depending on its route, it would be moving in the Onomea (No. 80204) or Hilo (No. 80401) State-designated aquifers.
- As the wastewater travels over the more than 32-km (20-mi) to the nearest wells (either the Kaieie Mauka well (No. 4708-03) in the Onomea Aquifer or Saddle Road Well "A" (No. 4110-01) in the Hilo Aquifer) there would be lateral dispersion of the wastewater plume that could be on the order of 10 degrees. If just 5 degrees is assumed to be conservative, the plume width after traveling 32 km (20 mi) would be about 2.8 km (1.75 mi).
- It would take the wastewater about 30 to 100 years to travel the 32-km (20-mi), based on an average permeability of 457 m (1,500 ft) per day, a gradient of 0.3 to 0.9 m per km (1 to 3 ft per

mi), and an effective porosity of 10 percent. It is assumed that no nutrient removal or decomposition would occur over this decades-long travel time. In actuality, virtually complete decomposition and/or adsorption of the remaining nutrients would very likely occur.

- Natural rates of groundwater movement in the Onomea and Hilo Aquifers are very high. Based on calculations in George A.L. Yuen & Associates (1992) adopted by the State Commission on Water Resource Management, groundwater flowrates in the two aquifers amount to 44 and 70 million gpd per coastal mile, respectively. Over the 2.8-km (1.75-mi) width of the wastewater plume, 19 to 25 klpd (5,000 to 6,500 gpd) of wastewater from Hale Pōhaku would be diluted by a factor of 12,000 to 25,000. Arriving concentrations of nitrogen and phosphorus, because of dilution alone with no removal or decomposition occurring anywhere en route, would be, at the low end of the dilution, 0.003 mg/l as nitrogen and 0.001 mg/l as phosphorus. Background levels of these nutrients in pristine Hawaiian groundwater are typically several hundred or more times higher than this. The potential impact based on this series of conservative assumptions is insignificant. When actual nutrient removal is considered, there is no impact.

Operation Impacts. Two aspects of the Outrigger Telescopes operations must be considered for their potential hydrologic and/or water quality impacts: (1) change in surface runoff from the W.M. Keck Observatory site, and (2) generation and disposal of domestic wastewater. These are discussed in the following sections. All other activities involving the use of water or the generation of other types of wastewater at W.M. Keck Observatory are entirely contained processes; those wastewaters are captured and stored in sealed containers and hauled off site for treatment and disposal elsewhere.

Surface Runoff from the W.M. Keck Observatory Site. Although the subleased area of the W.M. Keck Observatory site is about 2 ha (5 ac), only about 1.1 ha (2.7 ac) at the top of Pu‘u Hau‘oki have been leveled for the observatory’s use. The remainder of the subleased area consists of the slopes of Pu‘u Hau‘oki. The Keck I and Keck II domes and their connecting structure cover about 0.4 ha (1.0 ac), constituting the impervious surfaces on the leveled portion of the site. The remainder of the leveled area is covered with gravel and sand-sized cinder, both of which have substantial permeability. Although drainage swales may have been installed initially to accommodate runoff and snowmelt from the domes and other impervious surfaces, none remain today. Nonetheless, there is no evidence of erosion by surface runoff anywhere across the leveled area or down the slopes of Pu‘u Hau‘oki. Because the surface cinders are cohesionless and highly erodible, the fact that there is no evidence of surface flow or erosion is significant. It empirically demonstrates that the permeability of the cinder surface exceeds the rates of precipitation at the summit, even during the most severe storms. Consequently, surface runoff does not move across the leveled area or down the slopes.

Each of the six Outrigger Telescopes would have a 9.1-m (30-ft) dome, foundation, junction boxes, and other related facilities. All six would create a total of about 0.05 ha (0.12 ac) of additional impermeable surface on W.M. Keck Observatory’s leveled area,

representing a 12 percent increase of the impermeable surfaces at the W.M. Keck Observatory site. Based on the empirical evidence across the leveled area and down the slopes of Pu‘u Hau‘oki cited above, and because the relatively small increase in impervious surface would be at six physically separate sites, generation of surface runoff across the leveled area or down the slopes of Pu‘u Hau‘oki would not occur.

Subsurface Disposal of Domestic Wastewater. The volume of wastewater produced at the W.M. Keck Observatory is not measured. However, it is reasonable to assume that the volume of water trucked to the W.M. Keck Observatory site approximates the volume of domestic wastewater generated there. The amount of water trucked in that is used for other purposes at W.M. Keck Observatory site such as mirror washing is relatively insignificant. Based on delivery records, water trucked to the W.M. Keck Observatory site averages about 45 kl per month (12,000 gal per month) or 1.5 klpd (400 gpd). It is estimated that the Outrigger Telescopes Project would increase this amount by about 9.5 kl per month (2,500 gal per month) or about 0.3 klpd (80 gpd), a 20 percent increase. No new toilets or sinks would be installed for the Outrigger Telescopes. The Outrigger Telescopes are designed as equipment with no habitable spaces for personnel; all staff working on them during operations would use the existing Keck facilities.

Percolating wastewater from the W.M. Keck Observatory’s site seepage pit would ultimately reach groundwater beneath the summit or its southwest flanks. This wastewater does not travel to Lake Waiau or to the springs on the west side of Pōhakuloa Gulch for the following reasons:

- Lake Waiau is 1.74 km (1.08 mi) to the south-southwest and 177 m (580 ft) lower than the W.M. Keck Observatory. In the absence of a rather unique and unprecedented subsurface perching layer which extends continuously over this entire distance, a subsurface discharge from the W.M. Keck Observatory site could not move a sufficient distance laterally before dropping more than 177 m (580 ft) in elevation. In other words, if a subsurface discharge did move laterally toward the lake, it would be far below the elevation of the lake by the time it reached there.
- If a unique and unprecedented perching layer with sufficient areal extent and proper elevation and gradient to direct subsurface flow from the W.M. Keck Observatory site toward Lake Waiau actually existed, one or both of the following would occur:
    - Perennial springs would form in the intervening topographic tributaries of Pōhakuloa Gulch in Submillimeter Valley. No such springs exist.
    - Lake Waiau would constantly be overflowing through the low point on the west side of the crater rim, because its contributing watershed, rather than being limited to the confines of the Pu‘u Waiau crater, would be more than 10 times greater (in excess of 162 ha (400 ac)). This is not the case.
- Modeling in Ebel (2001) replicates the historic lake water level data in Woodcock (1980) with the only input to the lake being rain that falls within the crater rim. This is a contributing

watershed area of about 14 ha (35 ac). This modest input still results in overflow on approximately 20 percent of the days over the period modeled. If the contributing area was 10 times greater, continuous overflow would occur.

- The intrusive volcanic structures within the Pu‘u Waiau crater are nearly vertical barriers to perched subsurface water moving into the lake itself.
- The bottom of the lake is lined with thick sediments which are orders of magnitude less permeable than the flow lavas and/or glacial drift through which the percolate would travel. It would be essentially impossible for percolate to move laterally or upward through the sediments against the hydraulic pressure of the water in the lake. The percolate would move laterally around rather than through this poorly permeable obstruction with an adverse hydraulic gradient.
- Because the distance to the springs on the west side of Pōhakuloa Gulch is greater than to Lake Waiau (5.6 versus 1.7 km (3.5 versus 1.1 mi), it is even more unlikely that an aerially extensive and continuous perching layer would extend from Pu‘u Hau‘oki all the way to the springs.
- If an aerially extensive and continuous perching layer were that extensive, the flow at the springs would be far greater and more consistent than their highly variable and quite modest actual discharge.
- Given the trends of topography down the mountain’s south-southwest flank, a perched subsurface flow from Pu‘u Hau‘oki would be much more likely to emerge into Pōhakuloa Gulch rather than into the springs on the west of the gulch. No such discharge occurs.
- Isotopic analyses in Arvidson (2002) show that the water from the springs is similar to the isotopically “light” rainfall that occurs at high elevations near the summit. If wastewater had reached the springs after subsurface discharge at the summit, it would be identifiable by isotopic analysis. Because it originates as water trucked to the summit from sources at a far lower elevation, it would be isotopically “heavier” than the water actually discharged at the springs.

Based on the foregoing analysis, the only potential remaining impact of the W.M. Keck Observatory’s subsurface discharge of wastewater is on the groundwater at depth, which exists thousands of feet below the summit and its flanks. A conservative assessment of this impact can be made with the series of assumptions provided below. Because percolating wastewater from the Observatory site is not likely to move toward the east where groundwater flowrates are very high, the assumptions for this assessment need to be more realistic than the simple dilution calculations made for wastewater percolating from facilities at Hale Pōhaku.

- As with the raw domestic wastewater at Hale Pōhaku, nitrogen and phosphorus concentrations in the W.M. Keck Observatory’s wastewater are assumed to be 40 and 15 mg/l, respectively.
- Nutrient removal rates in the W.M. Keck Observatory’s septic tank and seepage pit system are limited to 20 percent for nitrogen and 10 percent for phosphorus. These removal rates reflect the portion of nutrients that would be captured in the septic tank as

floatable and settled solids. It is assumed that no nutrient removal occurs in the seepage pit.

- Based on the W.M. Keck Observatory's location, wastewater percolating from its seepage pit would move southwest and/or west.
- The wells nearest the southwest or west of the summit are the Waiki'i wells (Nos. 5239-01 and 02 in Table 3-6), 20.3 km (12.6 mi) to the west of the summit. For the purposes of this conservative assessment, it is assumed that all of the wastewater from the septic tank and seepage pit system would travel directly toward the Waiki'i wells.
- The decades-long travel of percolating wastewater from W.M. Keck Observatory's seepage pit to the Waiki'i wells would initially be for thousands of feet of nearly vertical travel through the vadose zone followed by lateral movement in the groundwater for about 19 km (12 mi).
- Nutrient removal rates have been documented for a similar travel path, albeit for a much shorter time and distance. Nance (2002) analyzed the disposal of effluent from the County's Kealakehe Wastewater Treatment Plant for vadose zone travel of just 15 vertical m (50 vertical ft) and a horizontal movement in groundwater of just 1.1 km (0.7 mi), Nance computed removal rates of 83 to 97 percent for nitrogen and 94 to 95 percent for phosphorus. Obviously, removal rates would be much greater for the far longer hypothetical wastewater travel time and distance from the W.M. Keck Observatory site to the Waiki'i wells. However, for this conservative assessment, removal rates of 80 percent for both nitrogen and phosphorus are assumed.

If the Waiki'i wells pump at an average of 0.3 mgd and they capture all of the remaining nutrients in the 480 gpd of the W.M. Keck Observatory's wastewater, their nutrient concentrations would be increased as shown in Table 4-4. The computed increases are 0.4 and 1.6 percent for nitrogen and phosphorus, respectively. Actual increases would be far less than these computed increases, and would have no impact on the quality of water pumped from the wells.

4.1.4 Solid Waste and Hazardous Materials Management

4.1.4.1 ROI for Solid Waste and Hazardous Materials Management

The ROI for solid waste and hazardous materials impacts from the Outrigger Telescopes Project depends upon the material and the manner of release. For example, wind-blown trash could be transported conceivably anywhere across the mountain, while a small spill and clean-up of liquid upon cinder would most likely be confined to the immediate area. For the purposes of this evaluation, considering the types of releases of waste and hazardous materials that have occurred on Mauna Kea in the past, the ROI is defined as the area within the MKSR, a corridor surrounding the Mauna Kea Access Road, Saddle Road, and the potential surface and subsurface water flow paths connected to these areas. Emphasis is placed on the W.M. Keck Observatory site because it is the location of the proposed Outrigger Telescopes Project.

TABLE 4-4. COMPUTED NITROGEN AND PHOSPHORUS INCREASES AT THE WAIKI'I WELLS

Constituent	Waiki'i Well Water		W.M. Keck Observatory Effluent Arriving at the Waiki'i Wells		Combined		
	Flow Rate (gpd)	Concentration (mg/l)	Flow Rate (gpd)	Concentration (mg/l)	Flow Rate (gpd)	Concentration (mg/l)	Percent Increase
Nitrogen	299,520	1.950	480	6.4	300,000	1.957	0.4
Phosphorus	299,520	0.245	480	2.7	300,000	0.249	1.6

4.1.4.2 Impacts of the Outrigger Telescopes Project on Solid Waste and Hazardous Materials Management

Solid Wastes

On-Site Construction and Installation Impacts. On-site construction activity would generate waste debris consisting of wood, scrap insulation, packaging material, waste concrete, and various construction-related wastes. This construction debris would be disposed of in large "roll-off" containers sized to accommodate the debris generated over several days of construction (UH IfA 2001a). No other waste material from the construction process would be disposed of in these roll-off containers. Other wastes, such as liquids, would be collected in leak-proof containers before being removed from the summit.

The construction contractor would remove all construction-related wastes from the summit and take them to an authorized disposal site at least weekly during the construction period (see Appendix F). Given these precautions, no impacts from on-site construction and installation activities are anticipated.

Operation Impacts. Operation of the Outrigger Telescopes would not generate substantially more solid waste than that currently generated by the Keck I and Keck II Telescopes. The existing infrastructure at the observatory would be used to collect the additional trash (UH IfA 2001A).

The W.M. Keck Observatory anticipates that the amount of trash generated by the additional personnel required to operate the Outrigger Telescopes would increase proportionally with the increase in manpower at the summit. The W.M. Keck Observatory anticipates an increase of up to four staff on average for the Outrigger Telescopes, an increase of about 17 percent. Thus the increase in trash generation would be about 0.6 m^3 (0.8 yd^3) per week (CARA 2004h). However, the W.M. Keck Observatory does not expect additional vehicle traffic would be needed to transport additional solid waste from the Outrigger Telescopes more often than the current one to two trips per week (CARA 2004e). As such, no impacts due to solid waste are anticipated from operation activities.

Additional Precautionary Measures. Although no impacts are anticipated from the construction, installation, and operation of the Outrigger Telescopes, additional precautionary measures described in this subsection would reduce the chance of an accidental release of solid waste. The Outrigger Telescopes on-site construction and installation contract(s) would contain provisions regarding the management of solid wastes. Particularly important are

measures to secure solid wastes against dispersal by high winds. Such dispersal could adversely affect plants and Wēkiu bug habitat and degrade the aesthetics of the surrounding area (see Appendices B and F). Examples of such provisions include but are not limited to:

- Construction containers will be equipped with cables to secure the tops and lids to prevent wastes from being blown or dispersed by wind into Wēkiu bug habitat or onto the surrounding slopes of Pu‘u Hau‘oki.
- Construction materials stored at the site will be covered with tarps or anchored in place, and will not be susceptible to movement by wind.
- Outdoor trash receptacles will be secured to the ground, have attached lids and plastic liners, and be collected frequently to prevent predators from foraging for food.
- Construction materials and trash blown into Wēkiu bug habitat or onto the surrounding slopes of Pu‘u Hau‘oki will be collected to the extent practicable, with minimal disturbance to the habitat and cultural properties.

Hazardous Materials

On-Site Construction and Installation Impacts. Some hazardous materials, such as paints, thinners, solvents, and fuel, would be used during the on-site construction and installation of the Outrigger Telescopes. Unused products and spent containers would be collected and transported offsite for proper disposal. Handling of these materials would be guided by a Construction Best Management Practices Plan that would be completed, reviewed, and approved prior to commencement of construction activities. With these measures in place, no impacts from onsite construction and installation activities are anticipated.

Operation Impacts. Operation of the Outrigger Telescopes would require periodic maintenance. The Outrigger Telescopes require fewer maintenance operations than the Keck Telescopes and, accordingly, fewer types and amounts of hazardous materials. With the exception of carbon dioxide, which is present as a compressed gas, no hazardous materials used in the operation of the Outrigger Telescopes would be stored on site. Instead, these materials, which are few in number, would be transported to the summit as needed (CARA 2000b). Once on the summit, hazardous materials used for the Outrigger Telescopes would be controlled by procedures in the CARA Safety Manual. It is not expected that any new materials (i.e. materials not currently used for the Keck Telescopes) would be needed for the Outrigger Telescopes. **No mercury would be used for the Outrigger Telescopes** (CARA 2001d). Given the reduced need for hazardous materials and the management practices in place to handle these materials, no impacts from operation activities are anticipated.

Table 4-5 compares current hazardous materials use for the Keck Telescopes with material required for the Outrigger Telescopes.

The following briefly describes anticipated observatory maintenance activities and operations for the Outrigger Telescopes.

Lubrication of Ball Bearings. During operations, the Outrigger Telescopes would rotate on wheels that contain sealed ball bearings. These bearings require periodic lubrication, which would be accomplished by injecting lubricant directly into the sealed bearing track. Old lubricant would be removed with a rag by simply wiping it from small holes placed along the bearing track.

TABLE 4-5. EFFECT OF OUTRIGGER TELESCOPES ON HAZARDOUS MATERIALS USE AT THE W.M. KECK OBSERVATORY

Material Class	Current Use at the W.M. Keck Observatory	Anticipated Requirements of Outrigger Telescopes
Cooling	Propylene glycol, Keck I, 1.1 kl (300 gal); ethylene glycol, Keck II, 1.1 kl (300 gal); 2.3 kl (600 gal) glycols in storage	No glycol used
Fuel	Diesel 9.5 kl (2,500 gal) in underground storage tank for emergency generator	No fuel required; emergency power provided by existing infrastructure
Hydraulic fluid	Each Keck Telescope uses 2.3 kl (600 gal); 210 l (55 gal) in storage	No hydraulic fluid used
Laser dye	Mixture of ethanol and R2 perchlorates	No laser dye used
Lubricants	Grease used as needed; several 20-1 (5-gal) pails in storage Each Keck Telescope uses 1.9 kl (500 gal); 0.4 kl (100 gal) in storage	Gear oil (66 l per Outrigger Telescope) and grease used; no additional lubricants stored on site
Mercury	5.8 kg (13 lb) in use, 7.7 kg (17 lb) in storage	No mercury used
Mirror decoating, recoating, and maintenance	Up to 4 mirrors (of 78) recoated each month; hydrochloric acid, 20 l (5 gal) in storage; potassium hydroxide, 2 kg (4 lb) in storage; copper sulfate, 1.4 kg (3 lb) in storage; hydrofluoric acid, several centiliters (several ounces) in storage	Up to six mirrors decoated with hydrochloric acid every 2 years; no additional chemicals stored on site
Other compressed gases	Carbon dioxide used for snow cleaning, two 8.6-kl (300 ft^3) bottles used each month; helium, nitrogen, oxygen, acetylene in use	Carbon dioxide used for snow cleaning monthly; 8.6-kl (300-ft^3) bottle stored in each Outrigger Telescope
Paints and related solvents	Various amounts stored on site	Used as needed; no additional paint and solvents stored on site

The rags and grease along with similar wastes from the Keck Telescopes would be disposed by a licensed disposal contractor (UH IfA 2001a).

Mirror Recoating. The Outrigger Telescope primary mirrors would require recoating in the same manner as the mirror segments for the Keck Telescopes. Thus, there would be an addition of four, and possibly up to six, Outrigger Telescope mirrors to the existing 78 Keck Telescope mirror segments that would require periodic recoating. The six Outrigger Telescope mirrors would increase the total number of mirrors requiring recoating by less than 8 percent. The W.M. Keck Observatory could wash the Outrigger Telescope mirrors once a year using a soap and water solution (no hazardous chemicals) and only re-aluminize them every 2 to 3 years at the same interval for recoating the Keck mirror segments (CARA 2001d).

The Outrigger Telescope secondary and tertiary mirrors would not require periodic recoating (CARA 2004e). The Outrigger Telescopes would contain smaller optics in the interferometer ranging in size from very small (25 millimeters (1 in (in)) to 0.5 m (1.6 ft)). The smaller optics would require periodic recoating, but because they are located in a more protected environment, recoating would only be necessary approximately every 4 years. The smaller optics could have silver or gold coatings. The W.M. Keck Observatory has not decided whether to recoat these optics on site or to send them out for recoating (CARA 2000d).

The procedure for removing the old aluminum coating on Outrigger Telescope mirrors and applying a new one would be the same as described previously for the Keck Telescope mirror segments. The active ingredients in the aluminum removal solutions would also be the same. The rinse water from the aluminum removal process would be collected and transported off the site.

The Outrigger Telescopes primary, secondary, and tertiary mirrors would require spray cleaning with carbon dioxide on a monthly basis, the same frequency as described for the Keck Telescopes. The W.M. Keck Observatory would store one 8.6-kl (305-ft^3) bottle in each Outrigger Telescope. It is anticipated that each bottle would last for more than 6 months (CARA 2004f).

Other Operations and Maintenance. The W.M. Keck Observatory would not use glycol or hydraulic fluid in the Outrigger Telescopes (CARA 2004e). The W.M. Keck Observatory would use 66 l (17.5 gal) of gear oil and 1 l (1 qt) of grease per Outrigger Telescope.

Additional Precautionary Measures. All on-site construction and installation contract(s) would contain provisions regarding the management of hazardous materials (see Appendix F). Even though there is no impact resulting from the handling of solid waste and hazardous materials, the following additional precautionary measures will be taken.

Such provisions include but are not limited to the following:

- Only the amount of hazardous materials that will be used for a particular activity will be transported to the W.M. Keck Observatory
- The contractor would maintain a log of all hazardous materials brought up to the summit. This log would be available for inspection by the CARA Safety Officer.
- Painting equipment would be cleaned off site to reduce the risk of a spill (CARA 2004d).
- Equipment will be refueled on site from a refueling truck (CARA 2004a). To minimize the potential for a fuel spill, no equipment fuel tank would be filled to the top.

4.1.5 Geology, Soils, and Slope Stability

4.1.5.1 ROI for Geology, Soils, and Slope Stability

The ROI for assessing the potential impacts from implementing the Outrigger Telescopes on geology, soils, and slope stability would be the summit of Mauna Kea and areas near Hale Pōhaku where construction staging and laydown activities would take place.

4.1.5.2 Impacts of the Outrigger Telescopes Project on Geology, Soils, and Slope Stability

On-Site Construction and Installation Impacts. There would be only small and not significant impacts during the construction phase of the Outrigger Telescopes. Materials excavated for foundations and connecting conduits for the Outrigger Telescopes would be removed for use elsewhere, and would not be deposited over the sides of the cones. Because Outrigger Telescopes 3 and 4 are to be built close to the steep edges of Puʻu Hauʻoki, retaining walls would be built at the upper edges of these slopes so that excavated cinders and debris do not cascade downslope during construction. This would also prevent foot traffic from degrading the slope edge following construction. Excavated material will be used as backfill to cover light pipes and airpipes, and to provide screened and washed cinder for Wēkiu bug habitat restoration.

A temporary silt fence will be installed along the crater rim to facilitate on-site containment of all material, including cinder, so that no material spills over the slope. A silt fence will be used whenever excavation occurs within 1.8 m (6 ft) of the slope.

The CARA Construction Manager and the on-site construction and installation contractor(s) will prepare a Construction Best Management Practices Plan (BMP) in consultation and coordination with OMKM and UH. The BMP will be finalized prior to the start of construction. This BMP will reference the MOA and include it as an appendix.

Operation Impacts. There would be no impacts during the operations phase of the Outrigger Telescopes.

Additional Precautionary Measures. Even though impact on soils, slope stability, and geology would be small and not significant, the following additional precautionary measure will be taken.

- All excavated material not necessary for backfill or Wēkiu bug habitat restoration will be transferred to other locations accessible from the established roads on the summit of Mauna Kea. These locations will be identified in consultation with the Hawaiʻi SHPO and OMKM prior to the start of construction.

4.1.6 Land Use and Existing Activities

4.1.6.1 ROI for Land Use and Existing Activities

Land use refers to the use permitted by the State Land Use Commission within a particular State Land Use District. Existing activities refer to the types of physical activities that occur within a designated area (e.g., hiking, sightseeing, scientific research).

Impacts on land use were based on whether project activities would be consistent with State and local plans and on whether land uses would be compatible with State land use designations. Impacts on existing activities were assessed by identifying the activities that occur within the ROI and evaluating whether the Outrigger Telescopes Project would have any short- or long-term effects on them.

The ROI for assessing land use impacts includes the MKSR and Hale Pōhaku. The ROI for assessing existing activities impacts includes the MKSR and other areas affected by on-site construction, installation, and operations; these include the Mauna Kea Natural Area Reserve, Hale Pōhaku, and vehicle travel routes.

4.1.6.2 Impacts of the Outrigger Telescopes Project on Land Use and Existing Activities

Land Use

On-Site Construction and Installation Impacts. The MKSR is contained entirely within the Resource Subzone of the Conservation District. On-site construction and installation of the Outrigger Telescopes would be consistent with uses permitted in the Resource Subzone (see Section 3.1.1). In addition, the proposal to locate the Outrigger Telescopes in the Astronomy Precinct is consistent with the recently adopted 2000 MKSR Master Plan (UH 2000b), which designates the MKSR as a multi-use resource, and currently supports a variety of scientific, cultural, and recreational uses (UH 2000b). Furthermore, the Outrigger Telescopes would lie within the area of the MKSR designated for astronomy activities and would be consistent with that use.

Support activities at Hale Pōhaku connected to the Outrigger Telescopes Project would also be consistent with current land uses. In conclusion, there would be no land use impact associated with this phase of the Outrigger Telescopes Project.

A Coastal Zone Management Act compatibility determination does not apply to NASA's proposal to fund the Outrigger Telescopes on Mauna Kea (DBEDT 2004).

Operation Impacts. The operation of the Outrigger Telescopes would be consistent with the current designated land use. There would be no land use impact associated with this phase of the Outrigger Telescopes Project.

Existing Activities

On-Site Construction and Installation Impacts. Activities associated with the on-site construction and installation of the Outrigger Telescopes Project would occasionally delay traffic along the Mauna Kea Access Road and temporarily increase noise levels. See sections related to transportation (Section 4.1.7) and noise (Section 4.1.11) impacts for additional information. It is also anticipated that the viewscape of the proposed site and construction staging areas at the summit and Hale Pōhaku would be temporarily impacted by the presence of large construction equipment, materials, and telescope components. See Section 4.1.12 for more information regarding visual impacts.

Although some transportation, noise, and visual impacts would occur, it is anticipated that the Outrigger Telescopes Project would not result in a long-term conflict with or have a substantial impact on existing activities in the ROI. The ability to use the land within the ROI for cultural and religious practices, astronomical and other scientific research, and a variety of recreational activities would remain consistent with the current use. In conclusion, all construction and installation activities on Mauna Kea would be conducted in a manner that would allow the surrounding area to remain accessible for all existing activities. See Section 4.1.1 for a detailed discussion of cultural and religious impacts.

Operations Impacts. All telescope and facility operations associated with the Outrigger Telescopes Project would be conducted in a manner that would preserve access to the surrounding area for all existing activities. The only continuing impact of the Outrigger Telescopes operations on existing activities would be the visual presence of the telescope enclosures. However, because the Outrigger Telescopes would be located next to the much larger Keck I and II structures, their

impact would be a small increment to the impact that has already occurred.

Mitigation Measures. Refer to the following sections of this chapter for mitigation measures associated with transportation (Section 4.1.7), noise (Section 4.1.11), and visual impacts (Section 4.1.12).

4.1.7 Transportation

4.1.7.1 ROI for Transportation

The ROI for assessing transportation impacts from the Outrigger Telescopes Project includes the MKSR and other areas affected by on-site construction, installation, and operations including Hale Pōhaku and vehicle travel routes.

Transportation refers to the movement of vehicles along roads. This section addresses the impact of short- and long-term traffic levels on the local traffic network and its effect on the natural setting of Mauna Kea.

4.1.7.2 Impacts of the Outrigger Telescopes Project on Transportation

On-Site Construction and Installation Impacts. An estimated 15 construction workers would be on the project site during the first 24 months; an additional 15 workers would overlap the construction work during the last 5 months to assemble the domes and install the telescopes. It is assumed that each worker would have a light-duty, gasoline-fueled vehicle traveling to the site from an off-mountain location 5 days a week (approximately 120 km (75 mi) per day). In addition, as described in Section 4.1.1, it is assumed that a cultural monitor and an archaeologist would travel daily from off-mountain to the summit. Four heavy-duty diesel trucks (cement, water, flatbed trucks, etc) would make 1,000 round trips over the life of the project traveling approximately 120 km (75 mi) per day. Other equipment would remain on site at Hale Pōhaku and would travel from there to the summit (approximately 13.4 km (8.3 mi)) as needed. At any one time as many as six container loads of dome enclosures and/or telescope components would travel from the harbor at either Kawaihae or Hilo to the summit area, and would be off-loaded at the staging area and delivered to the W.M. Keck Observatory for assembly.

Vehicular traffic would occasionally delay traffic along the Mauna Kea Access Road. The greatest traffic delays would occur when the telescopes and domes are trucked up the mountain. This traffic would occur only intermittently and thus should not regularly interfere with normal traffic flow. While construction vehicles are slow and difficult to maneuver, they would not have any long-term impact on either the road or overall traffic flow.

Construction traffic within the ROI would create minor short-term increases in dust and emissions and temporarily increase noise levels. See Section 4.1.10 for impacts associated with air quality and Section 4.1.11 for information on noise impacts.

It is also anticipated that the current viewscape of the proposed site and construction staging areas at the summit and Hale Pōhaku would be temporarily impacted by the presence of large construction vehicles. See Section 4.1.12 for more information regarding visual impacts. Overall, this project phase would result in short-term minor impacts.

Transportation of minimal quantities of hazardous materials (e.g., diesel fuel, motor oil, paints, and solvents) and wastes would be expected throughout the construction and installation phases of the Outrigger Telescopes Project (see Section 4.1.4). Handling these materials would be guided by a Construction Best Management

Practices Plan. No impact would be expected.

Operation Impacts. An estimated two to three roundtrips per day and about one roundtrip per night along the Mauna Kea Access Road would be required during the operations phase of the Outrigger Telescopes Project (UH IfA 2002b). The number of trips by service vehicles, such as water and fuel trucks, would not be expected to increase (UH IfA 2001a). In conclusion, this slight increase in traffic associated with this project phase would create a very small impact on transportation.

Mitigation Measures. Trips by heavy trucks will be scheduled during off-peak hours to avoid interfering with normal traffic flow in Kawaihae, Waimea, or along the Saddle Road. In addition, CARA will coordinate with other road users to avoid traffic problems when non-standard-sized loads are transported from the staging areas to the W.M. Keck Observatory.

4.1.8 Utilities and Services

4.1.8.1 ROI for Utilities and Services

The ROI for assessing utilities and services impacts of the Outrigger Telescopes Project includes the W.M. Keck Observatory, the MKSR, Hale Pōhaku, and vehicle travel routes.

This section addresses potential impacts on water supply, electrical supply and communications, and emergency services and fire suppression.

4.1.8.2 Impacts of the Outrigger Telescopes Project on Utilities and Services

Water Supply

On-Site Construction and Installation Impacts. On-site construction of four, and possibly up to six, Outrigger Telescopes would result in an increase in the demand for potable water due to the increased number of workers at the site and the implementation of dust controls and cinder washing (see Section 4.1.3.2). The construction contractor(s) would transport this additional water to the summit area. Therefore, there would be no impact on the existing water supply at the W.M. Keck Observatory site.

Operation Impacts. Current water consumption at the W.M. Keck Observatory site is typically 11 kl (3,000 gal) per week for all purposes (UH IfA 2001a). Operational support at the summit would not require additional water tanker trips nor would it impact the Island's water supply (UH IfA 2001a).

Electrical Power and Communications

On-Site Construction and Installation Impacts. On-site generators provided by the construction contractor would provide power. Electrical generators would be staged on site to provide additional electrical power for equipment during construction and installation. Only a minor increase in demand for electrical power on the summit distribution system would occur during this period. This increase would have no impact on the existing electrical supply system.

Operation Impacts. The electrical power requirement for each Outrigger Telescope is estimated to be 30 kilowatts (kW) (UH IfA 2001a). Peak demand load at the Hale Pōhaku substation for all facilities on the summit (including Keck I and Keck II) is currently approximately 2,230 kW. Peak electrical demand at the W.M. Keck Observatory site is currently 525 kW; operation of the Outrigger Telescopes would increase this demand by about 34 percent to 705 kW (CARA 2004i). Peak electrical power usage at W.M. Keck Observatory, with the two Keck Telescopes and the six

Outrigger Telescopes in operation, would be about 70 percent of its existing 1,000-kW capacity (CARA 2004i). The Hale Pōhaku substation has the electric power capacity to accommodate the additional operation of all six Outrigger Telescopes.

In conclusion, the addition of four, and possibly up to six, Outrigger Telescopes would have no impact on the electrical supply system at the W.M. Keck Observatory site.

The existing communications system for Keck I and Keck II has adequate capacity to accommodate the addition of the Outrigger Telescopes. Additional fiber optic cable systems would be installed to link the Keck Telescopes and the Outrigger Telescopes into a functionally integrated system. These activities would have no impact on the existing system.

Emergency Services and Fire Suppression

On-Site Construction and Installation Impacts. The need for emergency services is related to the number of personnel at the summit and the types of work or activities they perform. As stated already approximately 15 construction workers would be on the project site during the first 24 months; an additional 15 would overlap the construction work during the last 5 months to assemble the domes and install the telescopes.

The construction contractor would have the primary responsibility of ensuring worker safety. In the event of an injury or accident, the existing emergency preparedness plan and evacuation equipment and procedures that apply to the W.M. Keck Observatory and all observatories at the summit would be adequate to provide treatment on-site or evacuation off the summit. No additional equipment or personnel or modification of emergency procedures are anticipated during on-site construction. There would be no impact associated with this phase of the Outrigger Telescopes Project.

Operation Impacts. It is estimated that four personnel would be required for testing the Outrigger Telescopes and four more when operations begin. Existing emergency services and procedures would be adequate to accommodate this small increase in personnel.

The Outrigger Telescopes would include fire alarm systems and suppression equipment similar to those in use at Keck I and Keck II. No special fire suppression or response equipment or procedures would be required for operation of the Outrigger Telescopes. The additional personnel would follow established procedures and would be included in existing W.M. Keck Observatory fire drills and annual fire safety training. There would be no impact associated with this phase of the Outrigger Telescopes Project.

4.1.9 Socioeconomics

4.1.9.1 ROI for Socioeconomics

The ROI for assessing socioeconomic impacts would primarily be the MKSR and communities where construction staff and astronomers reside.

4.1.9.2 Impacts of the Outrigger Telescopes Project on Socioeconomics

On-Site Construction and Installation Impacts. It is anticipated that Construction workers would either commute from sea level or reside in at the Hale Pōhaku construction camp.

The cost for on-site construction and installation of four Outrigger Telescopes and domes is estimated at $10 million. The cost for on-site construction and installation of the remaining two Outrigger Telescopes

would probably be between $2.5 and $3 million. The total construction and installation cost of all six Outrigger Telescopes and domes would be about $13 million; a 2 percent increase in capital expenditures over that required for the existing Mauna Kea observatories (see Table 3-11). The addition of approximately 35 jobs (construction crews, archaeologist, cultural monitor, etc.) would temporarily increase the staff of the Mauna Kea observatories by about 7 percent. This construction spending and job growth would have a positive impact on the community.

Operation Impacts. NASA would also fund the Outrigger Telescopes operation. It is estimated that a total of eight full-time personnel would be added to the W.M. Keck Observatory staff; four would be hired when testing of the Keck Interferometric Array begins and four more when operations begin. In addition, there could be several new technicians who would work on the summit. Overall, the daytime presence at the summit would be increased by a maximum of seven people; The Outrigger Telescopes operations would increase the current operating budget of the W.M. Keck Observatory by $5 to $7 million a year. This represents an 11 percent increase in the total operating costs of the Mauna Kea observatories. Economic benefits would flow primarily to the Hilo and Waimea communities in the County of Hawaii. In summary, the Outrigger Telescopes Project would have a small positive socioeconomic impact on the County and State of Hawai‘i.

Commercial Activities. The addition of the Outrigger Telescopes at the W.M. Keck Observatory is not expected to produce any substantial increase in commercial tour traffic or similar activities.

4.1.10 Air Quality

4.1.10.1 ROI for Air Quality

The direct emissions ROI is considered to be the area around the Astronomy Precinct, a corridor surrounding the Mauna Kea Access Road and Saddle Road. Dust or equipment emissions from construction within the Astronomy Precinct or from traffic along the unpaved or paved roadways could impact air quality.

4.1.10.2 Impacts of the Outrigger Telescopes Project on Air Quality

On-Site Construction and Installation Impacts. On-site construction and installation of the Outrigger Telescopes and dome enclosures would result in short, small, but measurable, levels of air pollution. Dames & Moore analyzed the air quality impacts from on-site construction of the Outrigger Telescopes (Dames & Moore 1999b). Their findings are summarized below.

Short-term on-site construction effects would come from construction equipment and vehicles exhaust emissions, and fugitive dust emissions from earthmoving activities and vehicle travel on unpaved roadways.

In addition, portable electrical generators which produce exhaust emissions would be used to provide additional electrical power during construction and installation.

Emissions associated with construction activities would be short term and would end with the completion of on-site construction. Strict compliance by the construction contractor with the State Department of Health (DOH) Administrative Rules and the County of Hawai’i grading permit would minimize the short-term effects on air quality.

Air emissions receptors could include humans, flora and fauna, and observatory equipment and optics sensitive to dust concentrations. Cultural practitioners, construction workers, scientists, staff, and visitors to the area could potentially be affected.

Fugitive dust would result from the excavation of approximately 918 cubic meters (m^3) (1,200 cubic yards (yd^3)) of cinder to install about 274 m (900 ft) of light pipe and air pipe trenches and approximately 1,835 m^3 (2,400 yd^3) of cinder from excavation for telescope footings, dome foundations, and light tunnels.

Earthmoving activities would generate dust amounts that can be estimated based on the amount of area disturbed and the period of construction. As stated previously, underground site work for four, and possibly up to six, Outrigger Telescopes would require an estimated 15 construction workers on the project site during the first 24 months; an additional 15 construction workers would overlap during the last 5 months to assemble the dome enclosures and install the telescopes. Installation of the remaining two Outrigger Telescopes, if funded, would likely begin no earlier than 2007.

The Environmental Protection Agency's (EPA) recommended methodology (AP-42 Section 13.2.3 (USEPA 1995)) was used to estimate fugitive dust emissions using available construction equipment information (Dames & Moore 1999b) and soil data (HLA 1991). This analysis updated information on the potential equipment needs for the Outrigger Telescopes Project and used a revised installation schedule.

The fugitive dust emissions of particulate matter (PM_{10}) from the Proposed Action are estimated to be 1.40 metric tons (1.54 tons) or less for the peak construction year. This estimate does not take into account planned mitigation measures.

Table 4-6 summarizes the estimated maximum construction air pollutant emissions calculated and presented in the Dames & Moore analysis. This analysis used conservative assumptions. Each worker was assumed to drive a private, light-duty, gasoline-fueled vehicle to the summit work site, 120 km (75 mi) per day from Hilo or Waimea. This is a conservative assumption, because workers would likely carpool, and some workers would remain at Hale Pōhaku during the workweek. It was further assumed that four heavy-duty, diesel trucks (cement, water, flatbed trucks, etc.) would make 1,000 trips over the life of the project. Other equipment would remain on site and would be used according to the schedule presented in the report (Dames & Moore 1999b). Data about emissions from equipment operated more than 9 months of the year in the Dames & Moore report (Dames & Moore 1999b) were reduced proportionately to account for the on-site construction and installation schedule. Other equipment not considered in the Dames & Moore report was added using the same references as were used in the Dames & Moore report. Representative types of equipment were selected for the analysis and the total usage was estimated (Dames & Moore 1999b).

Carbon monoxide (CO) and nitrogen oxide (NO_x) emissions would be expected from on-site construction equipment and from construction workers vehicles and motorized construction equipment traveling to and from the summit. Much of the vehicular emissions of CO and volatile organic compounds would be emitted over the approximately 120 km (75 mi) of roadways between the Mauna Kea summit area and locations such as Hilo and Waimea, with much of this occurring below the typical

TABLE 4-6. SUMMARY OF THE ESTIMATED MAXIMUM CONSTRUCTION AIR POLLUTANT EMISSIONS (IN TONS PER YEAR)

Sources	Carbon Monoxide (CO)	Volatile Organic Compounds (VOC)	Nitrogen Oxides (NO_x)	Sulfur Oxides (SO_x)	Particulate Matter (PM_{10})
Fugitive dust emissions	—	—	—	—	1.54
Equipment emissions	0.15	0.04	0.29	0.03	0.04
Vehicular emissions	19.65	2.25	2.34	Negligible	Negligible
Total	19.81	2.29	2.63	0.03	1.58
Significance threshold	250	250	250	250	250

Note: Updated using EPA AP-42 Volume I for Fugitive Emissions and Volume II for Equipment and Vehicular Emissions.

inversion layer altitude of about 2,134 m (7,000 ft). The construction emissions would therefore largely have regional impact rather than a site-specific impact. The estimated emissions of all pollutants, including localized fugitive dust emissions, are anticipated to be well below the significance levels of 250 tons per year for suspended particulate and combustion emissions (Dames & Moore 1999b).

Installation of the Outrigger Telescopes primarily involves transporting the telescope dome enclosures and telescopes to the W.M. Keck Observatory site by flatbed trucks. The expected emissions from these activities, including localized fugitive dust and exhaust emissions from the trucks, would remain below the significance threshold for particulate and combustion emissions.

Summit wind velocity usually ranges between 16 and 24 km (10 and 15 mi) per hour, with speeds exceeding 160 km (100 mi) per hour during severe storms (Dames & Moore 1999b). Dust ash and cinder disturbed during excavation could be carried by these winds and deposited on adjacent slopes. Construction would be halted during storms. For purposes of estimating fugitive emissions, an average wind speed of 25 km (15 mi) per hour was assumed. It is possible that excessive dust could impact Wēkiu and their habitat as well as existing telescope mirrors and other sensitive equipment. Dust control at the Observatory site would therefore be imperative. Dust control mitigation measures are described below.

In summary, there would be a small impact on air quality from this phase of the project.

Operation Impacts. Air quality at the Astronomy Precinct and Hale Pōhaku would return to existing conditions once the Outrigger Telescopes Project on-site construction and installation is completed. A slight increase in vehicular traffic and emissions would likely result from scientists and Outrigger Telescopes Project staff traveling on the unpaved section (roughly 7.2 km (4.5 mi)) of the roadway from Hale Pōhaku to the project site. Overall air quality at Mauna Kea would remain very good because of low intensity of use and the substantial winds in effect most of the time. The operation of the Outrigger Telescopes would have no impact on air quality in and around Mauna Kea.

Mitigation Measures. CARA has made a commitment to NASA that the following mitigation measures would be implemented and made part of any construction contracts.

These measures have been included in the NHPA Section 106 MOA found in Appendix B and in the Construction Best Management Practices Plan in Appendix F.

Dust Controls. The following dust control measures will be therefore implemented.

- Potable water will be applied to excavation sites and cinder stockpiles to minimize dust during trenching, bulldozing or other soil disturbance activities. This water would be transported to the site and applied as needed during. It would not be expected to cause any negative impact to the Wēkiu bug; it is possible that application of water to excavation sites could increase the amount of moisture available for Wēkiu bugs.
- Dust generation will be minimized during construction to the extent practicable by water suppression. Only small or contained areas will be affected at any given time.
- Dust-generating activities will be suspended during periods of high winds, and water would be applied to recently exposed cinder and ash to minimize dust.
- Environmentally safe soil stabilizers will be used to reduce dust during and after on-site construction on roads and parking areas when application of potable water is inadequate for dust control.
- Environmentally safe soil stabilizers will be applied under light wind conditions to prevent cinder dust from drifting into Wēkiu bug habitat. Products considered for use will be reviewed by an entomologist knowledgeable of Wēkiu bug ecology before being considered for use.
- Cinder or ash will be moved to temporary stockpile areas and, if necessary, covered with tarps that are tied down. Permanent placement of excavated cinder fill and ash from the project area elsewhere on Mauna Kea during on-site construction will be determined in consultation with the SHPD and the OMKM.

Other mitigation measures will include requiring contractors to minimize combustion emissions by maintaining construction vehicles and equipment properly. Engine emissions will be controlled by the use of functional emission devices as required by law. Equipment idling will be kept to a minimum. Contractor compliance with dust control mitigation measures will be monitored as described in the Wēkiu Bug Monitoring Plan, Section 2.5 (see Appendix E).

4.1.11 Noise

4.1.11.1 ROI for Noise

The ROI for assessing noise impacts from the Outrigger Telescopes Project includes the MKSR and other areas affected by on-site construction, installation, and operations including Hale Pōhaku and vehicle travel routes.

The noise-sensitive receptors within the ROI include cultural practitioners, scientists, staff, recreational users, and other visitors. There are no fixed noise-sensitive receptors, such as residential areas, within the ROI. Noise impacts are inherently localized as noise levels decrease non-linearly with increasing distance from the source.

4.1.11.2 Impacts of the Outrigger Telescopes Project on Noise

On-Site Construction and Installation Impacts. Noise would result from excavation, trenching, grading, installation

of sheet piling for utility protection, installation of junction boxes, construction of light and air pipes, construction of telescope dome foundations, and installation of telescopes and domes.

Actual noise levels would depend upon the mix and duration of construction equipment and methods used. The vibrating hammer used to install sheet piling, would most likely be the loudest piece of equipment used during construction (approximately 95 A-weighted decibels (dBA) at 15 m (50 ft)). It is anticipated that the use of this equipment would be short-term, lasting 1 or 2 days. Short-term noise impacts will be minimized through the use of construction equipment and vehicles with proper noise muffling devices. No blasting would occur during the construction process. Noise from these activities would be inaudible at times at a relatively short distance from the source because of the existing background noise associated with the strong wind conditions at the summit.

Transport of materials and equipment and daily construction traffic would also create noise. Increased noise levels would occur intermittently along routes used by construction and operation equipment. On average, construction worker traffic is expected to add 15 trips in the morning and evening (UH IfA 2002b). Most heavy construction equipment would be stored on site during the construction period. See Section 4.1.7 for additional transportation information. It is anticipated that individuals at Hale Pōhaku and near the Mauna Kea Access Road could hear noise from increased vehicular traffic.

This intermittent, short-term noise could result in minor disturbances to scientists, staff, recreational users, and other visitors within the ROI. In addition, a noise level increase could affect cultural and religious practices. However, any noise disturbances or interruptions would end once on-site construction and installation is completed. Therefore, moderate noise impacts would be associated with this project phase.

Operation Impacts. Operation of the Outrigger Telescopes would result in a negligible increase in noise and a minor increase in vehicular traffic noise at Hale Pōhaku and along the Mauna Kea Access Road. See Section 4.1.7 for additional vehicular traffic information. In conclusion, there would be no impact associated with this phase of the Outrigger Telescopes Project.

Mitigation Measures. Any noise impacts on construction workers will be mitigated by adherence to appropriate Occupational Safety and Health Administration standards. Construction contractor(s) will be required to strictly comply with Hawaii Administrative Rule, Title II, Chapter 46, Community Noise Control. See Section IV of the Construction Best Management Practices Plan (BMP) in Appendix F.

4.1.12 Visual/Aesthetics

4.1.12.1 ROI for Visual/Aesthetics

The ROI for visual impacts is primarily the MKSR and any other area from which the W.M. Keck Observatory would be visible, including, but not limited to, Waimea and Honoka'a.

4.1.12.2 Impacts of the Outrigger Telescopes Project on Visual/Aesthetics

On-Site Construction and Installation Impacts. Any impacts to the view planes associated with on-site construction and installation of the Outrigger Telescopes Project would be temporary and short term. These impacts would stem from the transport of construction equipment and machinery up to Hale Pōhaku and to the

W.M. Keck Observatory site, and the minor additional vehicular traffic transporting the workforce to the work sites. Construction activities and machinery at the W.M. Keck Observatory site would be visible from most locations within the Astronomy Precinct. These activities and machinery would also generally be visible from off-mountain locations to the north and west of the summit such as Waimea and Honoka'a.

The use of dust control measures during construction will substantially mitigate this potentially visible evidence of construction activity.

Operation Impacts. The Outrigger Telescopes would be visible from most locations within the Astronomy Precinct. However, they would not be visible from the true summit, and one or more Outriggers would generally be obscured by the Keck Telescope domes.

Below the summit area, the mountain topography would determine visual impacts from the Outrigger Telescopes. The Outriggers would generally be visible from off-mountain locations to the north and west of the summit such as Waimea and Honoka'a. They would not be visible from locations to the east and south such as Hilo and the Saddle Road (see Figure 3-14). Where visible, the Outrigger Telescopes' visual impact would be small compared to the impact of the much larger Keck Telescope domes.

CARA has designed the dome ring walls to blend into the natural color of the surrounding weathered cinder. This is compliant with mitigation measures set forth in the 2000 MKSR Master Plan (UH 2000b) and the Section 106 MOA (see Appendix B).

In summary, the Outrigger Telescopes would have a small impact on Visual/Aesthetics.

4.1.13 Environmental Justice

Executive Order 12898 and the companion Presidential Memorandum signed February 11, 1994, direct Federal agencies to include in their NEPA documents an analysis of the human health and environmental effects of their actions on minority and low-income communities, and where appropriate, develop mitigation measures to reduce or avoid significant and adverse effects.

Evaluation of the environmental impacts of on-site construction, installation, and operation of the Outrigger Telescopes Project in Section 4.1 of this Draft EIS has indicated that these impacts would range from very small to negligible. Because there are no substantial human populations in the vicinity of the proposed project, these impacts would not result in any pollutant emission level that would potentially adversely impact human health.

Therefore, on-site construction, installation, and operation of the Outrigger Telescopes at the W.M. Keck Observatory would not have disproportionately high or adverse human health or environmental effects on low-income or minority populations. However, NASA recognizes the special cultural and spiritual significance of Mauna Kea to members of the Native Hawaiian community. See Section 4.1.1 for a discussion of the cultural resource impacts.

Mitigation Measures. See Chapter 5 for a summary of measures that would be implemented to mitigate cultural resource impacts.

4.1.14 Adverse Environmental Impacts That Cannot Be Avoided

Adverse impacts are divided into short- and long-term effects. Short-term effects are generally associated with construction and last only during the construction period. Long-term effects generally follow

completion of the improvements and are permanent. Adverse and unavoidable short- and long-term effects are described below:

4.1.14.1 Unavoidable Adverse Short-Term Effects

- Operation of construction equipment, trucks, and worker vehicles would temporarily impede traffic along the public roads serving Mauna Kea during the construction period. This minor impact would be intermittent and temporary and would cease once construction is completed. The transport of large machinery and large Outrigger Telescope components could temporarily impede traffic flow and result in temporary traffic delays on the highway serving Mauna Kea, the Mauna Kea Access Road, and the road to the summit. These impacts would be limited to a very brief period at the beginning and end of the construction period.
- Increased vehicular traffic and internal combustion engines on heavy equipment would generate emissions. These emissions would be localized and would not impact the overall air quality on the island of Hawai‘i. Emissions from construction-related vehicles and equipment would cease once construction is completed.
- Heavy construction equipment operations on site and increased traffic along the access road would lead to temporary generation of small dust particles. Although daily mitigation measures would be taken to significantly reduce these impacts, some soil would occasionally be subject to erosion during periods of high winds.
- Heavy construction equipment operations on site and the transport of large machinery along the public roads serving Mauna Kea would lead to intermittent and temporary increases in noise levels. This transport would occur during a very brief period at the beginning and end of the construction period.
- Construction equipment, related materials, and temporary structures located on site during the construction phase of the project would affect the visual quality of the area for some viewers. Any changes to the visual quality of the area would be temporary because all equipment and excess materials would be removed at completion of construction.

4.1.14.2 Unavoidable Adverse Long-Term Effects

- As indicated during the scoping for this EIS, the presence of the Outrigger Telescopes would adversely impact the visual quality of the summit area for some of the people using the mountain, particularly many Native Hawaiians.
- In addition, many Native Hawaiians believe the Outrigger Telescopes would add to the observatories' already adverse impacts on cultural values related to the mountain.

> *"When an agency is evaluating reasonably foreseeable significant adverse effects on the human environment in an environmental impact statement and there is incomplete or unavailable information, the agency shall always make clear that such information is lacking."*
>
> *40 CFR 1502.22*

- The small additional workforce necessary for operation of the Outrigger Telescopes would result in a small increase in wastewater at the Keck Observatory. While this is not

anticipated to have an adverse environmental impact, many Native Hawaiians view this as an adverse impact on the cultural values associated with Mauna Kea.

- Workforce traffic associated with the Outrigger Telescopes would result in very minor increases in noise levels along the public roads serving Mauna Kea, including the Saddle Road and the Mauna Kea Access Road.
- On-site construction and installation of the Outrigger Telescopes would disturb a small portion of Wēkiu bug habitat that was previously disturbed by Keck Observatory construction (see Section 4.1.3). However Wēkiu bug habitat would be restored at a ratio of at least 3:1.

4.1.15 Incomplete or Unavailable Information

Detailed project plans are not yet available for reasonably foreseeable future activities. In the absence of this information, the cumulative impact analysis has been carried out under a set of conservative assumptions.

Although knowledge of Wēkiu bug ecology and population dynamics is incomplete, existing information indicates that implementation of the Outrigger Telescopes Project would not have substantial adverse impacts on the Wēkiu bug or its habitat. Because the Outrigger Telescopes Project would disturb a very small amount of previously disturbed habitat at the margins of the already developed Keck Observatory site, the Project has committed to implementation of a Wēkiu Bug Mitigation Plan during on-site construction and installation, continuing into facility operation. Key elements of the Plan are restoration of Wēkiu bug habitat along the slopes of Puʻu Hauʻoki and in the crater bottom, monitoring the effectiveness of the restoration, and conducting additional studies of Wēkiu bug ecology. Thus, the Outrigger Telescopes Project would contribute substantially to the knowledge base of this rare species of Hawaiian biota.

4.1.16 Relationship between Short-Term Uses of the Human Environment and Maintenance and Enhancement of Long-Term Productivity

The proposed project would be an important addition to Hawaiʻi's growing research and development industry, which can provide broadened employment opportunities for State residents. The productivity of Mauna Kea's summit region, however, cannot be measured in purely traditional economic terms. Mauna Kea is a natural and scientific resource that belongs to all State residents and future generations. A goal of the 2000 MKSR Master Plan is to integrate and balance cultural, natural, education/research, and recreational values and uses in a physical and management plan which will provide a framework and structure for the responsible and sustainable stewardship of the MKSR.

4.1.17 Irreversible and Irretrievable Commitment of Resources

The proposed project would require a commitment of natural, physical, and human resources. In all of these categories, an irreversible and irretrievable commitment of resources would occur. A commitment of resources is irreversible when primary or secondary impacts limit the future options for a resource. An irretrievable commitment refers to the use or consumption of resources neither renewable nor recoverable for future use.

On-site construction of the Outrigger Telescopes would consume energy and

building materials. In general, natural and propane gas and diesel fuel would be consumed directly by construction equipment and to generate electrical power and heat. The electrical power requirements of each Outrigger Telescope are estimated to be 30 kW (UH IfA 2001a). Four Outrigger Telescopes would require 120 kW and six would require approximately 180 kW. The additional electrical demand would be supplied largely thru fossil-fuel power generation by the electrical utility supplying the observatories. Petroleum products would continue to be consumed during operation; however, quantities would be significantly less than during construction. Construction materials such as steel, cement, and aggregate would also be expended. These physical resources are generally in sufficient supply, and their use by the project would not have an adverse effect on their availability. In some instances, at least some material resources such as structural steel and copper wiring could be reclaimed, recycled, and reused.

Although the proposal specifically addresses areas that are currently used and previously developed, a small portion of a previously disturbed area containing Wēkiu bug habitat would be displaced, and an additional small portion would be disturbed. This small impact to Wēkiu bug habitat would be mitigated by 3:1 habitat restoration.

With respect to human resources, trade and non-skilled laborers would be used during the on-site construction and installation of the Outrigger Telescopes. An estimated construction crew of 15 workers would be on the project site during the first 24 months, with an additional 15 workers overlapping the construction work by 5 months to assemble the domes and install the telescopes. Outrigger Telescopes operations would require four additional personnel for testing and four more when operations begin. Labor is generally not considered to be in short supply, and commitment to the project would not have an adverse effect on the continued availability of these resources.

4.2 CUMULATIVE IMPACT ASSESSMENT

The Council on Environmental Quality (CEQ) NEPA implementing regulations at 40 CFR 1508.7 define cumulative impacts as the incremental environmental impacts of the action when added to other "past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions." Cumulative impacts can result from individually minor, but collectively significant, actions taking place over time.

As noted by CEQ in its handbook *Considering Cumulative Effects Under the National Environmental Policy Act* (CEQ 1997), no universally accepted framework for cumulative effects analysis exists. NASA, however, has taken into account the principles and steps outlined in CEQ's handbook in developing the cumulative impact assessment of the Outrigger Telescopes Project contained in this section.

During the scoping process for this EIS, NASA consulted with interested agencies and the public who identified the following important cumulative impact areas associated with the Outrigger Telescopes Project: the Wēkiu bug and its habitat on Mauna Kea; the release of sewage system effluents into subsurface cinder at the summit; and, even more importantly, the central role of Mauna Kea in the cultural and spiritual life of Native Hawaiians.

NASA then determined that the general geographic scope of the cumulative impact analysis (i.e., the project ROI) would be the

Steps in the Cumulative Impact Assessment

- *Consult with interested organizations and the public through public scoping.*
- *Determine the geographical boundary or ROI.*
- *Determine the time frame to be evaluated.*
- *Determine the data sources available. Ask the community, local organizations, and in this case, the existing Mauna Kea observatories for information regarding reasonably foreseeable projects or activities. Review documentation on past and present projects within the geographical boundary.*
- *Assess the cumulative impacts based on individual or combined activity within the ROI.*

MKSR and a corridor surrounding the Mauna Kea Access Road and the Saddle Road. area where NASA recognized that this general project ROI would not be appropriate for all environmental resources considered, thus the ROI was adjusted where necessary to accommodate the analysis of cumulative impacts for a given resource. For example, the ROI used to assess cumulative impacts on air quality is larger than the ROI used to assess the incremental impact on air quality from the Outrigger Telescopes Project. NASA also determined that, in general, the time frame for the cumulative impact evaluation would extend from about 1964, before the first telescope was installed on Mauna Kea until the year 2033 when the lease agreement between the State of Hawaii and UH ends.

NASA consulted with the community, local organizations, government agencies, and the existing observatories on Mauna Kea to identify projects and activities on or near Mauna Kea that could occur within the ROI and within the reasonably foreseeable future, i.e., between the present and 2033. Section 4.2.2 identifies and describes these activities.

NASA then identified the potentially affected environmental resources, and evaluated both the project specific and cumulative impacts on these resources.

4.2.1 Past Activities

Table 4-7 identifies activities on or adjacent to Mauna Kea completed since astronomy facilities were established on Mauna Kea in May 1964. Figure 2-4 shows the locations of the observatories and Figure 2-8 shows the Mid-Elevation Support Facilities. The description of impacts of these past activities is based on State and Federal environmental evaluations prepared for those activities. These documents are referenced in Section 1.4 and in Chapter 10 of this EIS.

University of Arizona Site Test Telescope. Erected in May 1964 on Pu‘u Poliahu, the University of Arizona 0.3-m (12-in) Site Test Telescope was used intensively for a 6-month test program. The telescope and enclosure were subsequently removed from the mountain.

UH 0.6-m (24-in) Telescope. Built by The U.S. Air Force in 1968 at the base of the Mauna Kea summit ridgeline within a 0.0065-ha (0.016-ac) area (US IfA 2004f), this 0.6-m (24-in) telescope is the oldest operational telescope on Mauna Kea. The U.S. Air Force transferred the telescope to UH in 1970. Faculty and students in the UH Hilo astronomy program now use the telescope primarily for teaching and research. Although the telescope was constructed prior to NEPA requirements, operation of the UH telescope facilities was

TABLE 4-7. PAST ACTIVITIES

Project	Location	Sponsor	Description	Project Completion Date
University of Arizona 0.3-m (12-in) Site Test Telescope	Mauna Kea Astronomy Precinct	University of Arizona	0.3-m (12-in) Site Test Telescope. All equipment was removed upon completion of testing.	1964
UH 0.6-m (24-in) Telescope	Mauna Kea Astronomy Precinct	UH	0.6-m (24-in) optical telescope	1968
Planetary Patrol 0.6-m (24-in) Telescope	Mauna Kea Astronomy Precinct	Lowell Observatory	0.6-m (24-in) optical telescope. This facility was removed to make way for Gemini North.	1968
UH 2.2-m (88-in) Telescope	Mauna Kea Astronomy Precinct	UH	2.2-m (88-in) optical/infrared telescope	1970
United Kingdom Infrared Telescope (UKIRT)	Mauna Kea Astronomy Precinct	United Kingdom	3.8-m (12.5-ft) infrared telescope	1979
NASA Infrared Telescope Facility (IRTF)	Mauna Kea Astronomy Precinct	NASA	3.0-m (10-ft) infrared telescope	1979
Canada-France-Hawai‘i Telescope (CFHT)	Mauna Kea Astronomy Precinct	Canada/France/ University of Hawai‘i	3.6-m (12-ft) optical/infrared telescope	1979

TABLE 4-7. PAST ACTIVITIES (CONTINUED)

Project	Location	Sponsor	Description	Project Completion Date
Hale Pōhaku Mid-Elevation Support Facilities	Mauna Kea, along the Mauna Kea Access Road	UH	The original construction camp, including stone cabins and temporary buildings, has since been progressively upgraded and expanded to include dormitory and support facilities to accommodate astronomers and visitors to the summit of Mauna Kea.	1983
Mauna Kea Access Road	Mauna Kea	State of Hawai‘i and MKSS	A jeep trail constructed in 1964 was realigned in 1975 and improved in 1985, allowing safer access to the summit.	1985
James Clerk Maxwell Telescope (JCMT)	Mauna Kea Astronomy Precinct	United Kingdom/Canada/ Netherlands	15-m (49-ft) millimeter/submillimeter antenna	1986
Caltech Submillimeter Observatory	Mauna Kea Astronomy Precinct	Caltech/NSF	10.4-m (34-ft) millimeter/submillimeter antenna	1987
Installation of underground utilities	Saddle Road to summit of Mauna Kea	UH and individual observatories	UH funded the design and installation of the underground power lines connecting the HELCO system at Saddle Road to the summit distribution loop.	mid-1980s

TABLE 4-7. PAST ACTIVITIES (CONTINUED)

Project	Location	Sponsor	Description	Project Completion Date
Very Long Baseline Array (VLBA)	Mauna Kea Science Reserve (outside Astronomy Precinct)	NRAO/AUI/NSF	25-m (82-ft) centimeter-wavelength antenna	1992
W.M. Keck Observatory	Mauna Kea Astronomy Precinct	Caltech/ University of California/ CARA	Two 10-m (33-ft) optical/infrared telescopes (Keck I and Keck II)	1992/1996
Subaru Telescope	Mauna Kea Astronomy Precinct	Japan	8.2-m (27-ft) optical/infrared telescope	1999
Gemini North Telescope	Mauna Kea Astronomy Precinct	USA/UK/Canada/ Argentina/Australia/ Brazil/Chile	8.1-m (26.2-ft) optical/infrared telescope	1999
Jeep Trail Closure	Puʻu Poliʻahu	OMKM	A 274 to 366-m (300- to 400-yard) trail extending up to Puʻu Poliʻahu was closed to vehicles to minimize disturbance to cultural sites.	2001
Submillimeter Array (SMA)	Mauna Kea Astronomy Precinct	Smithsonian Astrophysical Observatory/ Taiwan	Eight 6-m (20-ft) submillimeter antennas	2002
Temporary Optical Test Sites at Keck	W.M. Keck Observatory	Caltech/ University of California	Two temporary optical test sites to assist in the development of the interferometry capability; were removed in 2003.	2003
GTE Fiber Optic Cable Installation	Saddle Road to Hale Pōhaku	UH IfA	A fiber optic telecommunications line was installed connecting the Mauna Kea observatories to the GTE Hawaiian Telephone Company fiber optic system.	1998

addressed in a State EIS completed in 1975 (UH IfA 1975).

Planetary Patrol 0.6-m (24-in) Telescope. The Lowell Observatory of Flagstaff, Arizona, installed and NASA funded a 0.6-m (24-in) telescope and dome enclosure on the Mauna Kea ridgeline in 1968 for long-term monitoring of the planets in our solar system. The telescope was decommissioned and the dome enclosure removed in 1994 when the Gemini North Telescope, which now occupies the site, was constructed.

UH 2.2-m (88-in) Telescope. When this NASA-funded 2.2-m (88-in) telescope was constructed on 0.06 ha (0.14 ac) of the Mauna Kea summit ridgeline in 1970, it was the seventh largest optical/infrared telescope in the world and the first major construction on the mountain. This telescope is now operated by UH from the IfA facility in Hilo, Hawai‘i (UH IfA 2004f). Funded jointly by UH and NASA until 1997, UH now funds it entirely. Operation of the UH telescope facilities was addressed in a State EIS completed in 1975 (UH IFA 1975).

United Kingdom Infrared Telescope (UKIRT). Constructed in 1979 on a 0.49-ha (1.20-ac) parcel at the base of the ridgeline on the summit of Mauna Kea, the UKIRT is a 3.8-m (12.5-ft) diameter telescope optimized for observations in the infrared portion of the spectrum (JACH 2003). The Joint Astronomy Center operates the telescope from the UKIRT headquarters office in Hilo. A State Environmental Impact Statement was completed for the UKIRT facility in 1975 (UH IFA 1975).

NASA Infrared Telescope Facility (IRTF). Like the UKIRT, this 3-m (10-ft) telescope located at the summit of Mauna Kea is optimized for infrared observations. The telescope is operated and managed for NASA by UH from the IfA Facility in Hilo (IRTF 2001). In 1975, UH completed a State Environmental Impact Statement to evaluate the construction of the IRTF facility (UH IFA 1975). NASA also completed a separate Federal Environmental Impact Analysis for the IRTF facility in 1975 (NASA 1975). Today, IRTF serves as a national infrared observing facility for U.S. astronomers, and is used by UH faculty and students approximately 15 percent of the time.

Canada-France-Hawai‘i Telescope (CFHT). Funded jointly by Canada, France and State of Hawai‘i through UH, this optical telescope has a 3.6-m (12-ft) aperture and was completed in 1979 on a 0.74-ha (1.84-ac) parcel. The CFHT headquarters office is located in Waimea. A State EIS was completed in 1974 for the CFHT facility (CFHT 1974).

Hale Pōhaku Mid-Elevation Support Facilities. It is hazardous for persons to go directly from sea level to high altitudes without acclimatizing at an intermediate altitude. For this reason, a construction camp was built in 1968 when work began on the UH 2.2-m (88-in) Telescope. The camp was two-thirds of the way up the mountain at 2,804 m (9,200 ft) along the Mauna Kea Access Road. Three preexisting stone cabins were in this area. Subsequently, four additional temporary buildings were added for visitors and workers on the mountain.

In 1983, permanent mid-level facilities were opened at Hale Pōhaku. The original four observatory operators on the mountain, UH, NASA, United Kingdom, and Canada-France-Hawai‘i, contributed a total of $5.7 million for construction. A 20-person dormitory was added in 1990.

The current complex includes dormitories, separate employee housing, offices, and a large common area equipped with a kitchen, dining hall, and recreational areas. In

addition to the 72 rooms now available for astronomy support personnel and astronomers at Hale Pōhaku, five rooms are available for use exclusively by the Mauna Kea Support Services (MKSS) food and lodging staff (MKSS 2004c). A revised State EIS for the Hale Pōhaku Master Plan was completed in 1980 (State of Hawai‘i 1980).

Also in 1983, a Visitor Information Station (VIS) named for Ellison Onizuka, an astronaut and Hawaii native who perished in the *Challenger* explosion, was added to the Hale Pōhaku complex. Located approximately 198 m (650 ft) south of the main buildings at Hale Pōhaku (UH 2000b), the VIS includes an 88-square meter (m^2) (950-square foot (ft^2)) interpretive center for visitors to the mountain.

Of the four temporary buildings, two were removed and two relocated after the mid-level facilities were completed in 1983. Two were completely refurbished and relocated off the mountain to the Mauna Kea State Park. Two were moved south to create the first phase of the current construction camp, used initially by the Keck I Telescope workers. The need for this camp was realized in the mid-1980s when the scope and pace of observatory development increased. A Supplemental State EIS amending the 1983 MKSR Complex Development Plan was completed in 1985 for this construction camp housing.

The second phase of the camp included the addition of four cabin-like structures, raised off the ground on wood posts and nestled amid the *māmane* trees, with exteriors designed to blend into the surroundings. Each cabin has four bedrooms, with two beds each, for a total of 32 beds. Completed in 1994 for the Subaru project, the cabins housed the construction workers and some workers for the Keck II Telescope and the Submillimeter Array (SMA). The original relocated buildings currently provide office space, storage areas, and a multipurpose classroom. The cabins provide accommodations for VIS and Ranger staff and occasionally for UH Hilo astronomy program participants and special groups (MKSS 2004c). A portion of the camp could be used if future development requires living space for construction workers.

Today the Hale Pōhaku Mid-Elevation Support Facilities, including parking areas, are contained within a 7.8-ha (19.2-ac) footprint (MKSS 2004d).

Mauna Kea Access Road. A gravel road connecting the Saddle Road to Hale Pōhaku was constructed in the 1930s. A jeep trail from Hale Pōhaku to the summit was added in 1964 when the first telescope was installed. In 1975, the jeep trail was realigned to eliminate some of the steep grades and sharp turns, lengthening the original 10.5-km (6.5-mi) road to approximately 13.7 km (8.5 mi) (UH 1987).

The improved roadway was safer, but still dusty. In 1985, with funding from the State of Hawai‘i and W.M. Keck Observatory infrastructure contribution, the State of Hawai‘i Department of Transportation (DOT) designed a 6.1-m (20-ft) wide roadway beginning at Hale Pōhaku and looping around the summit. A portion of the roadway between the 3,597 m (11,800 ft) elevation level and the summit was paved to reduce dust and improve safety. Future plans include paving the roadway between Hale Pōhaku and the 3,597 m (11,800 ft) elevation level and developing additional parking areas and two runaway truck ramps, although this project is not currently funded (UH 1999). When the upper portion was paved in the early 1990s, the road from Hale Pōhaku to the summit was named after John A. Burns, the governor of Hawai‘i during the earliest years of astronomy development.

James Clerk Maxwell Telescope (JCMT). The 15-m (49-ft) JCMT is the world's largest radio telescope designed specifically to operate in the submillimeter wavelength region of the spectrum (JACH 2003). The telescope was completed in 1986 on a 0.61-ha (1.5-ac) parcel on the Mauna Kea summit plateau, west of the Caltech Submillimeter Observatory and south of the SMA. A joint venture between the United Kingdom, Canada, and the Netherlands, JCMT is operated by the Joint Astronomy Center from its headquarters office in Hilo (JACH 2003). The environmental impacts of the JCMT were addressed in the 1983 Mauna Kea Science Reserve: Complex Development Plan Final EIS (UH 1983a).

Caltech Submillimeter Observatory. The Caltech Submillimeter Observatory, completed in 1987, houses a 10.4-m (34-ft) radio telescope designed to work in the submillimeter portion of the spectrum within a compact 18-m (60-ft) dome. Caltech constructed this telescope on a 0.30-ha (0.75-ac) parcel between the three summit cinder cones —Puʻu Poliʻahu to the west, Puʻu Hauʻoki to the north, and Puʻu Wēkiu to the east (Caltech 1982). Caltech operates the telescope under a National Science Foundation (NSF) contract and manages it from the Caltech Submillimeter Observatory headquarters office in Hilo. A combined State and Federal EIS was completed in 1982 (Caltech 1982).

Installation of Underground Utilities. In 1982, following a 16-year attempt to provide off-site electrical power to the summit the State legislature appropriated funds for the Department of Accounting and General Services to conduct a second preliminary design and planning study for a permanent connection to the HELCO system. Based on the results of the study, during the mid-1980s, UH funded the design, construction, and installation of underground power lines connecting the HELCO system at Saddle Road to a summit distribution loop. Individual observatories funded the underground connection from their respective facilities to the summit loop. HELCO conducted the conduit installation and continues to be responsible for maintenance of the electrical system. These permanent power lines replaced a suite of generators that had been upgraded and augmented during the history of the astronomy complex (UH 1987).

Very Long Baseline Array (VLBA). The VLBA is an aperture-synthesis radio telescope consisting of 10 25-m (82-ft) remotely operated antennas, located across the country, from the U.S. Virgin Islands in the east to Hawaiʻi in the west. All 10 antennas are located in United States territories, and the entire project is Federally funded by NSF and managed from a central headquarters office in Socorro, New Mexico. The Hawaiʻi antenna was erected in 1992 at 3,719 m (12,200 ft), a lower elevation than the other observatories, on a 0.81-ha (2.01-ac) subleased parcel. A combined State and Federal Supplemental EIS was completed in 1988 for the VLBA Antenna Facility (UH IfA 1988) as a project-specific amendment to the 1983 *Mauna Kea Science Reserve: Complex Development Plan Final Environmental Impact Statement* (UH 1983a).

W.M. Keck Observatory. The W.M. Keck Observatory houses the world's two largest optical/infrared telescopes. These twin 10-m (33-ft) telescopes are located on the north side of the Mauna Kea summit on a 2-ha (5-ac) subleased parcel. The Keck I Telescope was completed in 1992 and the Keck II Telescope in 1996. Although the telescopes are usually used individually for astronomical research, about 10 percent of the time, the two telescopes are used together as an interferometer (UH IfA

1998b). The W.M. Keck Observatory is managed by CARA, a non-profit organization wholly owned by Caltech and the University of California. The Observatory headquarters office is located in Waimea. The 1983 *Mauna Kea Science Reserve: Complex Development Plan Final Environmental Impact Statement* (UH 1983a) included an environmental evaluation of the W.M. Keck Observatory site and the potential impacts of constructing both Keck Telescopes.

Subaru. Formerly known as the Japan National Large Telescope (JNLT), the Subaru Telescope is an 8.2-m (27-ft) optical infrared telescope located on Pu‘u Hau‘oki, just west of the W.M. Keck Observatory. Construction began in 1991 and first light was achieved in 1999 (Subaru 2003).

The footprint of Subaru totals 2.168 ha (5.356 ac). Operated by the National Astronomical Observatory of Japan, the Subaru Telescope Headquarters office is located in Hilo. The power and communication systems at the summit were extended, and the dirt road accessing the Subaru site was paved in conjunction with observatory construction. Based on the project description completed in 1991 for the JNLT (UH IfA 1991), the State Office of Environmental Quality Control determined that all environmental impacts had been addressed in the 1983 *Mauna Kea Science Reserve: Complex Development Plan Final Environmental Impact Statement* (UH 1983a).

Gemini North Telescope. Gemini North is a twin to the Gemini South telescope located on Cerro Pachón in Chile. Each telescope has an 8.1-m (26.2-ft) diameter mirror. Gemini North was completed in 1999 on 0.78 ha (1.93 ac) of the Mauna Kea summit ridge between the 2.2-m (88-in) UH Telescope and the CFHT on the site of the former UH 0.6-m (24-in) Planetary Patrol Telescope (UH IfA 1994). Originally, the United States provided 50 percent of the observatory funding in partnership with the United Kingdom (25 percent), Canada (15 percent), Chile (5 percent), Argentina (2.5 percent), and Brazil (2.5 percent). The NSF was designated as the Federal agency for the project (NSF 1993). The Gemini Headquarters office is located in Hilo. A Federal EA was completed for the Gemini Telescope in 1993 (NSF 1993). The environmental impacts of Gemini North were addressed in the 1983 *Mauna Kea Science Reserve: Complex Development Plan Final Environmental Impact Statement* (UH 1983a).

Jeep Trail Closure. In 2001, the Office of Mauna Kea Management (OMKM) officially closed the unpaved jeep trail extending up the side of Pu‘u Poli‘ahu (originally cut for the installation of the University of Arizona Site Test Telescope) by erecting barricades and posting signs prohibiting vehicular access, after Kahu Kū Mauna, the cultural advisors to the Mauna Kea Management Board, requested the closure to prevent vehicular disturbance to cultural sites. The 274 to 366-m (300 to 400-yard) trail is still accessible to hikers visiting the peak of Pu‘u Poli‘ahu and spiritual and cultural sites located on Mauna Kea (OMKM 2001).

Submillimeter Array (SMA). The SMA, a collaborative project of the Smithsonian Astrophysical Observatory and the Academia Sinica Institute of Astronomy & Astrophysics of Taiwan, was the world’s first interferometer dedicated to submillimeter astronomy. The array comprises eight 6-m (20-ft) antennas that can be moved among 24 pad locations. Astronomical signals from each antenna are transmitted through fiber optic cables to a supercomputer within the observatory called a Correlator (SMA 2004a). The SMA was

completed in 2003 on a 1.2-ha (3-ac) subleased parcel with additional easements for outlying antennas. The Smithsonian Astrophysical Observatory headquarters office is located in Cambridge, Massachusetts. The SMA is operated from a base facility in Hilo.

The SMA site can be accessed from a road that branches off the Mauna Kea Access Road and proceeds north through "Submillimeter Valley," past the Caltech Submillimeter Observatory and the JCMT. In connection with the SMA construction, the road extending from JCMT to the Pu‘u Poli‘ahu road was paved and a drainage channel added to the east side of the roadway (UH IfA 1994). A project description and State Environmental Review were completed in 1994 for the SMA (UH IfA 1994). Based on this project description and review, the State Office of Environmental Quality Control determined that all environmental impacts had been addressed in the 1983 *Mauna Kea Science Reserve: Complex Development Plan Final Environmental Impact Statement* (UH 1983a).

Temporary Optical Test Sites. Two temporary optical test sites were constructed on the W.M. Keck Observatory sublease, adjacent to the Keck II Telescope, to assist in developing the interferometry capability of the two telescopes. The test sites were connected to the basement of the Keck II Telescope by underground optical paths. The equipment was dismantled and removed in 2003. A Federal EA for the Temporary Optical Test Sites was completed in September 1998 (NASA 1998).

GTE Fiber Optic Cable Installation. A fiber optic telecommunications line was installed connecting the Mauna Kea Observatories to the GTE Hawaiian Telephone Company (GTE HTCo) fiber optic system. An overhead fiber optic line was installed between Pōhakuloa and the HELCO electrical substation at Pu'u Kalepeamoa, then through an underground conduit to Hale Pōhaku, parallel to existing underground electrical lines. The new fiber optic cables were then connected to an existing fiber optic link to the summit from Hale Pōhaku. All construction and installation complied with GTE HTCo standards and applicable State and County requirements (GTE HTCo and UH IfA 1995). A project description and environmental review were completed in 1995 for the GTE fiber optic cable installation (GTE HTCo and UH IfA 1995). Based on the project description and review, the State Office of Environmental Quality Control determined that the environmental impacts for this project had been addressed in the 1983 *Mauna Kea Science Reserve: Complex Development Plan Final Environmental Impact Statement* (UH 1983a).

4.2.2 Reasonably Foreseeable Future Activities

Table 4-8 identifies proposed projects on or adjacent to Mauna Kea that could reasonably contribute to cumulative impacts. For the purposes of this evaluation, reasonably foreseeable refers to initiation of on-site construction or implementation of a planned project on or near Mauna Kea through December 31, 2033, the end of the MKSR lease agreement between UH and the State of Hawaii (State of Hawai‘i 1968). If a project is not currently being pursued, but was included in the 2000 MKSR Master Plan, it was presumed to be reasonably foreseeable unless current information indicates otherwise.

This section identifies reasonably foreseeable future astronomy and non-astronomy-related projects within the ROI.

TABLE 4-8. REASONABLY FORESEEABLE FUTURE ACTIVITIES

Project	Location	Sponsor	Description	Projected Completion Date
1-m Class Instructional Telescope	UH 0.6-m (24-in) Telescope	UH, Hilo	UH-Hilo will assume responsibility for the existing 0.6-m (24-in) observatory site, and the new telescope it will place there, upon initiation of building renovation work (projected for third quarter of 2005).	2006
PanSTARRS	2.2-m (88-in) Telescope on Mauna Kea or Haleakala, Maui	U.S. Air Force	PanSTARRS would consist of four 1.8-m (6-ft) telescopes, each with a 3-degree field of view and a 1-billion-pixel digital camera, making it possible to observe the entire available sky several times during the dark portion of each lunar cycle.	2008
Site Testing and Monitoring	Mauna Kea Astronomy Precinct	UH IfA	UH IfA is proposing to install site-testing equipment in the northwest quadrant of the Astronomy Precinct and on the summit ridge, to assess the quality of those locations for astronomical observations. The northwest plateau installation would be temporary. The seeing monitor component of the summit ridge installation may be proposed as a permanent addition to the infrastructure.	2007
TMT	Astronomy Precinct Mauna Kea Science Reserve	UC/Caltech/ AURA/Canada	A Next Generation Large Telescope, with the ability to provide optical/infrared capabilities 10 times that of the largest exiting telescopes, is proposed to be located within the northwest plateau of MKSR.	2014

TABLE 4-8. REASONABLY FORESEEABLE FUTURE ACTIVITIES (CONTINUED)

Project	Location	Sponsor	Description	Projected Completion Date
OHANA	Six observatories on Summit of Mauna Kea	Paris Observatory, NASA, CFHT, UH, Gemini, and Keck	The Paris Observatory, in collaboration with several other Mauna Kea Astronomy Precinct observatories, proposes to develop an optical/infrared interferometer using an array of exiting telescopes on the summit of Mauna Kea, including UKIRT, CFHT, and IRTF.	Unknown
Redevelopment of CFHT, IRTF, and UKIRT	Summit of Mauna Kea	CFHT, NASA, UK	Redevelopment of 3 to 4-m (10 to 13-ft) telescope facilities.	Unknown
SMA Expansion	Summit of Mauna Kea	Smithsonian Astrophysical Observatory/ Taiwan	A conceptual plan considering adding 12 new antennas and 24 additional concrete pads.	Unknown
Visitor Information Station Expansion	Hale Pōhaku		A proposal to expand the Visitor Information Station at Hale Pōhaku.	Unknown
Completion of Mauna Kea Access Road	Mauna Kea Access Road		The Mauna Kea Access Road would be paved from Hale Pōhaku to 3,597-m (11,800-ft) elevation.	Unknown
End of Lease	MKSR	UH	All structures will be removed from Mauna Kea at the end of the lease (2033) unless otherwise negotiated.	2033
Training at PTA for Stryker Brigade Combat Team Army Transformation Project	Pōhakuloa Training Area	U.S. Army	The Stryker Brigade Combat Team Army Transformation Project would include constructing training and support facilities, acquiring additional lands, and changing training activities and locations.	2007

TABLE 4-8. REASONABLY FORESEEABLE FUTURE ACTIVITIES (CONTINUED)

Project	Location	Sponsor	Description	Projected Completion Date
Remotely Operated Microwave Facility	Eastern slope of Mauna Kea	County of Hawai‘i Police Department	The County of Hawai‘i Police Department proposes to construct a remotely-operated microwave facility on a 389-m^2 (4,192-ft^2) portion of the eastern slope of Mauna Kea at 2,475 m (8,121 ft), south of the MKSR.	December 2008
Keanakolu Road Improvements	Mauna Kea	Federal Highway Administration (FHWA)	FHWA plans to rehabilitate deteriorated road conditions along 19.9 km (12.4 mi) of Keanakolu Road, from its junction with the Mauna Kea Access Road to the entrance to Hakalau Forest National Wildlife Refuge.	Unknown
Development of DHHL Land Acquisition	Base of Mauna Kea Access Road	DHHL	DHHL began planning the long-term land use and management of 22,734 ha (56,178 ac) of public land in Humu‘ula and Pi‘ihonua. Land uses considered include homesteading, commercial/service businesses, ecotourism, forestry, ranching, farming, cinder quarrying, gorse control, and resource areas.	Unknown
Saddle Road Improvements	State of Hawai‘i DOT	State of Hawai‘i	A long-term DOT highway construction project that includes improvements and modifications to the Saddle Road between the Hilo side and Kona side of the island of Hawai‘i, including approximately 402 km (250 mi) of road to be modernized to meet American Association of State Highway and Transportation Officials standards.	Unknown

NASA has determined that a number of projects on Mauna Kea mentioned in other environmental documents (e.g., the 2000 MKSR Master Plan and the 2000 MKSR Master Plan EIS) are not reasonably foreseeable and are addressed at the end of this section.

The reasonably foreseeable future projects are still conceptual in nature. Currently no construction design or operation management plans with quantitative information to use in assessing impacts to environmental resource areas exist.

NASA applied general assumptions as appropriate to reasonably foreseeable future astronomy projects on Mauna Kea to evaluate their cumulative impacts. Additional resource-specific assumptions are provided in the individual environmental resource sections. Table 4-9 summarizes the characteristics of the reasonably foreseeable projects.

Generally Applicable Assumptions for Reasonably Foreseeable Future Activities

- With the exception of buildings to be modified, existing facilities will continue to employ the same number of staff, generate the same amount of waste (solid, hazardous, wastewater), and use the same amount of domestic water and electricity.
- During construction activities, the contractor would be responsible for dust and noise control, and air monitoring as required by applicable environmental regulations, permits, and other agreements.
- On-site electrical generators will provide additional power for equipment during construction and installation of future projects at sites where electrical power is not currently available.
- Equipment needed for on-site construction will be staged at either the summit staging area or the construction staging area at Hale Pōhaku.
- Workers will travel, sometimes in carpools, from Hale Pōhaku to the summit as needed.
- Construction and installation workers, sometimes in carpools, will use light-duty, gasoline-fueled vehicles to travel to the site from off-mountain locations 5 days per week (approximately 120 km (75 mi) per day).
- Water would continue to be trucked to the summit and to Hale Pōhaku, becoming domestic wastewater with subsurface disposal.
- It is assumed that on-site construction, installation, and operation of the future projects will adhere to stipulations in the MKSR Master Plan.
- Construction contractors and their personnel and telescope operators will comply with CDUP requirements, mitigation plans, and best management practices, as stipulated for each project.
- All future facility designs will incorporate new design guidelines — surface treatments (e.g., reflective versus non-reflective), geometrical designs, textures, and materials — to blend facilities into the surrounding environment and minimize visual impacts. All proposed development plans for future projects will be reviewed by the OMKM.

TABLE 4-9. KEY CHARACTERISTICS OF REASONABLY FORESEEABLE FUTURE ASTRONOMY ACTIVITIES

Project	Potential Timing			Type of Project			Construction Effort				Operation Workforce			
	2004-2007	2007-2032	2033	Recycle/Minor Addition	Facility Addition	New Facility	Smaller than OTP	Similar to OTP	Larger than OTP	Much Larger than OTP	Smaller than OTP	Similar to OTP	Larger than OTP	Much Larger than OTP
1-m UH	●			●			●				●			
PanSTARRS	●			●	●		●	●			●			
Site Testing and Monitoring	●			●			●				●			
TMT		●				●				●				●
OHANA	●			●			●				●			
Redevelopment of CFHT, IRTF, and UKIRT		●		●	●				●			●		
SMA Expansion		●			●		●				●			
Visitor Information Station Expansion		●			●			●	●			●	●	
Completion of Mauna Kea Access Road		●			●			●			●			
End of Lease			●			●				●				

Acronyms:

OTP = Outrigger Telescopes Project

POTENTIAL TIMING

1. 2004-2007: Project plans have advanced beyond the concept phase; project potentially initiated within the same timeframe as OTP.
2. 2007-2032: Project currently at conceptual stage only; project is unlikely to be initiated within the same timeframe as OTP.
3. 2033: End of current lease; consider bounding scenarios: all observatories will either continue to operate or be demolished.

TYPE OF PROJECT

1. Recycle/Minor Addition(s): Recycle projects assumed to be primarily internal to existing observatory facility with only minor addition(s) to current facility buildings resulting in little change in the facility footprint on the site. Minor addition(s) would occur within the currently disturbed area of the lease but less than OTP.
2. Facility Addition: Approximately same scale of additional observatory development as OTP. Additional development would occur within the confines of the already disturbed area(s) of the observatory site.
3. New Facility: Project would require either a new observatory site or extensive new facility work on an existing observatory site resulting in a substantially larger facility footprint on the site.

CONSTRUCTION EFFORT (i.e., Onsite Construction and Installation)

1. Smaller than OTP: Workforce about ½ that of OTP; magnitude and duration less than OTP.
2. Similar to OTP: Workforce about same size as OTP; magnitude and duration about same as OTP
3. Larger than OTP: Workforce larger than that required by OTP; Magnitude and duration greater than OTP.
4. Much larger than OTP. Magnitude, duration, and workforce much larger than that required by OTP.

OPERATION WORKFORCE

1. Smaller than OTP: Operation workforce about same as current facility.
2. Similar to OTP: Additional operation workers added; workforce about same size as OTP.
3. Larger than OTP: Operational Workforce larger than that required by OTP.
4. Much larger than OTP. Operational workforce much larger than that required by OTP.

REASONABLY FORESEEABLE FUTURE ASTRONOMY PROJECTS

- *1-m Class Instructional Telescope*
- *PanSTARRS*
- *Site Testing and Monitoring*
- *TMT*
- *OHANA*
- *Redevelopment of CFHT, IRTF, and UKIRT*
- *SMA Expansion*
- *Visitor Information Station Expansion*
- *Completion of the Mauna Kea Access Road*
- *End of Lease*

REASONABLY FORESEEABLE NON-ASTRONOMY RELATED PROJECTS

- *Army Transformation*
- *Remotely Operated Microwave Facility*
- *Keanakolu Road Improvements*
- *Development of DHHL Land Acquisition*
- *Saddle Road Improvements*

REASONABLY FORESEEABLE FUTURE PROJECTS

Replacement of the UH 0.6-m (24-in) with a 1-m (3.3-ft) Class Instructional Telescope. UH Hilo will acquire the UH 0.6-m (24-in) Telescope and proposes to replace it with a 1-m (3.3-ft) class instructional telescope. The existing dome enclosure would be renovated. The telescope would primarily be operated remotely from the UH Hilo campus with infrequent (3 to 4 nights per month) visits to the site, reducing the number of personnel visiting the site and the amount of traffic on the mountain. The facility would use equal or less electricity. UH Hilo has notified OMK M of their intent and will be submitting a formal application later this year. NSF has committed to funding the new telescope through a major research instrument grant, and UH will fund the building renovations. If approved, construction would begin in September 2005 and be completed by September 2006 (UH 2004).

Panoramic Survey Telescope and Rapid Response System (PanSTARRS). PanSTARRS is an innovative design for a wide-field imaging system being developed at UH IfA. The primary objective of PanSTARRS is to detect and characterize Earth-approaching objects, both asteroids and comets, that might pose a danger to our planet. This project would use four 1.8-m (6-ft) telescopes, each with a 3-degree field of view, to observe the available sky several times during the dark portion of each lunar cycle. Each telescope would be equipped with a one-billion-pixel digital camera.

This telescope grouping could obtain a huge amount of valuable information applicable to many other kinds of scientific programs, including mapping the amount of dark matter in the universe and looking for changes in variable stars to help understand the birth and death of stars and planets (UH IfA 2004a).

Sites in the Mauna Kea Science Reserve and Haleakala High Altitude Observatory, located on the islands of Hawai‘i and Maui, respectively, are being considered. Site selection for PanSTARRS would be based on technical, environmental, and cultural resource factors and is expected within the next year. It is currently estimated that, if a site is selected within the next year, the project would be completed by 2008 (UH IfA 2004a). If Mauna Kea is chosen, the UH 2.2-m (88-in) Telescope would be decommissioned so its site could accommodate PanSTARRS. Traffic to the PanSTARRS observatory would be approximately the same as today. Although energy use has not yet been estimated, the

increase in power needs for PanSTARRS is not expected to be substantial because of the comparative energy efficiency of modern equipment.

Site Testing and Monitoring. UH IfA is proposing to install temporary site testing equipment in the northwest quadrant of the Astronomy Precinct at a location along the existing jeep trail. This general area has been designated in the 2000 MKSR Master Plan as the proposed site for the Next Generation Large Telescope (NGLT). The current concept for the NGLT is the Thirty-Meter Telescope (TMT), as described below. The purpose of this site testing would be to assess the quality of the northwest plateau for astronomical observations and to determine its suitability for an NGLT project such as the TMT. The principal component of the site testing equipment would be a 6-m (20-ft) tower on top of which is mounted a seeing monitor instrument and its enclosure, together with a weather station module. Additional equipment would include a 30-m (98-ft) mast supporting microthermal probes and wind sensors, a pair of acoustic sounding instruments at ground level and a solar power unit to provide electricity for the instruments. For the mast, the possibility of using a deployable trailer-mounted unit is being explored. Testing is expected to begin in late 2004 or early 2005 and continue for approximately three years, after which all equipment would be dismantled and removed.

UH is also developing plans to install site testing equipment on the summit ridge at a location between CFHT and Gemini. The purpose of this installation is to assess the astronomical quality of the summit ridge using the same type of instruments that would be used on the northwest plateau. This would provide a reliable comparison between the two siting areas, as well as valuable information for the planning of possible future upgrades and replacements of the existing summit ridge observatories. It is also likely that the seeing monitor component would be useful for the ongoing operations of the existing observatories. The solar power unit would not be needed, as electricity is available nearby. Any use of the acoustic sounding instrument or the mast would be temporary, and in the case of the mast, it is expected that a deployable trailer-mounted unit would be used. Depending on how useful it turns out to be, UH IfA may propose to retain the 6-m (20-ft) tower and seeing monitor as a permanent addition to the observatory infrastructure.

Thirty Meter Telescope (TMT). Advances in telescope technology have made it conceivable to build an optical/infrared telescope roughly 10 times as powerful as the largest current telescopes (the twin Keck Telescopes). Such a development was envisaged in the 2000 MKSR Master Plan as the Next Generation Large Telescope (NGLT). A number of conceptual designs have been considered for an NGLT (UH IfA 2003). At the present time the leading candidate is the TMT, a concept being pursued through a collaboration between the University of California, Caltech, the Association of Universities for Research in Astronomy (AURA), and the Association of Canadian Universities for Research in Astronomy (ACURA). In addition to Mauna Kea, the TMT collaboration is also considering sites in Chile and Mexico. Features from the conceptual designs of the Giant Segmented Mirror Telescope, the California Extremely Large Telescope (CELT) and the Very Large Optical Telescope are being incorporated into the TMT design.

The site within the Astronomy Precinct being considered for the NGLT is located on the northern plateau. This site was chosen

for a number of reasons, including lower potential for wind damage to the facility and lower visibility from off-mountain locations (UH IfA 2000b). Site testing is proposed for the northwest plateau, as described above for site testing and monitoring. Similar tests are also being conducted at the Chile and Mexico sites. The TMT project is currently in the preliminary design phase; funding for construction has not yet been acquired. Should funding for construction be obtained in the future, offsite construction is expected to begin about four years later, with first light anticipated no earlier than 2014.

Optical Hawaiian Array for Nano-Radian Astronomy (OHANA). The Paris Observatory, in collaboration with several Mauna Kea observatories, proposes to develop a fiber optic interferometer using an array of existing telescopes on the summit of Mauna Kea, including two 10-m (33-ft) telescopes (Keck I and Keck II), two 8-m (26-ft) telescopes (Subaru and Gemini), and several 3 and 4-m (10 and 13-ft) telescopes (IRTF, CFHT, and UKIRT) (CFHT 2000c). These telescopes provide diverse capabilities for future interferometric observation, including baselines ranging from 50 to 1,000 m (164 to 3,281 ft), for more sophisticated and complex studies of stars, circumstellar phenomena, and extragalactic targets than have previously been possible (CFHT 2000b).

An initial collaboration of the interested parties, including CFHT, Keck, Gemini, UH, NASA (through IRTF), and Paris Observatory, identified three phases of the OHANA project. Phase I included three parts: (1) investigate the interface between adaptive optics and optical fibers by designing an injection module to test on some of the existing telescopes, (2) identify funding for the second phase by recruiting interested parties, and (3) determine the scientific advances possible with the proposed fiber optic interferometer. This phase has largely been completed except for testing the injection module on three of the seven telescopes used in the study (Subaru, IRTF, and UKIRT). Phase II, currently under way, involves connecting short-range telescope pairs to evaluate the project's feasibility. This is being tested at two sites: (1) between the two Keck Telescopes at a technically low-risk test site (because the operational characteristics of the existing interferometer are known) and (2) between Gemini and CFHT. Because these last two facilities are not currently connected, additional equipment is being installed to synchronize the telescopes. Phase III involves the operation of the future fiber optic interferometer and is, therefore, contingent on the success and completion of the first two phases. Based on the success of Phase II, funding would be provided proportionately by observatories involved in the strategic, logistic, and operational plans for the interferometer (CFHT 2004).

The OHANA Project currently plans to use existing infrastructure. Due to the cost of the special type of fibers required, during the experimental phases of the project, the same set of fibers will be used in existing conduits for testing between facilities. However, depending on which telescopes are being connected, there may be a possibility that fibers would be run over the ground.

If the project moves into Phase III, the administrators intend to use existing utility ducts to lay fiber cables. The location of the control center(s) is speculative; however, a space in one or more of the existing facilities is expected to be available. No external construction is expected to be necessary (CFHT 2004).

OHANA would operate only 1 to 3 nights per semester and only on very specific targets (CFHT 2004).

Redevelopment of CFHT, IRTF, and UKIRT. Redevelopment of the 3 to 4-m (10 to 13-ft) telescope facilities on Mauna Kea (CFHT, IRTF, UKIRT) was discussed in the MKSR Master Plan (UH 2000b). However, there are no proposals under consideration to pursue these projects.

SMA Expansion. A conceptual plan for SMA, discussed in the 2000 MKSR Master Plan, considers adding up to twelve new transportable antennas and 24 additional concrete pads to the original array (UH 1999). It now appears that any expansion of SMA may be substantially less than this, including only a few additional antennas and pads and the possible relocation of three existing pads located at the base of Pu‘u Poli’ahu to avoid interference with cultural sites. The existing array, however, has only been operational since November 2003. Any plans to expand are only conceptual at this time, and no funding is in place. Expansion would not be included in the near-term plans for the facility.

VIS Expansion. A proposed VIS expansion at Hale Pōhaku in conjunction with the proposed Mauna Kea Astronomy Education Center and a separate OMKM-proposed expansion are not currently funded.

Completion of the Mauna Kea Access Road. If the TMT Project is located on Mauna Kea, paving of the Mauna Kea Access Road likely would be completed. This would include paving the road from Hale Pōhaku to the 3,597-m (11,800-ft) elevation, and construction of additional parking areas and two runaway truck ramps. This project is not currently funded.

End of Lease. As a reasonably foreseeable future astronomy project, End of Lease in 2033 could result in a variety of outcomes ranging from continuation of observatory activities to complete removal of all observatories from the mountain. Because of this range of possibilities, the End-of-Lease is addressed separately in Section 4.2.15.

REASONABLY FORESEEABLE NON-ASTRONOMY-RELATED PROJECTS

Training at Pōhakuloa Training Area (PTA) for Stryker Brigade Combat Team Army Transformation Project. The use of PTA would increase in connection with the Stryker Brigade Combat Team Army Transformation Project. PTA is located in the saddle between Mauna Kea and Mauna Loa. This project would include constructing training and support facilities, acquiring additional land, and modifying training activities and locations. Although these proposed actions would take place at various locations at PTA, the primary project actions in the vicinity or north of Saddle Road would contribute to the cumulative impacts of the Proposed Action. This EIS considered the following in connection with the Army Transformation Project: construction of a tactical vehicle wash facility; construction of a range maintenance facility, a runway upgrade, and extension at Bradshaw Army Airfield; construction of a military vehicle trail; installation of an information infrastructure architecture fiber optic cable throughout the cantonment area; and construction of fixed tactical Internet antennas at various points along the Saddle Road. An EIS has been completed to evaluate the environmental impacts of these and other associated Army Transformation projects (USACE 2004).

Remotely Operated Microwave Facility. Under Special Permit No. 1220 (SPP1220), the County of Hawai‘i Police Department proposed to construct a remotely operated microwave facility on a 389-m^2 (4,192-ft^2) portion of Tax Map Key (TMK) 4-1-006:007 in the State Land Use

agricultural district. This district, referred to as Iolehaelea, is located on the eastern slope of Mauna Kea 2,475 m (8,121 ft) south of the MKSR. This proposed project would include construction of a 15-m (50-ft) tower and antenna, equipment shelter, and related improvements to be completed within 5 years of the effective date of the permit, issued by the County of Hawai‘i Department of Public Works-Building Division on December 17, 2003. Vehicles and equipment accessing the proposed project site would not be expected to use the Mauna Kea Access Road because other trails likely would provide a more direct route to the site.

Keanakolu Road Improvements. The Federal Highway Administration (FHWA) plans to rehabilitate a 19.9 km (12.4 mi) deteriorated portion of Keanakolu Road (also known as Mana Road) from its junction with the Mauna Kea Access Road to the entrance to Hakalau Forest National Wildlife Refuge to improve the road's unusually rough and hazardous driving conditions and improve USFWS administrative access to Hakalau. The FHWA plans to improve only areas with the most severe problems. Construction would occur only within the disturbed areas of the existing road and could consist of spot improvements such as adding coarse aggregate (gravel) to severely deteriorated surface areas to improve drivability; paving or reducing the vertical alignment of short portions of steeper grades to improve traction; widening the road surface at the more severe crests to improve sight distances for passing vehicles; and stabilizing channel crossings by constructing paved crossings with proper drainage structures to eliminate or reduce washouts.

Development of Department of Hawaiian Homelands (DHHL) Land Acquisition. Within an 82,354-ha (203,500-ac) land parcel set aside under the Hawaiian Homes Commission Act of 1921, the DHHL administers 22,734 ha (56,178 ac) of public land in Humu‘ula and Pi‘ihonua, located on the southeastern slopes of Mauna Kea between 1,426 and 2,682 m (4,680 and 8,800 ft). When the general leases of the five homestead pastoral operations on this land expired in 2002, DHHL began planning the long-term land use and management of this parcel. Land uses considered include homesteading, commercial/service businesses, ecotourism, forestry, ranching, farming, cinder quarrying, gorse control, and resource areas (State of Hawai‘i 2004).

No future land uses have been approved at this time (State of Hawai‘i 2004).

Saddle Road Improvements. Saddle Road is subject to serious traffic congestion when military convoys are transporting ammunition or troops for training. A long-term highway construction project includes improvements and modifications to the Saddle Road between the Hilo side and Kona side of the island of Hawai‘i. Approximately 78 km (48.5 mi) of road will be modernized to meet American Association of State Highway and Transportation Officials standards. Saddle Road, constructed in 1942, does not meet current design standards for roadways. It is the only access road to the Mauna Kea Access Road and the Astronomy Precinct and education facilities, the Army's Pōhakuloa Training Area, Waiki‘i Ranch, Kilohana Girl Scout Camp, Mauna Kea Station Recreation Area, and major hunting areas. A combined Federal/State EIS was completed in 1999 (USACE 2003). Construction has begun, but the implementation schedule and completion date for this project are not known.

PROJECTS NOT CONSIDERED FURTHER FOR MAUNA KEA

There are several projects that were never targeted for development on Mauna Kea, or were conceptually contemplated, but are not being considered further. These projects are discussed below.

Advanced Technology Solar Telescope. The Advanced Technology Solar Telescope, a project to help understand and predict changes in the Earth's climate and the solar-terrestrial environment (UH IfA 2003b), is not and has never been planned for the Mauna Kea Science Reserve (UH IfA 2004d).

Solar System Exploration Telescope. The Solar System Exploration Telescope was envisioned as a replacement for NASA's IRTF Telescope. It would be used to study the origin of our solar system by measuring the size and composition of objects beyond the orbit of Pluto and also could be used to study asteroids that come close to Earth, older solar systems around nearby stars, and the formation of new solar systems around very young stars (UH IfA 2001c). The project is no longer being pursued at this time (UH IfA 2004d).

National Planetary Telescope (NPT). This is the same concept as the Solar System Exploration Telescope discussed above. No further consideration is being given to the project at this time (UH IfA 2004d).

New Optical/Infrared Interferometer Array Site. The 2000 MKSR Master Plan (UH 2000b) addressed a potential plan for a new optical/infrared interferometer array within the next 20 years. This project would require a major Master Plan Amendment to gain approval for further planning. This amendment would require planning analysis, visual impact analysis, preparation of an EIS, and final review by the UH Board of Regents (UH 2000b). This project is not reasonably foreseeable at this time (UH IfA 2004f).

New Conventional Optical/Infrared Telescope. The final Master Plan included a provision to locate a conventional-size optical/infrared telescope at a new site in an area north of the summit ridge, with the intention to use this site only if a suitable summit ridge site was not available through recycling. Currently, the scope of future development of new facilities is significantly less than the Master Plan anticipated, and it is expected that summit ridge sites will be available through recycling for any new projects of this size. Therefore, it does not appear reasonably foreseeable that a telescope will be located at a new site north of the summit ridge.

CUMULATIVE IMPACTS

4.2.3 Cultural Resources

4.2.3.1 ROI for Cultural Resources

Cultural resources include historic and archaeological properties, and traditional cultural practices. The ROI for evaluating cumulative impacts on cultural resources includes the entire mountain from the Saddle to the summit, incorporating all areas of the mountain above approximately the 1,830-m (6,000-ft) elevation, which Native Hawaiians have identified as lands with very special traditional spiritual importance. The time frame in this case begins with the pre-Contact period. Table 4-10 outlines the history of Mauna Kea.

Mauna Kea has always been considered an integrated whole, a sacred place, in Hawaiian legend and history. Traditionally, Hawaiians visited the mountain's lower slopes to collect forest products, but the upper slopes and summit were visited only rarely by specialists such as cultural

TABLE 4-10. HISTORY OF MAUNA KEA

Year (C.E.)	Event
400–800	Pioneer Polynesian settlement.
1100–1800	Radiocarbon dates from adze quarry sites document Native Hawaiian use of quarries.
ca. 1600	Districts of Hāmākua and Hilo, including Mauna Kea summit, established during reign of ʻUmi a Liloa.
1778–79	Cook documents views of Mauna Kea and Hāmākua slopes.
1792–93	Capt. Vancouver gives cattle to Kamehameha I, who lets them graze around Mauna Kea and bans their killing for 10 years.
1823	William Ellis circles the island; his journal describes Mauna Kea and documents native traditions; Joseph Goodrich, with the Ellis party, visits the summit and finds a cairn.
1823–25	Journal of C.S. Stewart describes Mauna Kea.
1830	Hiram Bingham visits Mauna Kea with Kauikeaouli (Kamehameha III); describes Waiau and mountain. Hiram Bingham documents excursion of King Kamehameha III from Waimea to Mauna Kea.
1834	Dr. David Douglas traverses Mauna Kea.
1840	Charles Wilkes, Commander of U.S. Exploring Expedition, visits summit; Wilkes describes wild cattle at summit, well above the forests.
1841	William Richards documents Native Hawaiian astronomy and navigation; provides Hawaiian names for major plants.
1855–1868	Charles de Varigny, Secretary of French Consulate, visits Mauna Kea twice; describes in letters geese, wild cattle, boars, stray dogs, and plains stripped of *ohelo* berries by animals. Silverswords discovered at summit.
1862+	Boundary Commission Surveys: *ahupuaʻa* boundary at summit recorded by Wiltse in 1862 is eventually changed, changing lands where various *puʻu* and cultural features are located.
1870s–1880s	Boundary Commission hears Native Hawaiian testimonies concerning traditional uses of areas on Mauna Kea, establishes *ahupuaʻa* boundaries for all the islands. Hawaiʻi-born Curtis J. Lyons surveys Mauna Kea summit and surrounding areas.
1873	Isabella Bird traverses the saddle and describes Mauna Kea.
1882	Joseph S. Emerson surveys Kona, Kohala, and Puna, describes areas (other than Mauna Kea), describes and sketches the mountain.
1883	Queen Emma ascends the Summit.
1886	Humuʻula Sheep Station established.
1889–1891	E.D. Baldwin maps summit and near-summit areas.
1892	W.D. Alexander, Surveyor General, follows wagon road from Waimea to Mauna Kea, climbs the mountain, describes Waiau and the summit, records traditional practice of burial on the summit plateau.
1903	Hawaiʻi forest reserve system established to protect forests against fire and grazing — inspired by fires in Hāmākua.

TABLE 4-10. HISTORY OF MAUNA KEA (CONTINUED)

Year (C.E.)	Event
1930s	Civilian Conservation Corps plants tree and constructs horse and truck trails; vehicle trail around Mauna Kea at 7,000 feet elevation completed in 1935 – 167 miles in 12 hours 55 minutes.
1935 – 1936	Fence constructed around Mauna Kea Forest Reserve as sheep and goat exclosure; more than 40,000 sheep and goats exterminated within the exclosure.
1936, 1939	L.W. Bryan and the Civilian Conservation Corps build stone cabins for visitors' use at Hale Pōhaku.
1942 – 1945	Camps at Pōhakuloa established for U.S. Army and Marines combat training.
1943	Construction of Saddle Road.
1949	Paving of Saddle Road completed.
1956	Pōhakuloa Training Area created in 1956 as a U.S. Army installation.
1964	First road to the summit of Mauna Kea is bulldozed to facilitate astronomy development; NASA funds 12.5-in site-testing telescope.
1968	Air Force builds a 24-in telescope.
1970	UH completes 88-in telescope; Lowell Observatory builds a 24-in planetary patrol telescope on the summit ridge.
1974	NASA funds 3-m infrared telescope on Mauna Kea.
1979	IRTF, CHFT, UKIRT dedicated
1983	MKSR Development Plan adopted
1986	Caltech Submillimeter Observatory dedicated on Mauna Kea.
1987	James Clerk Maxwell submillimeter telescope dedicated.
1989	National Science Foundation funds Gemini North 8-meter Telescope on the site of the planetary Patrol observatory24-inch telescope on Mauna Kea.
1991	Keck I Telescope dedicated on Mauna Kea.
1992	Keck II Telescope site work begins;Very Long Baseline Array built, and site work begins for the 8.3-m Subaru, formerly know as Japan National Large Telescope.
1996	Keck II Telescope dedicated.
2000	UH Master Plan for MKSR approved.
2001	NASA proposes 2-meter class telescopes around Keck I and II Telescopes.
2002	Draft EA compiled for interferometer development; Submillimeter Array completed.
2004	EIS public meetings for interferometer development.

practitioners. The upper slopes on the south side contain a quarry where Hawaiians obtained material for use in manufacturing stone tools; the summit plateau above contains numerous shrines, evidence of pre-Contact ritual activities. The summit itself was regarded as a sacred landscape; no pre-Contact sites have been found in the summit area.

The primary projects considered in this evaluation include past, present, and reasonably foreseeable future astronomy-

related projects; end of lease; past, present, and reasonably foreseeable future non-astronomy activities; tourism; recreational use; and closing of the jeep trail at Pu‘u Poli‘ahu.

4.2.3.2 Impacts of Past and Present Activities on Cultural Resources

Pre-Contact Impacts. Hawaiians, according to the archaeological evidence, began using the upland areas comprising the Saddle and the slopes of Mauna Kea in the 12th or early 13th century (Athens and Kaschko 1989; Reinman and Schilz 1994). In the forested areas on Mauna Kea Hawaiians collected bird feathers from honeycreepers to make cloaks and helmets, captured dark-rumped petrel nestlings, hunted Hawaiian geese and ducks, quarried basalt and volcanic glass for stone tools, and harvested *koa* (for canoe hulls), *‘ōhia*, *māmane*, and other woods. Foot trails were created to access these areas and to provide paths across the island. Some Hawaiians began journeying to the summit, constructing shrines of upright stones on the summit plateau and burying the bones of their ancestors in the cinder cones (McCoy 1999; Maly 1999). They discovered and began to quarry the hard, dense, fine grained volcanic rock found near the summit along an escarpment below Pu‘u Waiau. Over a period of more than 500 years, craftsmen worked the quarry for stone to make adzes and other tools, leaving behind remains of numerous workshops and large piles of stone flake debris (McCoy 1990). Except for the activities at the quarry, the pre-Contact Native Hawaiian uses of Mauna Kea were generally on a small scale, without long-lasting adverse effects, resulting in a minimal impact to the mountain landscape.

Post-Contact Impacts. Contact with the Western world beginning with the arrival of Captain Cook in the islands in 1778 significantly altered the nature and intensity of the impacts on Mauna Kea.

The introduction of cattle and sheep in 1793 had devastating effects on the native vegetation of Mauna Kea over the next two centuries, severely affecting resources used by Hawaiians. The presence of large numbers of cattle and sheep on the mountain led to the near-disappearance of the silversword and the native *māmane* forests and grasslands as well as the loss of several native bird species.

Other avian species of cultural important to the Hawaiians, such as the *nēnē*, dark-rumped petrel, and *palila* became rare and endangered. The effects of grazing by feral animals and the development of large cattle and sheep ranches are discussed more fully in the Preface.

In the early years after Contact, visits by Native Hawaiians to the summit decreased greatly and few foreigners made their way to the summit. Later in the 19th century foreigners visited the mountain in ever-increasing numbers.

Trails worn by horses and humans had minimal impact on the mountain. Cart tracks were built in the late 19th century, followed by roads in the 1930s and 1940s, including one by the late 1930s that circled the mountain, as recorded by L.W. Bryan (Bryan 1921-1984).

The Saddle Road, built to provide access to the military training area at Pōhakuloa during World War II, was paved after the war, linking Hilo with Waimea. Along with the later paving of the road to Hale Pōhaku, this considerably eased access to Mauna Kea. The first road to the summit (sometimes referred to as the jeep trail) was cut in 1964, allowing development of the observatories, which began the same year. With respect to cultural resources, the easier access has had both adverse and beneficial

effects. The road made possible the construction of the telescopes on the summit and grading for these altered the natural landscape of the spiritually important summit cones. The presence of larger numbers of visitors, some engaged in off-road recreational activities, increased the potential for disturbance to cultural resources. On the other hand, the roads have also facilitated access to the summit by cultural practitioners and allowed Native Hawaiians and scientists easier access to identify, record, and propose measures to protect cultural resources and culturally important natural resources.

Archaeological surveys conducted during the development of observatories on Mauna Kea include a reconnaissance survey of the Astronomy Precinct and adjacent areas in 1982 (McCoy 1982a; McCoy 1982b) (see Figure 3-1). These surveys, and more recent ones in 1995 and 1997 (McCoy 1999), identified 93 archaeological sites, mostly shrines within the MKSR. Surface sites found during surveys in the vicinity of development projects have been flagged and protected during construction. However, in most cases, monitoring during construction to identify possible subsurface cultural deposits or human burials was not undertaken. Also, because traditional cultural properties in the summit region had not been defined before 1999, little consideration was given to impacts on these properties. Thus, development within the Astronomy Precinct may have damaged subsurface cultural resources and has altered the appearance of the Kūkahau‘ula traditional cultural property, interfered with views to and from the summit, and affected traditional cultural uses and practices.

Since cutting of the jeep trail and installation of the first telescope on Mauna Kea in 1964, cultural resources have substantially been altered. Past impacts include construction of several telescopes near or on the slopes of cinder cones that make up what the SHPD now recognizes as the historic property of Kūkahau‘ula. This is spiritually the most important area of the mountain in Native Hawaiian tradition and remains the focus of cultural practices.

The construction of the Keck, Subaru, Gemini North, and NASA Infrared Telescopes each resulted in the movement of more than 7,646 m^3 (10,000 yd^3) of earth; both cutting and filling altered the appearance of the summit area. Grading and filling for the Keck Telescopes leveled approximately 1.1 ha (2.8 ac) and cut as far as 11 m (35 ft) below the surface on the slope of one summit cone, Pu‘u Hau‘oki. The presence of these telescopes within the summit area continues to affect the performance of cultural practices. Nevertheless, the mountain retains a very rich traditional history with many archaeological sites, undoubtedly including some that have yet to be discovered.

In summary, past and present activities on Mauna Kea have substantially and adversely impacted cultural resources.

4.2.3.3 Impacts of Reasonably Foreseeable Future Activities on Cultural Resources

Future activities on the summit of Mauna Kea would continue the substantial adverse impact on cultural resources. No area at or near the summit is assumed to be devoid of archaeological properties, including the slopes surrounding the *pu‘u,* which can be indirectly affected by development on the *pu‘u*. Grading and removal of earth for new structures or roads, infrastructural redevelopment, or other observatory projects could adversely affect these resources. Further development could interfere with views and access to and from the summit or could hinder other cultural uses of the

general area. If an archaeological site is discovered during excavation, grading, or other activities before or during construction of future projects, mitigation measures such as those outlined in the Section 106 MOA (Appendix B) would help reduce the cultural impact.

Mitigation measures, such as the following, would reduce adverse effects.

- Archaeological surveys preceding any future ground-modifying work (including work on associated staging areas).
- Monitoring of ground-modifying activities by a qualified archaeologist.
- Consultation with representatives from the Native Hawaiian community before construction activities begin for on-site assessment of any area to be disturbed.
- Cultural monitoring during on-site construction and installation.
- Specification of procedures if a burial site is identified during excavation.

Even with such mitigation measures, some reasonably foreseeable future projects will have an unavoidable adverse impact on cultural resources. In particular, projects located in previously undisturbed areas have greater potential for altering topographical contours and disturbing archaeological sites and human burials. For a project such as TMT, which is both extremely large and proposed for a previously undisturbed site, adverse cultural resource impact is likely.

For reasonably foreseeable astronomy projects, it is assumed that appropriate mitigation measures will be implemented. At a minimum, on-site construction, installation, and operation will adhere to the stipulations established in the 2000 Master Plan for the MKSR. Project participants and construction contractors and their personnel will adhere to HRS 343 and conditions imposed under the CDUP process. Further, when Federal funds are involved, the NEPA process will be followed. In addition, all future astronomy projects are assumed to occur within the Astronomy Precinct, which was designed to avoid historic sites, preserve view corridors, and maintain the integrity and aesthetics of the cultural landscape as far as possible.Foot traffic within the MKSR may increase as future development, such as improvements to the Saddle Road, facilitates access to and within the summit region, possibly causing further disturbance of cultural sites in this region. Ranger monitoring and educational programs at the VIS are expected to help offset this potential cumulative impact to archaeological resources.

Even with all the mitigation measures discussed above, from a cumulative perspective, the potential impacts of reasonably foreseeable future activities are anticipated to be adverse and substantial.

4.2.3.4 Cumulative Impact Summary

Mauna Kea has a rich traditional history and many archaeological sites, including some that have yet to be discovered. Before 1982, only limited cultural and archaeological surveys were conducted in preparation for developments on the mountain. Thus, it is not known whether development of the Astronomy Precinct beginning in 1964 has damaged subsurface cultural resources. However, such development has clearly altered the appearance of the Kūkahau‘ula traditional cultural property, interfered with views to and from the summit, and affected traditional cultural uses and practices. Grading and removal of earth for new structures, redeveloped structures, roads, and other astronomy projects could further affect these resources adversely. Following appropriate mitigation measures, such as

those described in the NHPA Section 106 MOA, and developing project-specific mitigation measures for future activities would reduce adverse effects.

Mitigation measures developed for the Outrigger Telescopes Project and made part of the Section 106 MOA would minimize the impact of the Outrigger Telescopes Project and could potentially provide beneficial impacts, including community outreach and cultural stewardship.

From a cumulative perspective, the impact of past, present, and reasonably foreseeable future activities on cultural resources on Mauna Kea is substantial and adverse. The addition of the Outrigger Telescopes would have a small incremental impact.

4.2.4 Biological Resources and Threatened and Endangered Species

4.2.4.1 ROI for Biological Resources and Threatened and Endangered Species

For the purposes of this analysis, the ROI extends from the summit of Mauna Kea down to the elevation of the intersection of the Mauna Kea Access Road and Saddle Road. The potential impacts to the biological resources are primarily in the four ecological zones described in Section 3.1.3. The major activities considered in this evaluation include paving the Mauna Kea Access Road; past, present, and reasonably foreseeable future astronomy-related projects; and tourism and recreational use.

4.2.4.2 Impacts of Past and Present Activities on Biological Resources and Threatened and Endangered Species

The flora and fauna of the four ecological zones were described in Sections 3.1.3.1 and 3.1.3.2.

Summit Area Cinder Cones and *Area Below the Summit Cinder Cones*

Flora. According to historic reports, no vascular plants were observed on Mauna Kea above 4,115 m (13,500 ft) before 1940 (Hartt and Neal 1940). Lichens inhabiting rocks scattered over the surface of the cinders were the only vegetation seen on the summit cinder cones (Neal 1939, Hartt and Neal 1940). This condition has remained largely unchanged to the present. Habitats for lichens, mosses, and ferns below the summit cinder cones are widespread. Less than one percent has been disturbed or displaced by astronomy-related activities. The impacts of past and present activities on the flora of the *Summit Area Cinder Cones* and the *Area Below the Summit Cinder Cones* has been small and not significant.

Fauna. Eleven species of arthropods are believed to be the only indigenous animals on Mauna Kea above 3,566-m (11,700-ft). Quantitative information has been collected for only one of these species, the Wēkiu bug, a candidate for listing under the Endangered Species Act. Its population was first assessed in 1982. Wēkiu bugs were found to be very abundant on the summit cinder cones (Howarth and Stone 1982). In a second assessment in 1997/98 trap capture rates were found to have declined by 99.7 percent in comparable areas (Howarth and others 1999). In that study, trap capture rates were highest on cinder slopes presumed to have been previously disturbed by observatory construction. The cause of the decline is unknown. Hypotheses include changing weather patterns, habitat disturbance such as that caused by observatory construction and recreational activities, introduction of harmful alien species, and long-term population cycles (Howarth and others 1999). More recent sampling has found that Wēkiu bug trap capture rates have substantially increased

since 1998, in some areas returning to rates similar to those measured in 1982 (Pacific Analytics, LLC 2003b). Observational data collected during the 1997/98 assessment also suggested the lycosid spider population was comparable to what it was in 1982.

There have been several studies of the extent of Wēkiu bug habitat. An initial study in 1982 identified 232 ha (573 ac) of Wēkiu bug habitat, all above the 12,800 ft elevation (Howarth and Stone 1982) (see Table 4-11). This is a lower limit to the total Wēkiu bug habitat at that time, since it is very likely that Wēkiu bugs occurred elsewhere in unsampled areas. The 1997/98 study (Howarth and others 1999) found Wēkiu bugs only above the 13,400 ft elevation level, corresponding to a total area of 120 ha (300 ac). Later studies identified 579 ha (1,434 ac) of Wēkiu bug habitat extending down to the 11,715 ft level (Polhemus 2001; Pacific Analytics, LLC 2001; Englund and others 2002) (see Table 4-12). Since these studies, Wēkiu bug capture rates in some areas have nearly returned to the levels measured in 1982, which were the highest levels measured in any of these studies. It is therefore reasonable to infer that the 579 ha (1,434 ac) identified in the 2001-2002 studies is a lower limit to the current amount of Wēkiu bug habitat.

It is possible to set an upper limit to the percentage of this habitat that has been displaced or disturbed by astronomy-related activities. Astronomy-related activities (observatories, roads, and parking areas) above the 3,571 m (11,715 ft) elevation, the lowest elevation at which Wēkiu bugs have been found, have displaced about 17 ha (41 ac) and disturbed about an additional 8.5-ha (20.5-ac) of adjacent land. This 25.5 ha (63 ac) of displaced or disturbed land is 4.4 percent of the 579 ha that is estimated to be the lower limit to current Wēkiu bug habitat. The actual percentage of Wēkiu bug habitat displaced or disturbed by astronomy-related activities is likely to be lower than 4.4 percent for the following reasons: (1) 579 ha is a lower limit estimate of the current amount of Wēkiu bug habitat; (2) some of the 8.5 ha of disturbed area are currently the sites of the highest Wēkiu bug capture rates; and (3) only a portion of the 25.5 ha displaced or disturbed by astronomy-related activities was originally Wēkiu bug habitat. Thus, 4.4 percent is an upper limit to the fraction of Wēkiu bug habitat that has been directly and adversely affected by astronomy-related activities.

Although capture rates in some areas have nearly returned to the relatively high levels measured in 1982, this is not uniformly the case. On Pu‘u Wēkiu, where the highest capture rates (about 45 bugs/trap/3 days) were measured in 1982, current capture rates are relatively low (about 12 bugs/trap/3 days) (Pacific Analytics, LLC 2003). These areas are unaffected by astronomy development. However, other human activities (e.g., hiking and foot traffic) or natural phenomena (e.g., changing weather patterns) could be at least in part responsible for the low current capture rates.

The earlier studies of Wēkiu bugs had at least a small adverse impact on Wēkiu bug populations. The 1982 (Howarth and Stone 1982) and 2001 (Polhemus 2001) studies used baited ethylene-glycol traps to assess the populations. These traps caused 100 percent mortality of all insects captured in them. During the 1982 Arthropod

TABLE 4-11. WĒKIU BUG HABITAT DISPLACEMENT[a]

Habitat Population Density	Study Area Size of Wēkiu Bug Habitat	Area of Habitat Displaced by Observatories	Area of Habitat Displaced by Roads	Area of Habitat Displaced by Other
High	63 ha (156 ac)	2.4 ha (6 ac)	0.6 ha (1.6 ac)	0.2 ha (0.4 ac)
Moderate	120 ha (297 ac)	0 ha (0 ac)	0.4 ha (1 ac)	0 ha (0 ac)
Low	49 ha (120 ac)	1.5 ha (4 ac)	2 ha (4.4 ac)	0 ha (0 ac)
TOTAL	232 ha (573 ac)	4 ha (10 ac)	3 ha (7 ac)	0.2 ha (0.4 ac)

a. Wēkiu bug habitat in the 1982 study area on Mauna Kea and the area displaced by astronomy-related activities (Howarth and Stone 1982; R.M. Towill Corp 1997).

TABLE 4-12. WĒKIU BUG KNOWN SITES

Cinder Cone Habitat[a]	Area
Pu‘u Wēkiu, Hau‘oki, Kea	184 ha (452 ac)
Pu‘u Poliahu	95 ha (234 ac)
Pu‘u Haukea	51 ha (125 ac)
Pu‘u Mahoe	79 ha (196 ac)
Pu‘u Ala	59 ha (147 ac)
Pu‘u Poepoe	26 ha (64 ac)
Pu‘u Makanaka	75 ha (186 ac)
Unnamed Pu‘u near VLBA	12 ha (30 ac)
TOTAL	579 ha (1,434 ac)

a. Cinder cone habitat on Mauna Kea where Wēkiu bugs have been found (Wolfe and others 1997; Howarth and Stone 1982; Howarth and others 1999; Polhemus 2001; Pacific Analytics, LLC 2002a–2003d; Englund and others 2002).

Assessment more than 40,000 Wēkiu bugs were captured and killed. Conventional entomological wisdom holds that sampling does not impact insect populations. On the other hand, New (1984) stated that fragmented (geographically-isolated) populations can be vulnerable, and excessive collecting can sometimes tip the balance towards extinction. Since the 1982 study, live traps have been developed that enable sampling of the Wēkiu bug without causing high mortality rates.

Wēkiu bug populations may also have been affected by the introduction of alien species. These invasive species can potentially eliminate native arthropods from their summit habitats. In 1997, an alien species of hunting spider (family Clubionidae) was found on Pu‘u Wēkiu (Howarth and others 1999). This species was thought to be a potential resident of the summit, but so few

have been collected (Pacific Analytics, LLC 2002a – 2003d) that definitive conclusions can not be made. A non-indigenous sheetweb spider (Family Linyphiidae) has also been observed on the *Summit Area Cinder Cones* (Howarth and others 1999). Both species have the ability to capture and kill Wēkiu bugs and therefore have the potential to impact Wēkiu bug populations. The means of introduction of these two spiders are unknown. They may have arrived at the summit during construction of the observatories, from tourists visiting the mountain, or by other means. Data about the impact of these spiders are not available and concerns persist that these spiders may be having an adverse impact on Wēkiu bugs.

The only other harmful invasive alien arthropod species that have been identified from the *Summit Area Cinder Cones* are several species of parasitic and predaceous wasps (Howarth and Stone 1982; Montgomery 1988; Howarth and others 1999; Pacific Analytics, LLC 2002a – 2003d; Englund and others 2002). These wasps are carried by winds to the summit area from surrounding lowlands, and could potentially prey on or parasitize native resident arthropods. None of these wasps are thought to be residents of the summit or the *area below the summit cones* on Mauna Kea and therefore do not currently present a serious threat to native resident arthropods of the MKSR.

Some native resident species, such as the Wēkiu bug and lycosid wolf spider, depend upon aeolian (wind-blown) drift as food. It has been suggested that observatory domes and other buildings have altered the natural deposition patterns of drift. There is no evidence that this is the case, since Wēkiu bugs and lycosid wolf spiders continue to live on the cinder slopes downwind of the W.M. Keck Observatory site.

Spills of hazardous materials can also affect Wēkiu bugs and their habitat. Early biotic surveys of the Astronomy Precinct mentioned hazardous materials spills that occurred in Wēkiu bug habitat (Howarth and Stone 1982; Smith and others 1982). The principal spill (which affected about 18 m^2 (194 ft^2)) appears to have occurred beneath the 850 kW mobile generator (which powered all of the existing observatories at that time) at approximately the 4,023 m (13,200 ft) elevation level in the construction staging area near Pu‘u Haukea. In 1996 about 227 to 246 l (60 to 65 gal) of ethylene glycol were spilled at the Subaru Observatory. This spill was cleaned up and the contaminated cinder transferred to an authorized disposal site. In March 2004 between 76 and 114 l (20 and 30 gal) of ethylene glycol were spilled inside the W.M. Keck Observatory. Some of the ethylene glycol escaped under the exterior door and flowed into the cinder parking area outside. This spill was immediately cleaned up and the contaminated cinder transferred to an authorized disposal site. These spills were limited to small areas and cleaned up promptly and therefore had little impact on the Wēkiu bug population.

Concerns have also been expressed that wastewater from septic systems may impact Wēkiu bugs. Cesspools and seepage pits direct wastewater into the cinder several feet below the zone of activity of Wēkiu bugs and other arthropods. Wastewater from these sources is not expected to have an adverse effect on the natural ecosystem when the waste systems are working properly. In 1998, a sewage spill was observed in Wēkiu bug habitat in Pu‘u Hau‘oki crater. About 8-l (2-gal) of sewage leaked from an incorrectly installed septic line onto the cinder and snow. The contaminated cinder and snow were removed soon after the spill was reported and the leak repaired (Subaru 1998). While this spill was relatively minor,

this type of spill can cause habitat damage, filling interstitial spaces or disturbing cinder substrate structure that could take years to recover. No other sewage spills have been reported, and no direct effects of properly installed septic systems on Wēkiu bugs and other arthropods have been observed.

Scattered trash can also affect Wēkiu bugs. The 1982 botanical survey of Mauna Kea (Smith and others 1982) reported a considerable amount of rubbish scattered over the mountaintop. Trash can shade out plants, stunting their growth, and prevent aeolian deposition of food resources for the Wēkiu bugs and lycosid wolf spiders. UH responded to this concern in the 1999 MKSR Master Plan EIS by accepting responsibility for trash on the mountain within the Science Reserve (UH 1999). Since then trash has been conscientiously collected by Mauna Kea Support Services and observatory personnel, and is now rarely seen within MKSR.

Water runoff and sediment deposition along roads and drainage ditches has the potential to erode and cover habitat of Wēkiu bugs, lycosid spiders, and other summit-resident arthropods and plants in some places. Runoff and sediment are carefully controlled using swales, drains, and catch basins and only during extreme precipitation would erosion be expected to be a problem. As discussed previously, the summit region experiences limited rainfall and only small amounts of surface water runoff, and there are no impacts from water runoff on natural habitats on the *Summit Area Cinder Cones* or the area below them.

Trap capture rates of the other summit resident native arthropod species on Mauna Kea have not been measured or analyzed. Impacts to these other species and their habitats are probably similar to those experienced by Wēkiu bugs and lycosid spiders. However, since these other species are relatively widely distributed, the impacts in these two ecological zones are relatively small and of no significance.

No birds or other wildlife are known to nest or forage on the *Summit Area Cinder Cones* or the area below them.

In summary, there has been a substantial adverse impact on Wēkiu bugs in at least part (e.g., Pu‘u Wēkiu) of the two upper ecological zones. However, there is not enough information to determine the contribution of human activities to that impact. In particular, there is not enough information to determine the magnitude or significance of past and present astronomy-related activities on the Wēkiu bug and its habitat. There have been no significant impacts on other biological resources in these two zones.

Silversword/Alpine Shrub Zone

Flora and Fauna. About six miles of dirt road have been installed in the *Silversword/Alpine Shrub Zone*. This represents less than one percent of the entire range of silversword habitat on Mauna Kea. Based on the records of early naturalists, silverswords grew in abundance and were the dominant plants of the alpine ecosystem (Robichaux and others 2000). In the late 1700’s, sheep, cattle, and other ungulates were introduced to Hawai‘i, and silversword populations declined as the ungulates established populations on Mauna Kea. The small natural population of silverswords that persists on Mauna Kea now contains only 42 plants (Robichaux and others 2000). This population is more than 4 km (2.5 m) away from the nearest observatories. A court ordered ungulate removal program has reduced damage to silverswords and the chances for recovery have increased. Observatory construction is not believed to have had an impact on this species (USFWS

2004). This species will continue to receive protection through its Federal listing as an endangered species.

The other biological resources found in the *Silversword/Alpine Shrub Zone* are not unique to the zone and are found elsewhere on Mauna Kea. Other than the decline in the silversword resulting from the introduction of cattle, sheep, and other ungulates, there has been no significant impact of past and present activities on the biological resources in the *Silversword/Alpine Shrub Zone.*

Māmane/Subalpine Forest Zone

Flora. The *Māmane/Subalpine Forest Zone*, discussed in Section 3.1.3.4, extends from Saddle Road to about 2,804 m (9,200 ft). The open-canopied forest predominantly comprises *māmane* trees (*Sophora chrysophylla*), and is home to the federally listed endangered bird, *palila* (*Loxiodes bailleui*). Early 20th century expeditions noted the already degraded condition of the subalpine forest due to wild sheep and cattle grazing (Hartt and Neal 1940). Over a century and a half of grazing by feral ungulates resulted in increased evapo-transporation, causing a change in the understory conditions at Hale Pōhaku from moderately moist to deficient in moisture (Garrish 1979). Ungulates run away when humans are present, and human activity at Hale Pōhaku has brought a decline in feral ungulates there. This has consequently allowed the *māmane/naio* forest surrounding the mid-elevation support facilities to regenerate (Garrish 1979). Other than the substantial impacts resulting from grazing ungulates noted above, the impacts of past and present activities on the flora in the *Māmane/Subalpine Forest Zone* have been small.

Fauna. *Palila* were once found in the *māmane/naio* forests on west and southwest Mauna Loa and Mauna Kea. They currently occur only in the *māmane/naio* forest of Mauna Kea (Scott and others 1986) where there are available food resources, suitable nesting habitat, fewer ants, and fewer disturbances by humans. *Palila* reach their highest densities near Pu‘u La‘au on the western slopes of Mauna Kea. The population has fluctuated since 1975 and ecological research is ongoing. This bird is protected by its Federal listing as endangered.

Operations at Hale Pōhaku occupy only a small part of the critical habitat and are not considered a threat to the bird (USFWS 1979). NASA has requested an updated opinion regarding activities at Hale Pōhaku and their potential impact on *palila*. Dr. Paul Banko, principal investigator for the U.S. Geological Survey, Biological Resources Division *palila* research team was recently quoted as saying about *palila* that "In the last four to five years the population is stabilizing, even increasing a bit" (Smith 2003).

More than two hundred species of arthropods have been found to be associated with the *Māmane/Subalpine Forest Zone* (Gagne and Montgomery 1988; USDOT 1997). None of the species are on Federal or State lists of threatened and endangered species. There have been no measured impacts to the arthropod fauna of the *Māmane/Subalpine Forest Zone.*

Summary of Past and Present Activities on Biological Resources and Threatened and Endangered Species

“Silversword and *palila* have been substantially impacted from overgrazing of the *Silversword/Alpine Shrub Zone* and the*Māmane/Subalpine Forest Zone* by cattle, sheep, and feral ungulates. There have been small but no significant impacts on the flora in the *Summit Area Cinder Cones* and the *Area Below the Summit*

Cinder Cones ecological zones by past and present activities on Mauna Kea. Since 1982 there was a substantial adverse impact on Wēkiu bugs in at least part (e.g., Pu‘u Wēkiu) of the two upper ecological zones. However, there is not enough information to determine the contribution of human activities to that impact. In particular, there is not enough information to determine the magnitude or significance of past and present astronomy-related activities on the Wēkiu bug and its habitat. There have been small but no significant impacts to other fauna in the four ecological zones by past and present activities on Mauna Kea."

4.2.4.3 Impacts of Reasonably Foreseeable Future Activities on Biological Resources and Threatened and Endangered Species

The analysis of reasonably foreseeable future activities on the biological resources within the ROI is based on the information about these projects contained in Section 4.2.2. The impacts of these projects are discussed in the context of the four ecological zones described in Section 3.1.3. Astronomy sponsored studies on Mauna Kea have brought attention to the sensitive nature of the biological resources that live there. In 2000, the University of Hawai‘i created the Office of Mauna Kea Management, and gave it comprehensive management authority to protect the sustainability of Mauna Kea's resources (UH 2000b). That Office is developing guidelines and procedures for protecting these resources. Without these guidelines and the protection they would bring about, there is a potential for substantial and significant impacts on the biological resources of Mauna Kea. In this analysis, estimates of the intensity of impacts from reasonably foreseeable future activities are made with the assumption that OMKM guidelines, and review by the DLNR through the Conservation District Use permitting process, will require species and habitat protection for all future development.

<u>*Summit Area Cinder Cones* and the *Area Below the Summit Cinder Cones*</u>

<u>Flora</u>. It has been estimated that up to 4 ha (10 ac) of non-cinder habitat could be disturbed as a result of the grading and construction for new observatories, and their support facilities and roadways (UH 1999). The proposed new facility areas are in habitats used by lichens, mosses, and ferns, and contain three special interest areas of high lichen concentrations (Smith and others 1982). UH/IfA is aware of the three special interest areas of high lichen concentrations and would position new observatory facilities carefully to avoid destruction of sensitive populations of lichens and ferns, thus impacts are expected to be small to moderate, and not significant. If built on the proposed northern plateau site, it is estimated that the TMT would cover up to 2-ha (5-ac) of lichen habitat and could potentially disturb the three areas of special interest. Without careful placement of the TMT, impacts could be substantial because many of the lichen species there have not been observed elsewhere within the MKSR. The SMA expansion would also displace lichen habitat, but its impact would be small if confined to the development of only a few small telescope pads.

Dust generated by reasonably foreseeable future astronomy development would have only small impact to nearby flora because dust control measures would be implemented. Without these measures, dust could: (1) cover rocks and make them unsuitable for colonization by lichens and mosses; (2) cover existing plants, depriving them of light needed to photosynthesize; or

(3) abrade the plants as it is blown by the wind (Sohmer and Smith 1982).

Disposing of excess excavated material would likely be carried out after consultations with OMKM. Potential impacts from appropriate disposal would be small.

In summary, habitat protection measures are likely to be required in Conservation District Use Permits for reasonably foreseeable future astronomy development, and this development is therefore likely to have only a small impact on the flora of the *Summit Area Cinder Cones* and the *Area Below the Summit Cinder Cones*.

Fauna. Reasonably foreseeable future astronomy facilities planned on the *Summit Area Cinder Cones*, such as the Testing and Site Monitoring and redevelopment of the UH 0.6-m (24-in) and 2.2-m (88-in) telescopes, would have small impacts on adjacent habitats. Redevelopment of the UH observatories, CFHT, IRTF, and UKIRT has a lower potential for impact on the Wēkiu bug than new observatory development t on the summit ridge. The implementation, in any redevelopment projects, of protection measures similar to those proposed for the Outrigger Telescopes (see Appendix D, Wēkiu Bug Mitigation Plan in this DEIS) would protect adjacent habitats from construction materials, waste, or dust migrating off-site; from equipment mobilization and staging; from contamination of cinder habitat with hazardous materials; and from introduction of invasive species.

It is likely that future scientific ecological studies would have a negligible to small impact on sensitive species such as the Wēkiu bug because the refinement of sampling methods has reduced mortality to about two percent. Scientists walking in habitat can disturb tephra cinders and crush them to dust-sized particles. When live-traps are used predominantly for all future Wēkiu bug studies, and care is taken to not disturb large areas of habitat when sampling, there would be a small and not significant impact from future scientific research.

The probability for fuel spills has been lessened because power is no longer generated at the summit. As long as any future spills of any hazardous materials were limited to small areas and cleaned up promptly, there would be little impact to the Wēkiu bug and other fauna.

Although reasonably foreseeable future development would take place in arthropod habitats in the *Area Below the Summit Cinder Cones*, the prominent species that live there, lycosid spiders and summit moths, are both widespread below the summit area (Howarth and others 1999), and are likely to experience only a small impact from future projects. The development of new sites in the *Area Below the Summit Cinder Cones* would have a no impact on Wēkiu bugs because the sites have only small patches of Wēkiu bug preferred habitat (Howarth and Stone 1982, Wolfe and others 1997).

Rules prohibiting off-road driving on the MKSR are enforced by rangers who frequently patrol the area. Thus, off-road vehicles would cause little damage to habitat and have no impacts on sensitive species. Visitors to the summit of Mauna Kea have the potential to impact natural resources. Walking off trails and collecting rock souvenirs can disturb Wēkiu bug habitat. Increased tourism, resulting from future development and use of the summit for recreation, may increase inadvertent disturbance to natural habitat. This manner of habitat disturbance could potentially have moderate to substantial impacts on Wēkiu bug populations.

In summary, appropriate protection of Wēkiu bug habitat would reduce the potential impacts to Wēkiu bugs and other resident species. Foreseeable future astronomy activities would have a potentially small to moderate impact on the nearby fauna, but other causes of habitat disturbance could potentially have moderate to substantial impacts.

Silversword/Alpine Shrub Zone

There are no reasonably foreseeable future projects in this zone. The potential for future impacts from traffic through this zone is small and not significant.

Māmane/Subalpine Forest Zone

Reasonably foreseeable future projects in this zone, such as the Visitors Information Station Expansion, completion of the Mauna Kea Access Road, Army Transformation, Remotely Operated Microwave Facility, Keanakolu Road Improvements, and Development of DHHL Land Acquisition are not expected to have a any impact on the flora and fauna within the ROI because the actions would occur outside the ROI, and because the amount of habitat disturbed within the ROI, if any, would be small compared to the amount available.

Summary of Reasonably Foreseeable Future Activities on Biological Resources and Threatened and Endangered Species.

Reasonably foreseeable future projects have small, but not significant impacts to the biological resources within the ROI. Almost all of these impacts would be prevented by appropriate protection measures similar to those outlined in the Wēkiu Bug Mitigation Plan if implemented. If protection measures are not implemented, there is a potential for substantial and significant impacts from reasonably foreseeable future projects on the biological resources of Mauna Kea.

4.2.4.4 Cumulative Impact Summary

There have been substantial impacts to biological resources, but the best available information does not always permit complete understanding of the causes of those impacts. The impact of past, present, and reasonably foreseeable future activities from all causes is likely to be small. The incremental impact of the Outrigger Telescopes Project is small and not significant. Further, on balance, the impact from the Outrigger Telescopes Project is likely to be beneficial to biological resources. Overall, considering past, present, and reasonably foreseeable future activities, the cumulative impact to biological resources is adverse and significant.

4.2.5 Hydrology, Water Quality, and Wastewater

4.2.5.1 ROI for Hydrology, Water Quality, and Wastewater

The ROI is the summit area and the potentially connected surface and subsurface flow paths. Surface runoff pathways are identifiable by surface topography. Subsurface flow paths— consisting of the nearly vertical downward travel through unsaturated lavas and lateral movement with groundwater— ultimately extend all the way to the island's shorelines.

4.2.5.2 Impacts of Past, Present, and Reasonably Foreseeable Future Activities on Hydrology, Water Quality, and Wastewater

The impacts of past and present activities on hydrology and water quality are reasonably represented by the impacts of the present 12 observatories at the summit and the support facilities at Hale Pōhaku. These impacts are considered and quantified in this section along with those of foreseeable future projects.

Basis for the Quantifying Cumulative Impacts. The following assumptions were used to quantify the cumulative impacts.

- The sites of all 12 observatories at the summit will continue to be used.
- The Outrigger Telescopes Project at the W.M. Keck Observatory will be implemented as proposed.
- The TMT will be constructed at a new site at the northwest plateau. Site preparation and facility construction would be initiated at some point after completion of the Outrigger Telescopes Project. The maximum construction workforce would be about 60 workers all of whom would temporarily reside at Hale Pōhaku. The finished footprint and rates of water use and wastewater generation during TMT operation would be similar to the existing W.M. Keck Observatory.
- The PanSTARRS project will be built at the site of the UH 2.2-m (88-in) Telescope. Its water use and wastewater generation would be similar to the average of the present Mauna Kea observatories which is about 150 gpd.
- Water would continue to be trucked to the summit and to Hale Pōhaku as it is now.
- The average water use by the observatories in 2003 is, as a first order approximation, representative of past, present, and future water use (except for the redevelopment and expansion described above). The 2003 water use rates are compiled in Table 4-13.
- Also as a first order approximation, all water trucked to the summit would become domestic wastewater with subsurface disposal. Wastewater treatment and disposal systems for new facilities would be similar to those in place for the existing observatories (see Table 4-14).
- As with present practice, all other wastewater (such as for mirror washing) would continue to be captured in containers and trucked down the mountain for treatment and disposal elsewhere.
- Future water use and wastewater disposal at Hale Pōhaku would increase in proportion to the estimated increase in water use at the summit.
- The unpaved 7.4-km (4.6-mi) long segment of the summit access road from just above Hale Pōhaku to 3,627-m (11,900-ft) elevation would ultimately be paved.
- Based on the foregoing assumptions and present rates of water use compiled in Table 4-13, the ultimate water use and wastewater disposal amounts at the summit and at Hale Pōhaku would be as shown in Table 4-15. These assumptions result in an estimated increase in water use and wastewater generation of about 25 percent.
- Projects will comply with all regulations, mitigation plans, and construction best management practices.
- With the exception of Wēkiu bug habitat restoration and monitoring, all reasonably foreseeable future projects, as appropriate to the given project, would implement environmental protection and mitigation measures similar to those proposed for the

TABLE 4-13. WATER USE AND WASTEWATER GENERATION

Location	Rate of Water Use and Wastewater Generation	
	At Present (gpd)[a]	Future (gpd)
At the Summit		
Existing Observatory Sites	1,780	1,815
New Sites	0	400
Total	1,780	2,215
At Hale Pōhaku	3,800	4,730

a. gpd = gallons per day.

TABLE 4-14. WASTEWATER GENERATION AND TREATMENT AND DISPOSAL SYSTEMS AT THE MAUNA KEA OBSERVATORIES

Name of Facility	Average Wastewater Flow Rate (gpd)	Treatment and Disposal System
W.M. Keck Observatory	399	4-kl (1,000-gal) septic and 4-m (12-ft) deep seepage pit
NASA Infrared Telescope Facility	50	5-kl (1,450-gal), two compartment septic tank and leach field (27 m (90 linear ft))
Canada-France-Hawai‘i Telescope	295	Septic tank and leach field
Subaru Telescope	360	5-kl (1,250-gal) septic tank and two seepage pits
Gemini North Telescope	122	4-kl (1,000-gal) septic tank and 3-m (10-ft) deep seepage pit
University of Hawai‘i Telescopes 0.6 m and 2.2 m (24 in and 7.2 ft)	115	9.5-kl (2,500-gal) septic tank and leach field
United Kingdom Infrared Telescope	111	4-kl (1,130-gal), two compartment septic tank and leach field (23 m (75 linear ft))
Caltech Submillimeter Telescope	65	2-m (7-ft) diameter, 3-m (10-ft) deep cesspool
James Clerk Maxwell Telescope	109	2-m (8-ft) diameter, 4-m (13-ft) deep cesspool
Submillimeter Array	118	4-kl (1,000-gal) septic tank and leach field (81 m (265 linear ft))
Very Long Baseline Array	31	2-m (7-ft) square-shaped, 3-m (10-ft) deep cesspool

1 gal = 0.0038 kl

1 m = 3.2808 ft

TABLE 4-15. WATER DELIVERIES TO THE SUMMIT OBSERVATORIES IN GALLONS PER MONTH, JANUARY THROUGH DECEMBER OF 2003

Month	UH	IRTF	UKIRT	CFHT	JCMT	CSO	KECK	NRAO	SUBARU	GEMINI	SMA	TOTAL
January	2,100	1,800	2,500	8,200	2,500	1,800	10,000	-	10,000	5,000	6,100	50,000
February	3,400	3,200	6,400	7,500	2,500	2,000	14,200	1,750	8,000	-	5,650	54,600
March	1,600	600	3,200	10,000	5,700	1,500	10,000	-	24,000	3,500	3,800	63,900
April	1,700	1,500	1,900	3,400	2,400	1,300	10,500	2,000	10,000	2,400	2,900	40,000
May	2,450	500	1,500	10,000	2,400	1,800	19,500	800	5,000	3,550	2,500	50,000
June	600	1,000	5,100	5,000	4,300	3,000	11,200	-	15,000	2,000	2,800	50,000
July	2,500	2,500	5,600	8,600	3,700	1,400	10,000	700	15,000	2,600	2,400	55,000
August	2,400	2,600	3,000	13,000	2,200	2,000	14,800	2,000	10,000	3,000	-	55,000
September	5,000	1,200	-	7,000	4,100	2,000	10,500	2,200	10,000	3,200	4,800	50,000
October	10,000	-	5,700	10,000	4,300	2,500	15,000	-	10,000	10,000	2,500	70,000
November	5,400	500	3,100	10,000	3,200	1,900	10,000	1,000	9,500	1,800	3,600	50,000
December	5,000	2,950	2,500	15,000	2,500	2,700	10,000	850	5,000	7,500	6,000	60,000
Total for the Year	42,150	18,350	40,500	107,700	39,800	23,900	145,700	11,300	131,500	44,550	43,050	648,500
Average (gpd)	115	50	111	295	109	65	399	31	360	122	118	1777

Note: The average wastewater flow rate is assumed to be equivalent to the average amount of water trucked to each observatory for the January through December 2003 period.

Outrigger Telescopes Project Wēkiu Bug Mitigation Plan.

Possible Hydrologic Impacts. As described in Section 4.1.4.2, there are two categories of possible hydrologic impacts to consider: changes to surface runoff; and impacts to groundwater due to subsurface wastewater disposal. Each of these is discussed in the sections following.

Possible Changes to Surface Runoff. Exclusive of the summit access road, the total area disturbed for the installation of the 12 existing observatories is approximately 7 ha (17 ac). This includes the impervious surfaces at each of the observatories (which amounts to less than 2 ha (4 ac)), adjacent and generally unpaved leveled areas, and access driveways. The 7-ha (17-ac) area distributed among the 12 observatories comprises about three percent of the 212-ha (525-ac) area of the Astronomy Precinct and less than 0.2 percent of the 4,452-ha (11,000-ac) MKSR. If a new site is developed for the TMT and expansion at existing sites occurs as assumed in Section 4.2.2, the estimated disturbed area would not likely exceed 10 ha (25 ac)— about 5 percent of the Astronomy Precinct and about 0.2 percent of the entire MKSR.

A thorough examination of all 12 observatory sites at the summit reveals a similar situation with regard to surface runoff as exists at W.M. Keck Observatory. Across all of the disturbed areas that surround the impermeable surfaces at each of the 12 observatories, strong winds have removed fine particles from the surface cinders, leaving behind a permeable layer of coarse sand and gravel-sized particles. At all 12 individual observatory sites, there is no evidence of surface runoff across these gravel surfaces; the capacity of this layer to absorb water has always been greater than the rate of precipitation. In other words, no surface runoff comes off these sites and runs down the slopes of the various volcanic cones on which they are located. As long as the new site for the TMT or redeveloped existing sites are configured similarly, no additional surface runoff would be created.

In contrast to the lack of runoff from the observatory sites, the access road from the Saddle Road up to and around the summit does create surface runoff and, to a limited extent, does alter the path of natural surface runoff from the mountain's slopes. Roadway lengths are from Saddle Road to Hale Pōhaku (all paved 10.1-km (6.3 mi)); from Hale Pōhaku to the summit (13.4-km (8.3 mi) of which 7.4 km (4.6 mi) is unpaved); and the loop around the summit, a portion of which is unpaved (2.7 km (1.7 mi). At an average width of 14 m (45 ft), including cuts and fills beyond the travel way and road shoulders, the total area of this 26.2 km (16.3 mi) of road is almost 36 ha (90 ac). This area is relatively small in relation to the mountain itself. For example, it is less than one percent of the 4,452-ha (11,000-ac) MKSR that is entirely above 3,658-m (12,000-ft) elevation.

Depending on road slopes, drainage improvements, and adjacent topography, surface runoff from the roadway and shoulders sheet flows off the road prism or is conveyed in road swales to specific discharge points. Because there are numerous points of discharge along the road and the rates of discharge at each point are relatively modest, the identifiable effects, including minor erosion and deposition of silt, sand, and gravel, are limited to tens to several hundred feet downslope from the points of discharge. Another significant aspect is that none of the identifiable paths of surface runoff extend to or below 1,829-m (6,000-ft) elevation. In other words, most of the surface runoff ultimately becomes groundwater recharge, with a small amount lost to evaporation. From this perspective,

the fact that there is surface runoff from the roadways does not alter the ultimate fate of the originating precipitation.

Assuming that the 7.4-km (4.6-mi) long unpaved road segment above Hale Pōhaku is ultimately paved, the amount of surface runoff would increase slightly, but the volume of sediment carried off the road surface and downslope would be substantially reduced. On balance, this would be an improvement over existing conditions.

Subsurface Disposal of Domestic Wastewater. Subsurface disposal of wastewater occurs in two general locations: (1) the seven cesspools and two septic systems at Hale Pōhaku, and (2) individual observatory sites at the summit. Each observatory on Mauna Kea operates an individual wastewater system (IWS) approved by the State of Hawai‘i Department of Health (UH 1999). No plan exists to replace these systems with a common sewage system (UH 1999). Licensed septic waste haulers pump the digested biosolids from each IWS periodically. The IWSs are inspected by observatory maintenance crews periodically. The exceptions are VLBA, UKIRT, and JCMT which do not inspect or pump out their systems periodically (JAC 2004b; VLBA 2004).

The only wastewater entering these systems is from domestic sources (e.g., sinks, toilets, urinals) and cleaning water (e.g., mop water). Prior to 2002, CFHT and the W.M. Keck Observatory directed process wastewater from mirror decoating into their respective IWSs. Due to concerns from community groups, this practice has been discontinued.

Hale Pōhaku. Based on the assumptions presented at the start of this section, the current 14 klpd (3,800 gpd) of wastewater disposal at Hale Pōhaku could ultimately increase to 18 klpd (4,730 gpd). At the summit, the current 7 klpd (1,780 gpd) of wastewater disposal could increase to 8.4 klpd (2,215 gpd). Both are increases approximately 25 percent higher than the current rates of discharge.

A conservative analysis of the impact of subsurface wastewater disposal at Hale Pōhaku was presented in Section 4.1.3.2. That analysis was based on the period of construction of the Outrigger Telescopes when wastewater generation at Hale Pōhaku was estimated to vary between 20 and 25 klpd (5,300 and 6,500 gpd) over a 24-month period. The subsurface wastewater discharge rates assumed for that analysis would be somewhat less than the anticipated, long-term 18-klpd (4,730-gpd) rate of disposal at Hale Pōhaku, making the previous results equal to or greater than the long-term impacts. Key findings of that analysis are summarized as follows:

- Because of Hale Pōhaku’s location relative to Mauna Kea’s south rift zone, wastewater percolating through the vadose zone would be likely to move in an easterly direction toward the Hilo area.
- If all removal and/or degradation of nutrients in the wastewater are ignored, including that which occurs in the cesspool and septic tank systems, through the thousands of feet of movement through the vadose zone, and during the tens of miles of travel in groundwater, only dilution would be available to mitigate the impact of the discharges. The rate of dilution would be at least 12,000 to 25,000 times. As a result of dilution alone, nutrient concentration levels in wells to the east of the summit would be essentially negligible compared to the natural

levels in pristine Hawaiian groundwater.

- Because nutrient removal and degradation would actually occur over this decades-long travel route, no actually measurable impact would occur.

There will be a period of time during the construction of TMT when up to 60 construction workers may be temporarily housed at the Hale Pōhaku. During this period, water use and wastewater disposal at the Hale Pōhaku may temporarily be on the order of 38 klpd (10,000gpd). This is greater than the rates used for the period of construction of the Outrigger Telescopes (up to 25 klpd (6,500 gpd)) and the anticipated longer-term rates after the TMT is completed (18 klpd (4,730 gpd)). However, the same assumptions used for the analysis in Section 4.1.4.2 are still applicable and the conclusions reached are still the same. By dilution alone, impact of the temporary increase of wastewater produced by TMT construction workers residing at Hale Pōhaku would be negligible. Actual degradation of organic matter in the wastewater will occur over the decades-long travel path, further mitigating this temporary impact.

Observatory Sites. In Section 4.1.3.2, the impact of the subsurface disposal of 1.8 klpd (480 gpd) of domestic wastewater from the W.M. Keck Observatory septic system is analyzed. Key points of that analysis, which are relevant to an analysis of cumulative impacts of subsurface wastewater discharges at the summit, would be:

- For the reasons given previously, none of the subsurface disposal of wastewater at the summit observatories would end up in Lake Waiau or as discharge from any of the perched springs on the west side of Pōhakuloa Gulch.
- Based on the locations of the observatories relative to the mountain's rift zones and a conservative estimate of impact, it is assumed that percolating wastewater at the summit would move to the south and/or west.
- The nearest wells in that general direction are 20.2-km (12.6-mi) away in Waiki'i.

Based on the series of assumptions provided in Section 4.1.3.2, increases in the Waiki'i wells of nitrogen and phosphorus percentages of 2 klpd (480 gpd) of wastewater discharged at W.M. Keck Observatory were calculated to be 0.4 and 1.6 percent, respectively.

If this same series of assumptions as described in Section 4.1.3.2 are used, the anticipated long-term total wastewater discharge at the summit of 8.4 klpd (2,215 gpd) could result in nitrogen and phosphorus increases in the Waiki'i wells of no more than 1.8 and 7.4 percent, respectively. Increases of this magnitude would not impair use of the Waiki'i wells for potable water consumption.

The actual increases would likely be far less than estimates using a series of conservative assumptions. Nutrient removal rates in the decades-long travel time from the summit to the Waiki'i wells would be far greater than assumed and capture of all the remaining nutrients by the Waiki'i wells, also one of the assumptions of the analysis, would be a highly improbable result.

4.2.5.3 Cumulative Impact Summary

The impact of all past, present, and reasonably foreseeable future astronomy related projects, including the Outrigger Telescopes Project, on the hydrologic

system is negligible. Therefore, the cumulative impact on hydrology and water quality is not significant.

4.2.6 Solid Waste and Hazardous Materials Management

4.2.6.1 ROI for Solid Waste and Hazardous Materials Management

The ROI for solid waste and hazardous materials depends on the material and the manner of release. For example, wind-blown trash could be transported anywhere across the mountain, while a spill on cinder and clean-up of several liters of liquid would most likely be confined to the immediate area. For purposes of this evaluation, the ROI is the area within the MKSR, a corridor surrounding the Mauna Kea Access Road and the Saddle Road, and the potential surface and subsurface water flow paths.

4.2.6.2 Impacts of Past and Present Activities on Solid Waste and Hazardous Materials Management

Solid Waste. Past construction activities on Mauna Kea have generated debris, and past facility operations have generated trash and other solid waste. These materials have been collected in containers, removed periodically from the site, and disposed of at authorized landfills. However, there have been releases of these wastes on Mauna Kea. As described in Section 4.2.4.3, researchers performing a botanical survey in 1982 reported a considerable amount of trash around the mountaintop. Trash can have a detrimental effect on flora and fauna and can spoil the visual appeal of the surroundings. UH responded to this concern in the 1999 MKSR Master Plan EIS by accepting responsibility for waste removal within the MKSR. Since then, trash has been collected by Mauna Kea Support Services, including trash left by visitors to the summit, and is now rarely seen within the MKSR.

Trash generation rates for present facility operations are given in Table 4-16. Estimates range from one 110-l (30-gal) bag weekly at the VLBA and JAC to 1.1 kl (290 gal) daily at Hale Pōhaku. The aggregate weekly rate is approximately 16.7 kl (4,400 gal). Each facility puts its trash in standard containers for transport and disposal off site.

The impacts to flora, fauna, and aesthetics as a result of past and present solid waste generation have been small, transient, and not significant.

Hazardous Materials. Past construction activities and facility operations on Mauna Kea required the use of and generated waste from hazardous materials, including paints and solvents, vehicle and generator fuel, lubricants, hydraulic fluid, glycol coolants, acids (used in mirror decoating), and mercury. Despite best efforts to prevent spills, a small number have occurred since observatory operations began at the summit. Hazardous material releases, if large, can potentially have an adverse effect on biological and water resources and can degrade aesthetics by discoloring the ground. Table 4-17 summarizes known spills that have occurred either at the summit, along the Mauna Kea Access Road, or at Hale Pōhaku. Some of these spills occurred within the confines of an observatory building and usually did not reach the outside environment. Others occurred outside and were, in most cases, identified immediately and cleaned up quickly and thoroughly, eliminating any potential for lasting impact. Best available information suggests none of the mercury spills reached the outside environment. However, the mercury spills prompted recommendations for better equipment and training at the Canada-France-Hawaii

TABLE 4-16. CURRENT WASTE AND HAZARDOUS MATERIALS USE AT THE MAUNA KEA OBSERVATORIES AND HALE PŌHAKU

Observatories	UH (0.6-m (24-in) and 2.2-m (88-in))	CFHT	NASA IRTF	UKIRT	CSO	JCMT	VLBA	W.M. Keck Observatory	Gemini North	Subaru Telescope	SMA	Hale Pōhaku Mid-Elevation Support Facilities
Start of Operations	1968 (0.6 m (24 in)) 1970 (2.2 m (88 in))	1979	1979	1979	1987	1987	1992	1992 Keck I 1996 Keck II	1999	1999	2002	1980s
Safety and/or Hazardous Materials Management Plan	Written plan available	Written plan available	Written plan available	Written plan available	Written plan available	Written plan available	Written plan available	Written plan available	Written plan available	Written plan available	Written plan available	Written plan available
Hazardous Material Disposal and Recycling	Licensed hazardous waste transporters transport any hazardous waste to a licensed disposal facility	Contractor handles hazardous material, offsite disposal; waste streams include ethylene glycol, hydraulic fluid, diesel fluid, refrigerant, oils and lubricant, paint and related solvents	Licensed hazardous waste transporters transport any hazardous waste to a licensed disposal facility	Contractor handles hazardous material, offsite disposal	Contractor handles hazardous material, offsite disposal	Contractor handles hazardous material, offsite disposal	Used gear box oil shipped to HQ in New Mexico and disposed by contractor	Contractor handles hazardous material, offsite disposal	AC system and used generator oil, ethylene glycol, paint, solvent, oily rags, all trucked to Hilo and disposed by Unitek; refrigerant is recycled	Contractor handles hazardous material, offsite disposal	Hydraulic oil from antenna transporter disposed of by oil processor in Hilo	Licensed hazardous waste transporters transport any hazardous waste to a licensed disposal facility

TABLE 4-16. CURRENT WASTE AND HAZARDOUS MATERIALS USE AT THE MAUNA KEA OBSERVATORIES AND HALE PŌHAKU (CONTINUED)

Observatories	UH (0.6-m (24-in) and 2.2-m (88-in))	CFHT	NASA IRTF	UKIRT	CSO	JCMT	VLBA	W.M. Keck Observatory	Gemini North	Subaru Telescope	SMA	Hale Pōhaku Mid-Elevation Support Facilities
Mirror De-coating and Re-aluminizing	Performed at the UH 2.2-m (88-in) observatory, 113 l (30 gal) of liquid waste from stripping (HCl, $CuSO_4$, $CaCO_3$, Alconox); Since 2000, effluent containerized for offsite disposal; aluminum applied by vapor deposition; recoating every two years	Performed in summit observatory; 2,300 l (600 gal) water, HCl, $CuSO_4$, neutralized w/ slurry of $CaCO_3$; Since May 20002, effluent containerized for offsite disposal; aluminum re-coating applied by vapor deposition, one mirror processed per year	Performed at CFHT, mirror processed every 3 to 4 years	Performed at CFHT	N/A	N/A	N/A	Performed in summit observatory; 150 l (40 gal) water, HCl, $CuSO_4$, neutralized with slurry of KOH; Since 2002, effluent containerized for offsite disposal; aluminum re-coating applied by vapor deposition, up to four mirrors processed per month	Performed in summit observatory; HCl solution, KOH and $CuSO_4$, neutralized with a slurry of $CaCO_3$ and KOH, 90 l (25 gal) of solution, up to 4,200 l (1,100 gal) rinse water; effluent containerized for offsite disposal; aluminum re-coating applied by sputtering plasma flow with no waste; coated primary in Jan 2004, previous April 2000	Performed in summit observatory; HCl, $CuSO_4$, ethanol, neutralized w/ baking soda and up to 10,000 l (2,600 gal) water, baking soda; effluent containerized for offsite disposal	N/A	N/A
Fuel for Back-up Generator	Propane, two 40-l (10.6-gal) tanks attached to generator; generator used once in 10 years	Diesel, 7,600 l (2,000 gal) in 19,000-l (5,000-gal) underground storage tank, 280 l (75 gal) in generator; fuel oil is replaced as needed every few years	No back-up generator	Diesel, one 19-l (5-gal) fuel container stored outside; estimate 1/4 container used yearly	Propane, four 45-kg (100-lb) storage tanks refilled at 3 to 5 year intervals	Propane, eight 87-l (23-gal) tanks stored outside; estimate 1/4 tank used yearly	Diesel, 950-l (250-gal) double walled tank; replenished about once yearly, rarely used	Diesel, 9,500-l (2,500-gal) double walled underground storage tank	Diesel, 680-l (180-gal) double walled tank underneath generator; exercise the generator one hour weekly, then tank topped off with 30 l (8 gal) fuel	Diesel, 3,800-l (1,000-gal) underground tank; refilled every few years	Diesel, 3,800-l (1,000-gal) double walled above ground tank; generator not yet installed	No back-up generator

TABLE 4-16. CURRENT WASTE AND HAZARDOUS MATERIALS USE AT THE MAUNA KEA OBSERVATORIES AND HALE PŌHAKU (CONTINUED)

Observatories	UH (0.6-m (24-in) and 2.2-m (88-in))	CFHT	NASA IRTF	UKIRT	CSO	JCMT	VLBA	W.M. Keck Observatory	Gemini North	Subaru Telescope	SMA	Hale Pōhaku Mid-Elevation Support Facilities
Hydraulic Fluid	1,500 l (400 gal) in use, 570 l (150 gal) in storage, replaced every 5 years	1,135 l (300 gal) in use, 2,100 l (600 gal) in storage; systems replenished once in past 10 years	340 l (90 gal) in use, 19 l (5 gal) in storage, replaced as needed	Less than 114 l (30 gal) in use in both UKIRT and JCMT; less than 19 l (5 gal) in storage	190 l (50 gal) in use, 19 l (5 gal) in storage, added to equipment as needed	Less than 114 l (30 gal) in use in both UKIRT and JCMT; less than 19 l (5 gal) in storage	106 l (28 gal) in use, 76 l (20 gal) in storage, replaced yearly	4,500 l (1,200 gal) in use, 208 l (55 gal) in storage	1,500 l (400 gal) in use, replaced as needed every several years	2,600 l (690 gal) reservoir, 208 l (55 gal) in storage	380 l (100 gal) in use, 150 l (40 gal) in storage	Normally less than 208 l (55 gal) on hand, recycle 760 l (200 gal) yearly
Cooling Media	Liquid nitrogen, use 300-l (80-gal) monthly; R-22 in use, two 14-kg (31-lb) containers in storage; ethylene glycol, 380 l (100 gal) in use, 190 l (50 gal) in storage	50:50 mixture glycol + water 1,900 l (500 gal) in use, 830 l (220 gal) in storage; liquid nitrogen used 640 l (170 gal) monthly (evap), 320 l (85 gal) stored; helium also used, one cylinder in storage; refrigerants used, 73 kg (160 lb) R-502 and 23 kg (50 lb) R-404a	Propylene glycol, 302 l (80 gal) used, replaced as needed; stores 38 l (10 gal) @100 percent, 320 l (85 gal) @ 40 percent w/ water; liquid nitrogen and liquid helium in use; refrigerants used, 91 kg (200 lb) R-134A and 68 kg (150 lb) R-409A	Ethylene glycol + water mixture, 227 l (60 gal) in use	50:50 Mixture ethylene glycol and water 76 l (20 gal); 100 l (26 gal) helium, 120 l (32 gal) nitrogen, equal amounts stored; use rates, 100 l (26 gal) helium weekly, 120 l (32 gal) nitrogen monthly	Ethylene glycol + water mixture, 170 l (45 gal) in use	Helium, one 8,300-l (2,200-gal) bottle used every three years, one bottle in storage; Refrigerant R-22, 5.9 kg (13 lb) in use, 1 kg (2.2 lb) in storage	Propylene glycol, 1,135 l (300 gal) in use, ethylene glycol, 1,135 l (300 gal) in use; 2,270 l (600 gal) glycols in storage	60/40 mixture ethylene glycol/water, 4,162 l (1,100 gal) in use, 416 l (110 gal) in storage; closed cycle helium cooling for instruments, none consumed, a few helium gas cylinders stored	Ethylene glycol, 13.6 kl (3,600 gal) in use, 416 l (110 gal) in storage, refilled as necessary; refrigerant R-22, 227 kg (500 lb) in use, none stored	Glycol + water mixture, 189 l (50 gal) in use, 114 l (30 gal) in storage; refrigerant R-22, 82 kg (180 lb) in use, none stored	None used at facility
Paint, Related Solvents	About 38 l (10 gal) on site, mostly spray cans, several used per month as needed	38 l (10 gal) paint on site, used for occasional touch up	189 l (50 gal) on site, used on monthly basis depending on job requirements	Less than 19 l (5 gal) onsite	Paint, 83 l (22 gal) on site for cosmetic touch up; thinner, 7.6 l (2 gal) on site	Less than 19-l (5-gal) onsite	Acrylic roof coating 19 l (5 gal), spot repairs, once per year	Various amounts on site, used as needed	About 76 l (20 gal) in storage; thinner, several liters in storage; used maybe once per week	None on site	Paint and primer 45 l (12 gal) in use and storage; mineral spirits 7.6 l (2 gal) in use and storage	Solvent, 190 l (50 gal) mostly in parts washer, recycled

TABLE 4-16. CURRENT WASTE AND HAZARDOUS MATERIALS USE AT THE MAUNA KEA OBSERVATORIES AND HALE PŌHAKU (CONTINUED)

Observatories	UH (0.6-m (24-in) and 2.2-m (88-in))	CFHT	NASA IRTF	UKIRT	CSO	JCMT	VLBA	W.M. Keck Observatory	Gemini North	Subaru Telescope	SMA	Hale Pōhaku Mid-Elevation Support Facilities
Oil and Lubricant	Lube, 76 to 114 l (20 to 30 gal) in use	Oil and lube, 95 l (25 gal) in storage	114 l (30 gal) stored on site	Between UKIRT and JCMT, about 76 l (20 gal) stored on site	Grease, about 23 kg (50 lb), and lubricants, 45 l (12 gal) stored onsite	Between UKIRT and JCMT, about 76 l (20 gal) stored on site	Gear lube, 19 l (5 gal), grease, 57 l (15 gal), and motor oil, 7.6 l (2 gal) in storage	Oil, 3,800 l (1,000 gal) in use, 380 l (100 gal) in storage	Grease, about 23 kg (50 lb), and oils, 380 l (100 gal) in storage	Lubricant for periodic service of back up generator, none stored onsite	Engine oil, 34 l (9 gal) in use, 38 l (10 gal) in storage; lubricant 4.5 kg () 10 lb) in use, 4.5 kg (10 lb) in storage	Oil, less than 380 l (100 gal) in storage
Mercury	Primary mirror support for 2.2-m (7.2-ft) only, 13.6 kg (30 lb) in use, 9.1 kg (20 lb) in storage	Mercury used in radial support tube for secondary mirror; 7.7 kg (17 lb) in use, 9.5 kg (21 lb) in reserve	About 51 kg (112 lb) in support tube for primary mirror, none held in reserve	No mercury used	No mercury used	No mercury used	No mercury used	1.4-m (4.6-ft) secondary mirror support; 5.9 kg (13 lb) in use, 7.7 kg (17 lb) in storage	No mercury used other than a few thermometers	No mercury used	No mercury used	No mercury used
Trash	Two to three 114-l (30-gal) bags weekly	Four bins, 1.5 m^3 (2 yd^3) each, generated monthly	Three 114-l (30-gal) trash bags weekly	About one 114-l (30-gal) trash bag for both facilities weekly (UKIRT and JCMT)	About 900 kg (2,000 lb) generated yearly	About one 114-l (30-gal) trash bag for both facilities weekly (UKIRT and JCMT)	One 114-l (30-gal) bag weekly	2.3 m^3 (3 yd^3) dumpster emptied 1 to 2 times weekly	Several 190-l (50-gal) trash bags weekly	18 kg (40 lb) generated daily	Two to four 190-l (50-gal) drums weekly	0.7 to 1.1 m^3 (0.9 to 1.5 yd^3) daily
Green Products	Try to use environmentally friendly products whenever possible	Mindful of selecting green products	Seek better products on an as needed basis, switch to friendly products whenever possible	No information	Does not survey market-place for such products	No information	Routinely survey the market-place for these items	Surveys periodically for green products	Surveys marketplace for green products	Does not survey marketplace for such products	Surveys periodically for green products	Not routinely, but does have an upgraded parts washing facility

Notes:
N/A means category not applicable

TABLE 4-17. HAZARDOUS MATERIAL AND SEWAGE SPILLS ASSOCIATED WITH ASTRONOMY OPERATIONS ON MAUNA KEA

Date	Location	Material(s)	Accident/Response
1979 (estimated)	CFHT Facility (indoors)	Hydraulic fluid	A hydraulic system filter clogged, leading to the backfilling of a drain, which overflowed and caused roughly 1.9 l (0.5 gal) of hydraulic fluid to spill onto an optical tube. There is also anecdotal recollection of a spill and cleanup related to a burst hydraulic pump in the early years of observatory operation.
1982	Now known as the summit area construction staging area	Diesel fuel	During a biological survey, Howarth and Stone (1982) noted an area of staining (18 m^2 (194 ft^2)) on the ground near a temporary generator and suspected a diesel fuel spill. The generator has since been removed.
1989	NASA IRTF (indoors)	Mercury	A mercury spill (9 kg (20 lb)) resulted from the puncture of the primary mirror support ring. Cleanup was performed in accordance with written observatory procedures using commercial products designed for mercury recovery.
October 3, 1990	CFHT Facility (indoors)	Mercury	Mercury spill from a pinched secondary mirror support bladder. Facility was evacuated temporarily during cleanup.
1995	W.M. Keck Observatory (indoors)	Mercury	Three mercury spills have occurred at the observatory: August 10, 1995, while working on f/15 secondary, resulting in a 5-ml (1- teaspoon) spill. September 15, 1995, while working on f/15 secondary mirror, resulting in a 100-ml (7-tablespoon) spill. November 6, 1995, while transferring mercury between containers, resulting in a spill of 5 to 10 ml (1 to 2 teaspoons). All three spills occurred in the mirror handling room, and were cleaned up promptly. None resulted in any mercury seepage into the ground or the septic system. As a result of these incidents, the observatory revised mercury handling and response procedures. No subsequent mercury spills have occurred.
November 3, 1995	Mauna Kea Access Road near Very Long Baseline Array	Diesel fuel, engine and hydraulic oil	Truck involved in construction of SMA overturned, causing fuel tank and engine lines to rupture, releasing approximately 227 l (60 gal) of fluids onto surface cinder; impacted media were excavated and removed by truck owner within 24 hours.
September 3, 1996	Subaru Telescope	Ethylene glycol	Release occurred when a pallet carrying two 208-l (55-gal) containers failed, and the containers fell to the cinder and ruptured. Cleanup was performed immediately to recover free liquid and excavate affected cinder. All contaminated materials were bagged and disposed of.

TABLE 4-17. HAZARDOUS MATERIAL AND SEWAGE SPILLS ASSOCIATED WITH ASTRONOMY OPERATIONS ON MAUNA KEA (CONTINUED)

Date	Location	Material(s)	Accident/Response
1998 (estimated)	UH 2.2-m Telescope facility (indoors)	Mercury	More than 5 years ago a few drops of mercury escaped on several occasions while the mirror support ring was being drained or refilled during the recoating process. These were cleaned up according to the UH mercury cleanup procedures.
January 15, 1998	Subaru Telescope	Sewage	Improper installation of septic tank led to freezing, which created a clog and a spill of about 7.6 l (2 gal) on the ground and snow. A plumber repaired the clog, and the observatory added cinder atop the septic system to insulate against freezing.
June 5, 1998	CFHT facility (indoors)	Mercury	In order to align a lens, a pool of mercury was lifted to the bottom of the lens to create a reflected image. During the procedure about a "thimble full" of mercury spilled from an overflow dish to the concrete floor. The mercury was cleaned up quickly. Afterward, recommendations were made for additional training and better equipment for containment.
1990 to 2000 (date estimated)	Caltech Submillimeter Observatory	Hydraulic fluid	In past years, on a few occasions, small amounts of hydraulic fluid seeped out of joints in the dome hydraulic system and dripped onto the concrete pad under the dome. No fluid traveled beyond the concrete pad. An ongoing hydraulic system inspection program detects any seepage source. The source is eliminated, and all traces of fluid on the concrete pad are immediately cleaned up.
2003 (date estimated)	Hale Pōhaku	Crankcase oil and hydraulic fluid	Crankcase oil and hydraulic fluid leaked from a piece of equipment. The soil was excavated, tested, and sent to a landfill in compliance with State health department regulations. The facility has taken measures to reduce the likelihood of this type of spill recurring.
2003	Hale Pōhaku	Transmission oil	Two oil drips beneath an old truck used to transport mirror for the Joint Astronomy Center. Total amount of the leakage estimated at less than 950 ml (1 qt). The Joint Astronomy Center dug out cinders under drip areas and removed them for disposal. Absorbent pads were used to stop further drips; the truck was removed.
2003	Smithsonian Astrophysical Observatory Submillimeter Array	Hydraulic fluid	Hydraulic leak onto asphalt, about 473 ml (0.5 qt), caused by decayed seals. Cleaned using approved "pig-mat" absorbent material, which was disposed of appropriately.
February 2004	Smithsonian Astrophysical Observatory Submillimeter Array	Diesel fuel	Diesel leak onto asphalt, less than 3,800 ml (4 qt), caused by decayed seals. Cleaned using approved "pig-mat" absorbent material, which was disposed of appropriately.

TABLE 4-17. HAZARDOUS MATERIAL AND SEWAGE SPILLS ASSOCIATED WITH ASTRONOMY OPERATIONS ON MAUNA KEA (CONTINUED)

Date	Location	Material(s)	Accident/Response
March 30, 2004	W.M. Keck Observatory	Propylene glycol	The spill occurred during testing of an auxiliary glycol cooler when one of the hoses accidentally became dislodged from its barbed fittings. Spill estimated between 76 and 114 l (20 and 30 gal), with approximately two-thirds escaping outside the facility. The CARA Safety Officer handled spill response; affected cinder was contained, removed, and disposed of at a local landfill. The observatory notified OMKM, which advised on disposal.

facility and a revision to mercury handling and response procedures at the W.M. Keck Observatory.

Current facility operations on Mauna Kea use and generate waste from similar types of hazardous materials. Table 4-16 summarizes current hazardous materials use and applications at the observatories and Hale Pōhaku. The facilities use many of the same hazardous materials, with some notable exceptions. Of the eight optical observatories, only five perform mirror recoating operations on site (UH–2.2 m, CFHT, W.M. Keck, Gemini North, and Subaru) and only four use mercury for mirror support (UH–2.2 m, CFHT, IRTF, and W.M. Keck).

Each facility has written procedures for handling hazardous materials and provides training for workers involved in such activity. In addition, each observatory has emergency procedures for responding to chemical spills.

In summary the impacts to biological resources and aesthetics as a result of past and present handling of hazardous materials (i.e., accidental spills) have been small and not significant.

4.2.6.3 Impacts of Reasonably Foreseeable Activities on Waste and Hazard Materials Management

Solid Waste. Reasonably foreseeable future activities, whether new construction, facility redevelopment, or continued operation of current facilities, would presumably generate solid wastes similar to those described under past and present activities.

For the purposes of this analysis, it is assumed that, during construction, mitigation measures would be implemented to reduce the possibility of waste dispersal, e.g., securing lids and/or heavy tarps over disposal containers and construction materials; securing outdoor receptacles to the ground; and arranging for more frequent waste removal.

Solid waste streams related to facility operations would increase if proposed new facilities, such as the TMT, are constructed. It is assumed these waste streams would be handled in a fashion similar to other observatories. It has been assumed for the purpose of this evaluation that the TMT would generate trash at a rate similar to that of the W.M. Keck Observatory (i.e., 4.6 m^3 (6 ft^3) per week). Facility redevelopment, if realized, would likely increase the amount of solid waste generated, but only slightly in proportion to additional staff. As observatories become more remotely operated, the amount of waste generated at the Mauna Kea summit would be reduced.

There are no future plans to consolidate waste containerization among observatories on the summit.

It is assumed that proposed development of non-astronomy-related facilities (e.g., the remotely operated microwave facility) and communities (e.g., DHHL land development) would have similar waste management practices.

Overall, no significant impact from solid waste management within the ROI is expected from reasonably foreseeable future activities.

Hazardous Materials. It is assumed that reasonably foreseeable future activities would use and generate waste from hazardous materials similar to those generated by past and present activities.

It has been assumed for the purpose of this evaluation that the TMT would use and generate waste from hazardous materials at a rate similar to that of the W.M. Keck Observatory.

It is assumed that new or redeveloped facilities would each have written standard operating and emergency procedures for handling hazardous materials and would provide training for workers accordingly.

It is assumed that contractors would provide only the necessary amounts of paints and solvents on the summit, eliminating temporary storage needs there, and that transportation of hazardous materials and waste would be coordinated with other construction traffic to minimize the chance for an accident and release at the summit or along the Mauna Kea Access Road.

Given these assumptions and other procedures available to manage hazardous materials, no significant impacts within the ROI are expected from reasonably foreseeable future activities.

4.2.6.4 Cumulative Impact Summary

Solid Waste. Impacts of solid waste on biological or hydrological resources or aesthetics from past, present, and reasonably foreseeable activities have been small, if any, transient, and not significant. Table 4-18 compares the estimated solid waste load of the Outrigger Telescopes Project to past, present, and reasonably foreseeable generation rates for the summit observatories and Hale Pōhaku. The data show a minor increase due to the Outrigger Telescopes Project. The incremental impact of the Outrigger Telescopes Project would therefore be small and not significant.

Hazardous Materials. Impacts of hazardous materials on biological resources or aesthetics from past, present, and reasonably foreseeable activities have been small and not significant. Table 4-16 compares the estimated hazardous materials use of the Outrigger Telescopes against past, present, and reasonably foreseeable use rates for the summit observatories and Hale Pōhaku. The data show minor increases resulting from the Outrigger Telescopes and no mercury or glycol use. The incremental impact of the Outrigger Telescopes Project would therefore be small and not significant.

4.2.7 Geology, Soils, and Slope Stability

4.2.7.1 ROI for Geology, Soils, and Slope Stability

For this discussion, geology, soils, and slope stability refers to the impact of human activity on all geologic features of Mauna Kea, especially on the morphology of cinder cones and on the processes of erosion, which can cause the excavation, transport, and redeposition of soils and cinders.

The ROI for assessing the potential impacts from implementing the Outrigger Telescopes Project on geology, soils, and slope stability would be the summit of Mauna Kea, Hale Pōhaku, construction staging and laydown locations, and on roadways that connect these facilities.

4.2.7.2 Impacts of Past and Present Activities on Geology, Soils, and Slope Stability

The development of each Mauna Kea summit observatory has been accompanied by localized site developments that have significantly modified the preexisting landscape and impacted geologic structures and slope stability. The development of the NASA IRTF, the W.M. Keck Observatory, and the Subaru Telescope were accompanied by great modification of the physiography of Puʻu Hauʻoki and the unnamed cinder cones to the west, as connecting roads were built (Figure 4-2) and as the tops of these cones were flattened to prepare foundations for the telescopes. Most of the material removed from these

TABLE 4-18. EFFECT OF THE OUTRIGGER TELESCOPES ON SOLID WASTE GENERATION AND HAZARDOUS MATERIALS USE ON PAST, PRESENT, AND REASONABLY FORESEEABLE FUTURE ACTIVITIES AT THE MAUNA KEA OBSERVATORIES AND HALE PŌHAKU

Material Class	Total of Past, Present, and Reasonably Foreseeable Future Activities at Mauna Kea Observatories and Hale Pōhaku	Anticipated Increment of Outrigger Telescopes Project
Glycol cooling media	More than 24,000 l (6,300 gal) total in use and storage	No glycol used
Fuel storage for backup generator	Diesel, 26,600 l (7,000 gal) Propane, more than 1,000 l (264 gal)	No fuel required; emergency power provided by existing infrastructure
Hydraulic fluid	About 16,000 l (4,200 gal) total in use and storage	No hydraulic fluid used
Oil and lubricants	About 5,700 l (1,500 gal) total in use and storage	Gear oil (66 l (17 gal) per Outrigger Telescope) and grease used; no additional lubricants stored on site
Mercury	About 82 kg (180 lb) total in use and storage	No mercury used
Mirror decoating, recoating	More than 52 mirrors decoated and recoated each year	Up to three mirrors decoated and recoated each year.
Paints and related solvents	Total in use and storage: Paint, more than 525 l (140 gal) Solvent, more than 200 l (53 gal)	Used as needed; no additional paint and solvents stored on site
Trash	About 16.3 m^3 (21.3 ft^3) generated weekly	About 0.6 m^3 (0.8 ft^3) generated weekly

cones was transported away for use elsewhere or deposited on the floor of the Pu‘u Hau‘oki crater, but some material was pushed over the sides of the cones. These small areas of disturbed, redeposited rock and soil debris have steeper slopes than the preexisting natural slopes, which had become gentler and more stable over the past tens of thousands of years since their formation through natural processes (Hooper 1998). The artificially steepened slopes consist of poorly consolidated loose cinders, lava fragments, and admixed sand that are more easily disturbed than the materials of original, preconstruction slopes.

The construction of the access road to Mauna Kea’s summit caused localized modification of preexisting terrain, through excavation of road cuts and filling of natural low-lying areas. Subsequent to construction, significant erosion of loosened materials adjacent to the unpaved sections of the access road has occurred during times of heavy rainfall or rapid snow erosion, and this erosion has transported large quantities of sand and gravel to low-lying areas as much as 91 m (300 ft) downslope from the road, especially onto the flat-lying area northeast of Pu‘u Keonehehee (Figure 4-3). This erosion and redeposition occurred some time after December 1976, since aerial photos taken at that time do not show these deposits. Major efforts to mitigate this problem have been successful through the construction of settling basins along the roadway which trap sediment and allow road runoff water to percolate into the highly

FIGURE 4-2. ROAD ALONG THE WEST SLOPE OF PU'U HAU'OKI

Note the steepened angles of the artificial slope versus the natural undisturbed slope below.

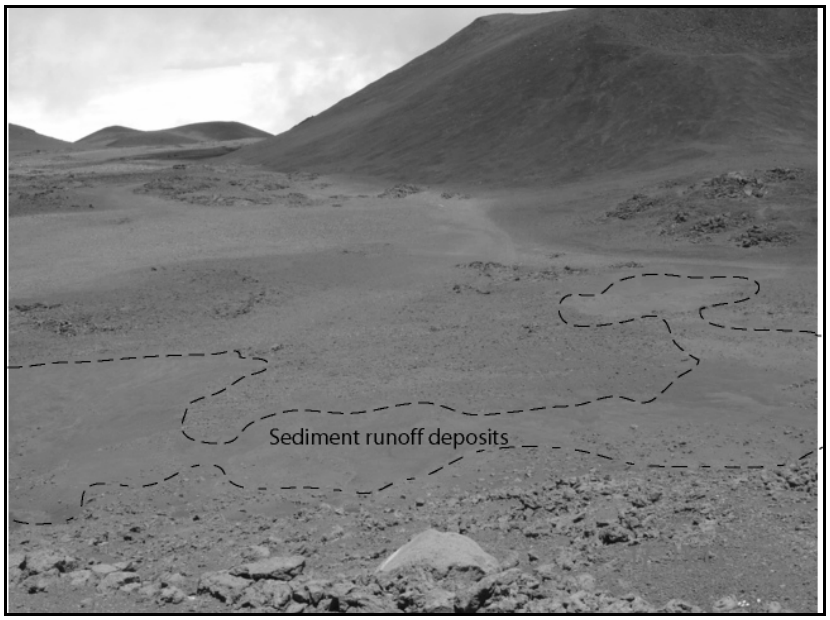


FIGURE 4-3. RECENT SEDIMENT DEPOSITS BELOW MAUNA KEA ACCESS ROAD AT 3,505-M (11,500-FT) ELEVATION

Note these sediments were deposited by runoff from the roadway after construction.

permeable underlying rocks. Ongoing road grading operations result in debris being pushed over embankments in some places (Figure 4-4), but this material does not travel far onto undisturbed ground.

In summary the impact of past and present activities on geology, soils, slope stability has been substantial.

4.2.7.3 Impacts of Reasonably Foreseeable Future Activities on Geology, Soils, and Slope Stability

Reasonably foreseeable future activities, e.g., redevelopment of current summit ridge observatories, would not be expected to substantially alter the current topography of the summit cinder cones. These activities would potentially have a small impact on the geology, soils, and slope stability of very localized areas. It is assumed that, if the TMT were to be implemented on the northwest plateau, excavated cinders would not be used in a way that would impact other previously undisturbed surfaces. It is also assumed that adequate engineering standards would be maintained to prevent unwarranted settling or deformation of foundations during future seismic activity.

The impact of human foot travel over the summit cones also needs to be considered as a factor in the degradation of cone slopes as recreational visitor numbers increase. Human foot traffic can accelerate modification of cone slopes and disturb natural habitats. These impacts can be reduced by educating visitors to the fragility of the cinder cones and encouraging them to remain on roadways and established trails.

4.2.7.4 Cumulative Impact Summary

The impact of past and present activities on geology, soils, and slope stability has been substantial. The impact of foreseeable future activities is anticipated to be small. The Outrigger telescopes would add a small and not significant incremental impact. The overall cumulative impact has been significant.

4.2.8 Land Use and Existing Activities

4.2.8.1 ROI for Land Use and Existing Activities

The ROI for assessing land use impacts includes the MKSR, Hale Pōhaku, and a corridor surrounding the Mauna Kea Access Road and the Saddle Road. The ROI for assessing existing activities impacts includes these areas and the Mauna Kea Natural Area Reserve.

4.2.8.2 Impacts of Past and Present Activities

Although the formation of the Astronomy Precinct, Hale Pōhaku, and the roadways accessing these areas has been consistent with State land use policies, existing activities have been substantially affected by past and present actions. Observatory development and improved access to the summit have changed the conditions in which current activities, such as traditional cultural practices and hiking, occur. These impacts are evaluated in detail in relevant sections of this document. Overall, the past and present activities listed in Table 4-7 have resulted in a substantial impact on existing activities.

4.2.8.3 Impacts of Reasonably Foreseeable Future Activities

It is anticipated that most reasonably foreseeable future activities listed in Table 4-8 would be consistent with State and local plans and compatible with State land use designations. The reasonably foreseeable future activities compatible with current land use designations, i.e., astronomy-related activities consistent with the Conservation District and resource subzone

FIGURE 4-4. ROADWAY EMBANKMENT BELOW THE MAUNA KEA ACCESS ROAD AT 3,170-M (10,400-FT) ELEVATION

Note material from road-grading operations is pushed over the embankment, but does not travel far down slope.

designations, would result in little or no impact on land use. Reasonably foreseeable future activities that do not conform to the types of uses permitted by the State Land Use Commission would require the current land use designation to be amended for a new type of use. In particular, the DHHL Land Acquisition would require rezoning the land for residential or preservation, depending on the chosen use(s). This development could impact access to the MKSR or result in rerouting the access road because the land parcel overlays the existing roadway. Consequently, this action could result in substantial land use impacts.

With the exception of the DHHL Land Acquisition, it is anticipated that most reasonably foreseeable activities would not impact existing activities. The suitability of the land within the ROI for cultural and religious practices, astronomical and other scientific research, and a variety of recreational activities would remain similar to the present. Paving the remainder of the Mauna Kea Access Road could impact existing activities by providing improved access to the summit region.

In summary, foreseeably future activities would not impact land use and existing activities. Exceptions are the DHHL Land Acquisition and paving of the remainder of the Mauna Kea Access Road, which could potentially have substantial impacts.

4.2.8.4 Cumulative Impact Summary

Most past, present, and reasonably foreseeable future activities on Mauna Kea have been consistent with State and local plans and compatible with State land use designations. The Outrigger Telescopes Project would have no incremental impact on land use.

From a cumulative perspective, the impacts of past, present, and foreseeably future activities on existing activities on Mauna Kea are substantial. The addition of the

Outrigger Telescopes to the existing observatories on the mountain would have a small incremental impact.

4.2.9 Transportation

4.2.9.1 ROI for Transportation

Transportation refers to the movement of vehicles along roads. The ROI for assessing transportation impacts includes the MKSR and other areas affected by on-site construction, installation, and operations including Hale Pōhaku and vehicle travel routes.

4.2.9.2 Impacts of Past and Present Activities on Transportation

The road from the saddle to Mauna Kea has undergone significant realignments and improvements over the years. In the 1930s, a gravel road was established that enabled vehicles to travel to Hale Pōhaku. The first jeep trail to the summit was developed when the NASA-funded 30-cm (12-inch) telescope installation began in 1964. In 1975, the jeep trail to the summit was realigned to eliminate some of the steep grades and sharp turns in the original alignment. In 1985, with funding from the State of Hawai‘i and the W.M. Keck Observatory, the Hawai‘i DOT began to design a 6-m (20-ft) wide roadway beginning at Hale Pōhaku and looping around the summit. This trail was named after John Burns, the governor in office in the 1960s at the time of the initial observatory development on Mauna Kea. The roadway was later paved between the 3,597-m (11,800-ft) level and the summit.

The creation of access roads allowed visitors, including many Native Hawaiians, to travel to the summit area for the first time. Today, thousands of visitors and Native Hawaiians travel to Mauna Kea each year to participate in a variety of cultural, scientific, and recreational activities. Table 3-9 in Section 3.1.8.3 summarizes the current traffic volume within the ROI by showing the traffic associated with astronomy-related activities and traffic associated with other activities.

Generally, traffic levels are low; however, during construction periods or during major astronomical events, traffic can become congested. Such delays are infrequent and do not impede overall traffic circulation.

The increase in traffic volume associated with the past and present activities listed in Table 4-7 has also resulted in substantial changes to the natural setting of Mauna Kea, resulting in increased levels of noise, dust, air emissions, and visual impacts. See sections related to noise (Section 4.2.12), air quality (Section 4.2.13), and visual impacts (Section 4.2.14) for additional details. Overall, the past and present activities listed in Table 4-7 have had a substantial impact on transportation.

4.2.9.3 Impacts of Reasonably Foreseeable Future Activities on Transportation

Impacts from the reasonably foreseeable future activities listed in Table 4-8 would potentially generate similar transportation impacts as discussed in Section 4.1.12.2 for the Outrigger Telescopes Project. Traffic volume in the ROI would increase due to an increase in construction and operation activities associated with the reasonably foreseeable activities listed in Table 4-8. In addition, NASA expects the numbers of tourists to increase in the future.

Traffic volume associated with construction and installation activities of future projects would create a moderate short-term impact on the local traffic network, notably traffic delays. The overall number of service and support staff needed at the summit to operate potential facilities would create a small impact. In addition, the increase in

remotely operated observatories could lessen the impact of traffic associated with facility operations.

Overall, traffic associated with the construction, installation, and operation of most facilities listed in Table 4-8 would remain relatively low and comparable to the Outrigger Telescope Projects traffic volumes discussed in Section 4.1.12.2. Construction efforts are expected to be larger for the TMT, resulting in a moderate traffic volume increase from current conditions. This increase is expected to have a moderate impact on the overall traffic conditions within the ROI.

Substantial impacts could result from projects that require roadway alterations and improvements, such as the Keanakolu and Saddle Road improvement projects. These projects would result in traffic delays in the short term and potential long-term impacts associated with alteration of the existing landscape. In addition, visitor traffic volume would eventually increase as a direct result of greater access to Mauna Kea.

Depending on the approved land use, additional transportation impacts would result from the DHHL Land Acquisition project. Its development could impede access to the MKSR or result in changes to the access road because the land parcel overlays the existing roadway. Increased development associated with the DHHL Land Acquisition would be expected to increase traffic along the Saddle Road. A residential community built along this corridor would generate community-based travel — residential, domestic, occupational, services, and education-related traffic — industrial, military, and recreational traffic. This would result in a substantial impact.

Transportation of minimal quantities of hazardous materials (e.g., diesel fuel, motor oil(s), paints, and solvents) and wastes would be expected throughout the course of constructing, installing, and operating additional facilities on Mauna Kea (see Section 4.2.7). Handling of these materials would be guided by best management practices. No impact is anticipated.

4.2.9.4 Cumulative Impact Summary

The past, present, and reasonably foreseeable future activities listed in Table 4-7 and 4-8 resulted in greater access for visitors and Native Hawaiians traveling to Mauna Kea. As a result, there has been a substantial increase in traffic volume along the access road. This increase has resulted in a substantial impact on the natural setting of Mauna Kea.

The on-site construction and installation of the Outrigger Telescopes would result in a small, short-term increase in the current traffic volume. Operations of the Outrigger Telescopes would contribute only a small increase in current traffic levels. From a cumulative perspective, the transportation impact on Mauna Kea has been significant. The addition of the Outrigger Telescopes to the existing observatories on the mountain would have a small incremental impact.

4.2.10 Utilities and Services

4.2.10.1 ROI for Utilities and Services

The ROI for assessing cumulative impacts includes the Astronomy Precinct, the MKSR, Hale Pōhaku, and vehicle travel routes.

This section analyzes potential impacts on water supply, electrical supply and communications, and emergency services and fire suppression.

4.2.10.2 Impacts of Past and Present Activities on Utilities and Services

Water Supply. Each major facility at the summit and at Hale Pōhaku was designed with its own underground water storage and distribution system. Water is trucked weekly from Hilo to Mauna Kea. Table 4-19 provides the storage capacities of each observatory and of Hale Pōhaku. Currently, the observatories use approximately 208 kl (55,000 gal) of domestic water every month and the Mid-Elevation Support Facilities use 95 kl (25,000 gal). The past and present water supply to the ROI is insignificant compared to the overall demand for water on the island of Hawai'i.

Electrical Power and Communications. During the early years of telescope development, on-site generators provided power to individual facilities. This changed when construction of power lines began in 1985 (UH 1999). Once power lines were brought to Hale Pōhaku, additional construction efforts soon brought power to the summit via an underground distribution system. Initial construction of the distribution system was completed in 1988 (UH 1999). In 1995, an upgrade to the electrical system added an underground distribution loop at the summit and provided service to the SMA (UH 1999).

Power is currently provided to the summit by aboveground power lines that run from the Saddle Road to Hale Pōhaku and by the underground conduit between Hale Pōhaku and the underground distribution loop at the summit. The dynamics of the electrical distribution system for the summit are described in Section 3.1.9.2. Each observatory is connected to the underground distribution loop by a conduit line. The Hale Pōhaku substation has a capacity of 6,000 kVA, only about 53 percent of which is currently used. Each observatory manages its own power use and most have backup generators in case of a power outage. Table 4-19 provides the average annual electrical use for each observatory. Diesel fuel or propane is kept on site to fuel the generators as needed. Table 4-19 describes backup generator capacities and loads.

The initial communications system installation coincided with the power installation in 1985. Fiber optic cables were added in the 1990s via aboveground cables that attached utility lines to Hale Pōhaku, and from there by the existing electrical underground conduits, to the underground distribution loop at the summit that serves the observatories. These upgraded communication system capabilities, provided by Verizon, allow real-time communication between the summit facilities and on- and off-island headquarters offices, as well as Internet communication.

There have been no substantial impacts on the electrical or communication system other than the improvements listed above.

Emergency Services and Fire Suppression. Section 3.1.9.3 provides a general discussion of emergency preparedness procedures and programs that have been established for the Astronomy Precinct. MKSS has established a summit-wide Emergency Preparedness and Medical Evacuation Plan and encourages site-specific first aid and emergency training. Each observatory maintains a health and safety management plan that includes emergency planning procedures. Several facilities conduct additional training and drills with staff to ensure preparedness. Emergency plans contain fire prevention and safety procedures. Fire extinguishers and smoke alarms are located in all facilities. On January 16, 1996, three workers died in a fire during construction of the Subaru Telescope. The fire was caused during a

TABLE 4-19. OPERATIONS AND UTILITIES MANAGEMENT ON MAUNA KEA

Observatory	Type	Electrical Power Use[a] (Monthly) Backup Generators	Water Use (Monthly)[b] /Storage Capacity	Management Plans and Programs	Outreach and Education Programs
Subaru	O-IR	233,900 kWh/mo/ 270 kW backup generator with 3.8-kl (1,000-gal) diesel fuel tank	41 kl (10,958 gal)/ 38 kl (10,000 gal)	A[a], B	MKOOC[c], Base facility visitor's gallery
IRTF	IR	62,000 kWh/mo/ no backup generator	6 kl (1,688 gal)/ 15 kl (4,000 gal)	A[a], C[a]	MKOOC[c], IfA outreach
CFHT	O-IR	94,000 kWh/mo/ 250 kW backup generator with 19-kl (5,000-gal) diesel fuel tank	34-kl (8,975 gal)/ 2 x 23 kl (6,000 gal)	B, C[a]	MKOOC[c], Astronomy Education and Outreach Program
Gemini	O-IR	136,000 kWh/mo 118 kW backup generator with 681-l (180-gal) diesel fuel tank	15 kl (4,050 gal)/ 38 kl (10,000 gal)	A[a], B	MKOOC[c], Public Information and Outreach Office
UH 2.2-m (88-in)	O-IR	28,000 kWh/mo/ 5kW backup generator with two 38-l (10-gal) propane tanks	13 kl (3,513 gal)/ 30 kl (8,000 gal)	A, C	MKOOC[c], IfA outreach
UH 0.6-m (24-in)	O				
UKIRT	IR	53,300 kWh/mo 7 kW backup generator with 76-l (20-gal) diesel fuel tank	14 kl (3,682 gal)/ storage capacity	A, C[a]	MKOOC[c], JAC Outreach
JCMT	SM	37,800 kWh/mo 20 kW backup generator with 8 – 568-l (150-gal) propane tanks	13 kl (3,317 gal)/ storage capacity	A, C[a]	
VLBA	R	29,000 kWh/mo/ 100 kW backup generator with 946-l (250 gal) AST of diesel fuel	No data/ 3.8 kl (1,000 gal)	A, C	MKOOC[c]
Caltech	SM	18,980 kWh/mo/ 30 kW backup generator fueled with propane	7.5 kl (1,992 gal)/ 7.6 kl (2,000 gal), 1,135 l (300 gal)	B	MKOOC[c], CSO Education and Public Outreach

TABLE 4-19. OPERATIONS AND UTILITIES MANAGEMENT ON MAUNA KEA (CONTINUED)

Observatory	Type	Electrical Power Use[a] (Monthly) Backup Generators	Water Use (Monthly)[b] /Storage Capacity	Management Plans and Programs	Outreach and Education Programs
SMA	O-IR	120,000–150,000 kWh/mo no backup generator at present but intend to install a about 500 kW generator with diesel fuel tank	15 kl (3,914 gal)/ 23 kl (6,000 gal) capacity	A, C	MKOOC[c]
W.M. Keck Observatory	O-IR	237,000 kWh/mo 250 kVA backup generator with (2,500-gal) diesel fuel tank	46 kl (12,142 gal)/ 15 kl (4,000 gal), 30 kl (8,000 gal)	B	MKOOC[c]
Hale Pōhaku	N/A	30,000 kWh/mo No backup generator at present	94 kl (25,000 gal)/ 2 x 151 kl (40,000 gal)	A, C	VIS, MKOOC

Sources: CFHT 2004; CSO 2004a; CSO 2004b; Gemini Observatory 2004; Joint Astronomy Center 2004; NASA IRTF 2004; SMA 2004b; Subaru 2004b; UH IfA 2004b; UH IfA 2004d; VLBA 2004

a. HELCO provides electrical power to the Mauna Kea facilities.

b. Potable water trucked in by MKSS and stored in on-site tank.

c. The Mauna Kea Observatories Outreach Committee (MKOOC) coordinates observatory support for the Visitor Information Station at the Ellison Onizuka Center for International Astronomy. This partnership provides education resources for the children, residents, and visitors on the island of Hawai‘i through programs and outreach activities. See www.mkooc.org for more information.

Acronyms:
IR-Infrared
O-Optical
SM-Submillimeter
R- Radio

Management Plans:

A- Emergency Management Plan
B- Health and Safety Plan
C- Hazardous Materials and Toxic Waste Plan
D- Other Standard Operating Procedures and/or Best Management Practices
*Plan is a section and chapter within the Health and Safety Plan

welding procedure when a slag ignited insulation behind an elevator shaft.

4.2.10.3 Impacts of Reasonably Foreseeable Future Activities on Services

Water Supply. Contractors would truck in domestic water needed on site during the construction phase of future projects. Water needs would increase at Hale Pōhaku to accommodate crews residing at the construction camp.

As shown in Table 4-19, Hale Pōhaku has two 152-kl (40,000-gal) water tanks and typically uses only 95-kl (25,000-gal) per week. The water storage and distribution system is designed to support larger water capacities when needed. During these construction activities, extra water would be trucked to Hale Pōhaku.

The operations of smaller projects (such as the Outrigger Telescopes, the 6-m (20-foot) Testing and Site equipment, and the SMA expansion) and redevelopment projects (such as PanSTARRS and the 1-m (3.3-ft) Class Instructional Telescope) probably would not require additional water tanker trips to Mauna Kea. Current water provisions should support these improvements.

However, larger projects (such as the TMT) would require at least two water storage tanks and a water distribution system as part of its design. Domestic water needs probably would meet or exceed the largest current water user, W.M. Keck Observatory. This would represent a moderate increase in demand for water.

Water supply improvements would be necessary to serve the Humu'ula community on DHHL lands below Hale Pōhaku, depending on the use(s). This would be a logical future source for water trucked to Hale Pōhaku and the summit, instead of sources requiring the long trip from Hilo along Saddle Road.

Electrical Power and Communications. Continued use of existing facilities probably would not increase power needs on the summit. Redevelopment of existing facilities could slightly increase power use, or alternatively could provide more modern and efficient operations. With both possibilities considered, a moderate increase in power needs would be estimated.

Most new development projects listed in Table 4-8 would require new power and communication conduits to be cut from the junction box to the specified sites. Although not all power needs have been calculated for future projects at this time, it is estimated that overall electrical use would not exceed the existing capacity. In conclusion, the expected increase in electrical demand to support the foreseeable future activities within the Astronomy Precinct would result in a small impact on the current electrical system.

Redevelopment projects could reuse existing communications fiber optic lines. This system is relatively new and should support such operations. New development projects would require new fiber optic lines to be installed during the electrical installation process. New fiber optic lines would also be required to connect to antennas added to the SMA site. These additional lines would be a small modification of the current communications system.

Emergency Services and Fire Suppression. It is assumed that the MKSS Emergency Preparedness and Medical Evacuation Plan would be updated to support any future projects. Each new facility would develop an emergency and

health and safety management plan and would conduct drills and training. Medical supplies, fire extinguishers, and smoke detectors would be distributed appropriately throughout the facilities.

Additional staff and crews on site during construction and installation activities would increase the potential for an incident to occur. It is assumed that emergency medical technicians would be available. Each worker would be aware of emergency procedures prior to commencing work on the mountain. Hale Pōhaku will continue to be used as an acclimation point.

4.2.10.4 Cumulative Impact Summary

Water Supply. Past, present, and reasonably foreseeable future activities on Mauna Kea have led to the development of a water supply system, which constitutes a substantial impact on water supply. The water usage and traffic associated with water delivery are small and not significant in comparison to overall island water usage and Mauna Kea traffic levels. The addition of the Outrigger Telescopes to the existing observatories on the mountain would have almost no incremental impact.

Electrical Power and Communications. Past and present activities on Mauna Kea have led to the development of electrical power and communications infrastructure, which constitutes a substantial impact on such capability. Reasonably foreseeable future activities are anticipated to have a small additional impact on electrical power and communications. The Outrigger Telescopes Project would have no incremental impact on the existing electrical distribution and communications systems.

Emergency Services and Fire Suppression. Past and present activities on Mauna Kea have led to the development of emergency services and fire suppression capability. It is anticipated that foreseeable future activities would require similar additional development. The addition of the Outrigger Telescopes to the existing observatories on the mountain would have no incremental impact.

4.2.11 Socioeconomics

4.2.11.1 ROI for Socioeconomics

The ROI for socioeconomic resources includes the County of Hawai‘i. Long-term cumulative effects that could occur would be related to an increase in employment in the ROI. Any economic effects (i.e., increased employment, income, and spending) of the Proposed Action and cumulative activities listed in Tables 4-7 and 4-8 would be expected to last for the duration of construction and operational activities, collectively projected through the end of the Astronomy Precinct lease life, or 2033. Population projections through 2020 generated by the State of Hawai‘i indicate continued slow growth in Hawai‘i County, as well as in the State of Hawai‘i (USDOC 2001b). Table 4-20 provides long-range population projections for the island of Hawai‘i. Past, present, proposed, or conceptualized projects identified as potentially affecting the socioeconomic condition of the County of Hawai‘i include the general development of the Astronomy Precinct and observatories on the mountain, jobs created and revenue generated by construction and operation of the observatories, supplemental jobs and revenue generated by future astronomy-industry jobs, and tourism to Mauna Kea.

4.2.11.2 Impacts of Past and Present Activities on Socioeconomics

Since its introduction to Mauna Kea and Hawai‘i, astronomy has become a local industry has providing substantial economic and educational benefits to the State and local communities. In general, the majority

TABLE 4-20. RESIDENT POPULATION PROJECTIONS FOR THE ISLAND OF HAWAI'I: 2000 TO 2025

Type of Population and Year	State Total	Hawai'i
Resident Population (1,000)[a]		
2000	1,197.3	144.6
2005	1,236.1	151.4
2010	1,291.1	159.6
2015	1,349.1	168.3
2020	1,406.2	176.9
2025	1,461.6	187.7
Share of State Population (percent)		
1998	100.0	12.1
2000	100.0	12.1
2005	100.0	12.2
2010	100.0	12.4
2015	100.0	12.5
2020	100.0	12.6
2025	100.0	12.8

Source: USDOC 2001b

a. The resident population is defined as the number of persons whose usual place of residence is in a given area, regardless of the person's physical location on the date of estimate or census. It includes military personnel stationed or home-ported in the area, but excludes persons of local origin attending school or in military service outside the area.

of the funds used for the construction and operation of observatories on the MKSR were provided by entities outside of the State of Hawai'i. At least one-third of the funds used for construction were spent on local services, and more than 80 percent of the operating funds were spent in Hawai'i, mostly within the County. Table 3-11 summarizes the capital costs of the observatories and the number of local residents employed by each facility. The numbers total over $600 million spent and almost 500 jobs created within the County of Hawai'i (UH IfA 2002a). The W.M. Keck Observatory and Subaru provide the greatest amount of money annually, and the W.M. Keck Observatory provides the most local jobs of the observatories (UH IfA 2002a).

4.2.11.3 Impacts of Reasonably Foreseeable Future Activities on Socioeconomics

Continued operation of the existing facilities would prolong the external operational funding spent within the County and State. Local staff would continue to be employed. Proposed observatory redevelopment would prolong the use of existing facilities, thereby securing future revenue and jobs. Proposed new observatories would increase the amount of operational funding brought into the State and would increase the number of local community members employed. The construction and installation of all future projects would bring additional temporary revenue and jobs to the County and State through materials purchase, equipment

rental, and construction crew hiring. It is estimated that the proposed TMT project would double the existing revenue generated by all current observatories together and potentially increase by close to 100 percent local jobs for staff astronomers, engineers, engineering and equipment technicians, software programmers, and administrative personnel (UH IfA 2004e). The State and County economies would benefit further from any increased tourism.

4.2.11.4 Cumulative Impact Summary

In summary, the impact of past, present, and reasonably foreseeable future activities within the Astronomy Precinct on socioeconomics is substantially positive. The Outrigger Telescopes Project would add a small positive increment to this impact. The overall cumulative impact on socioeconomics is substantial and positive.

4.2.12 Air Quality

4.2.12.1 ROI for /Air Quality

The ROI for cumulative impacts on air quality is the entire island of Hawai'i. The emission sources considered in this analysis are those within the MKSR, Hale Pōhaku, and a corridor surrounding the Mauna Kea Access Road and the Saddle Road.

4.2.12.2 Impacts of Past and Present Activities on Air Quality

As discussed in Section 3.1.11.2, air quality on Hawai‘i is excellent and has remained in attainment status with State and National Ambient Air Quality Standards (NAAQS). Past sources of air emissions in the MKSR have been from short-term construction projects in the area of the summit, vehicles accessing the summit, and fugitive dust along the unpaved portion of the access road or from off-road driving. The development of the mountain has increased traffic to the summit and along the Saddle Road, which has generally increased vehicular emissions and fugitive dust generation. This emission source has steadily increased as the Astronomy Precinct has become more developed and has peaked during construction activities. Initiatives such as closing vehicular access to the Pu‘u Poli‘ahu jeep trail and paving the upper part of the Mauna Kea Access Road have reduced fugitive dust in the summit area. Air quality has remained within attainment levels.

Volcanic activity is another source of air pollution. These volcanic events emit sulfur oxides and particulate matter into the atmosphere, temporarily elevating pollutant levels across the island. Past volcanic activities have not produced permanent significant impacts on the air quality of the island or the summit area.

Observatory operations generally do not produce air emissions. Minor emission sources include facility maintenance that could emit minimal levels nitrogen oxides.

4.2.12.3 Impacts of Reasonably Foreseeable Future Activities on Air Quality

Proposed activities on the mountain that could potentially affect the air quality within the ROI would be similar to past and present activities. Construction of facilities on Mauna Kea and at the base of the mountain (PTA and Hawaiian Homestead development), general maintenance of these facilities, roadway improvements, and vehicular traffic would be the primary sources of air emissions. These emissions would include nitrogen oxides from vehicle exhaust and fugitive dust. Activities associated with the Army Transformation at PTA would produce long-term dust emissions as described in the EIS for that project (USACE 2004). However, this would be localized below the inversion layer

and would not affect the air quality throughout the rest of the ROI.

The reasonably foreseeable future activities within the ROI would not violate SAAQS and NAAQS.

4.2.12.4 Cumulative Impact Summary

Past and present activities within the ROI have had a minor continuing impact on air quality. Foreseeable future activities would have similar impacts. The Outrigger Telescopes Project would employ mitigation measures as discussed in Section 4.1.10.2 and would have a very small incremental impact. Overall, the cumulative impacts to air quality are small.

4.2.13 Noise

4.2.13.1 ROI for Noise

The ROI for assessing noise impacts includes the MKSR and other areas affected by on-site construction, installation, and operations including Hale Pōhaku and vehicle travel routes.

Noise-sensitive receptors within the ROI include cultural practitioners, scientists, staff, recreational users, and other visitors. There are no fixed noise-sensitive receptors, such as residential areas, within the ROI.

4.2.13.2 Impacts of Past and Present Activities of Noise

Past and present activities listed in Table 4-7 have resulted in a small continuous ambient noise level increase within the ROI, attributed primarily to the increase in vehicular traffic associated with these activities. Additional short-term noise increases have occurred as a result of construction and installation associated with the activities listed in Table 4-7. See Section 4.1.12.2 for a discussion of noise impacts associated with construction and installation activities. General operation activities generate inherently low noise levels and make a negligible contribution to the ambient noise level.

The current ambient noise level within the ROI is extremely low; some users of Mauna Kea may be particularly noise sensitive. In particular, cultural practitioners within the immediate vicinity of a noise source could potentially be disturbed. Most disturbances are low level, discrete events rather than a substantial increase in the overall ambient noise level. In general, current noise levels are compatible with existing activities within the ROI. Consequently, noise levels from past and present activities have had a small impact.

4.2.13.3 Impacts of Reasonably Foreseeable Future Activities of Noise

Impacts from the reasonably foreseeable future activities are anticipated to generate noise at levels comparable to those of past and present activities. Construction and installation activities would lead to larger increases in noise levels within the ROI for shorter periods of time. It is anticipated that noise levels would remain compatible with existing activities within the ROI, constituting a small impact. Furthermore, it is anticipated that future construction and installation activities would be consistent with the State of Hawai‘i community noise standards (Hawai‘i Administrative Rules, Title 11, Chapter 46).

4.2.13.4 Cumulative Impact Summary

The impact of noise from past, present, and reasonably foreseeable future activities is generally small. The Outrigger Telescopes Project would have no incremental impact. Although individual construction events would continue to produce occasional increased noise levels, overall noise conditions in the ROI would remain low.

4.2.14 Visual/Aesthetics

4.2.14.1 ROI for Visual/Aesthetics

The ROI for assessing cumulative visual impacts is the MKSR and any off-mountain areas from which the Mauna Kea observatories would be visible—such as Hilo, Waimea, and Honoka‘a.

4.2.14.2 Impacts of Past and Present Activities on Visual/Aesthetics

The astronomy facilities at the summit of Mauna Kea have become a prominent, and to many Native Hawaiians notorious, feature. At least some of the observatories are visible from most locations within the MKSR and from many off-mountain locations including Hilo, Waimea, and Honoka’a. In particular, the summit ridge observatories (UKIRT, UH 2.2-m, Gemini North, and CFHT) are visible from Hilo; IRTF, the W.M. Keck Observatory, and Subaru are visible from Waimea and Honoka’a. The observatory structures are white or silver to minimize internal temperature variations which can affect seeing quality. Whereas most of the observatory structures are curved domes, Subaru has an unusual paneled structure that renders it less visible much of the day. However, Subaru appears extremely bright at sunset from off-mountain locations where it is visible owing to specular reflections of sunlight from its flat surfaces.

Although not within the specific ROI for visual impacts, the Hale Pōhaku Mid-Elevation Support Facilities were constructed with design restrictions. These structures were sited and constructed to follow mountain contours and colored to blend with the surrounding natural features and terrain.

4.2.14.3 Impacts of Reasonably Foreseeable Future Activities on Visual/Aesthetics

In general, reasonably foreseeable future activities with the greatest potential for visual impact would be those that involve development of a previously undeveloped site. The principal such project is the TMT, which is being considered for a site on the northwest plateau. This location would take advantage of a northerly extension of the summit ridge to entirely block views on the new facility from Hilo and partially block views from Honoka’a (Master Plan 2000). Redevelopment of an existing facility would have a small to minimal visual impact as long as the basic frame of the structure remained unaltered. Any modifications would follow design guidelines specified in the 2000 Master Plan limiting size, color, and surface materials so as to minimize the observatory’s visual impact. All future projects will be reviewed by the Design Review Committee for adherence to these guidelines prior to approval (UH 1999).

Construction activities on the mountain can create a local visual impact from dust, trash, and equipment. It is expected that dust and trash will be minimized throughout construction phases on all future projects on Mauna Kea through appropriate management plans which include dust and trash controls. All construction equipment would be removed from the site and the mountain after construction is completed.

4.2.14.4 Cumulative Impact Summary

The visual impacts of past and present astronomy-related activities in the MKSR have been substantial. Future visual impacts may be minimized by new design guidelines and careful site selection of new development projects. Mitigating dust generation, enforcing strict trash control, and minimizing on-site staging areas would

reduce local short-term visual impacts. The Outrigger Telescopes Project would add a small incremental visual impact. Overall, the cumulative visual impact from past, present, and reasonably foreseeable activities is substantial.

4.2.15 Cumulative Impacts of End of Lease

As a reasonably foreseeable future astronomy project, End of Lease in 2033 could result in a variety of outcomes and, thus, its precise nature is unclear at this time. Two bounding scenarios will be addressed for the purposes of this cumulative impact analysis:

(1) All observatories (i.e., those currently existing and the reasonably foreseeable future projects) would continue operation beyond 2033; and

(2) All observatories operating on Mauna Kea as of 2033 would be decommissioned and completely removed from the mountain.

4.2.15.1 Continued Operation of All Observatories Beyond 2033

This scenario assumes that all environmental protection and mitigation measures required for operation of the Mauna Kea observatories including the reasonably foreseeable future astronomy projects undertaken prior to 2033 would continue beyond that point in time. The impacts of continued operation of all observatories on Mauna Kea beyond 2033 would be similar to the cumulative impacts that have been addressed throughout Section 4.2. Continued operation of the observatories would have little to no adverse incremental impacts on solid wastes and hazardous waste management; geology, soils and slope stability; land use and existing uses; transportation; utilities and services; air quality; flora and fauna; the Wēkiu bug and its habitat; hydrology and water quality; and noise through the indefinite future beyond 2033. The incremental impacts of the Outrigger Telescopes Project would remain a minor contributor.

The principal cumulative environmental impacts resulting from continued operation of the observatories beyond 2033 would largely be on cultural resources and visual/aesthetics. The cumulative impact on cultural resources was addressed in Section 4.2.3 where it was noted that the impact of past and present astronomy and related projects has been adverse substantial, and the cumulative impact associated with operation of the existing observatories and reasonably foreseeable future astronomy projects is anticipated to be adverse and substantial. Thus, continued operation of the astronomy facilities beyond 2033 would, in turn, continue to be substantial and adverse. Cultural resources and associated uses would continue to share the mountain with astronomy and other uses such as recreation and tourism. The incremental impact of the Outrigger Telescopes Project would continue to be a minor contributor to this overall cumulative impact beyond 2033.

The cumulative impact on visual/aesthetics associated with astronomy on Mauna Kea was addressed in Section 4.2.14. The substantial cumulative impact of past, present, and reasonably foreseeable future astronomy projects would continue. It would vary in intensity depending upon the viewing location and the viewer. The incremental impact of the Outrigger Telescopes Project would represent a minor contributor to the overall cumulative impact of the Mauna Kea astronomy facilities on visual/aesthetics.

With respect to socioeconomics, operation of the existing and reasonably foreseeable future observatories beyond 2033 would continue to have substantial and positive

impacts on the local and State economies, employment, and education. Currently the observatories support about 500 jobs (see Section 3.1.10). Employment levels in 2033 and beyond would probably be greater, particularly when development and operation of the TMT on Mauna Kea is considered. By 2033 it is reasonable to assume that the total economic activity generated by the observatories would exceed the inflated equivalent of the approximately $130 million/yr currently flowing into the County of Hawai'i and the inflated equivalent of the approximately $140 million flowing to the State. Indirect employment within the County and the State generated by observatory expenditures would also continue beyond 2033. Mauna Kea would remain the premier ground-based astronomy location in the world and Hawai'i would continue to attract the best astronomers and astronomy research projects. The educational opportunities for students at all levels to learn in such an atmosphere would continue as would the community-based programs conducted and supported by the observatories. The incremental impact of the Outrigger Telescopes Project would continue to be a small and positive part of the substantial beneficial cumulative impacts of continued observatory operation on socioeconomics beyond 2033.

4.2.15.2 Decommissioning and Demolition of All Observatories

For this End of Lease 2003 scenario, the general assumptions for the reasonably foreseeable future astronomy projects noted in Section 4.2.2 pertain. The following additional assumptions have also been made:

- The observatories, support facilities, and underground structures, exclusive of the Mauna Kea Access Road and the Hale Pōhaku Mid-Elevation Support Facilities, would be dismantled, demolished, and completely removed from the mountain.
- Explosives would not be employed in accomplishing the demolition. Each facility would first be stripped of recyclable materials; mechanical methods (e.g., wrecking balls, jack hammers) would be employed to demolish the existing structures.
- There is not enough surplus cinder on Mauna Kea at present, nor would enough cinder be produced during dismantlement, demolition, and removal, to restore the pre-observatory topography of the observatory sites; each site would be left in a neat and tidy condition with adequate drainage controls installed to preclude erosion at the abandoned sites.
- Environmental protection and mitigation measures similar to those that would be employed for the Outrigger Telescopes Project (e.g., dust controls and protection of Wēkiu bug habitat) would be an integral part of all approved observatory removal plans.
- Decommissioning and demolition of all of the observatory facilities would take place over a number of years to avoid overburdening the contractor work force, road capacities, the Hale Pōhaku facilities, and other support facilities such as the construction staging areas. Phased implementation would lessen the impact on other resources and uses of the mountain such as cultural practices and recreation. The principal cumulative impacts would be experienced primarily in the areas of cultural resources, biological resources,

transportation, socioeconomics, visual aesthetics, noise, and solid waste.

Cultural Resources. Dismantling, demolition, and removal of each observatory facility would have to be accompanied by appropriate measures to protect known cultural resources and nearby sites. Each demolition project would have to plan for and accommodate the possibility of encountering heretofore undiscovered sites during removal of foundations and underground structures. Given that each of the observatories would be located on previously disturbed sites, known cultural resources should not be directly or adversely impacted by the dismantlement, demolition and removal of each observatory. The possibility exists that ground vibrations from demolition equipment such as jack-hammers and wrecking balls could impact the stability of physical resources such as shrines in nearby areas and would have to be considered during development of demolition plans and techniques.

Overall, with reasonable care and planning, any adverse impacts to physical sites should be small and not significant. The presence of large demolition equipment and heavy trucks on the observatory sites and along the Mauna Kea Access Road, and demolition activities themselves, would substantially and adversely impact cultural practices. This would occur throughout the relatively lengthy period required to remove all of the observatories and support structures, after which this source of adverse impact would cease. When all observatories have been removed from the mountain, the cumulative adverse impact to cultural resources would be greatly reduced. However, given that restoration of pre-observatory topography at each of the former sites is not considered feasible at this time, reduced but still substantial adverse cumulative impact on cultural resources would persist. The incremental impact of removing the Outrigger Telescopes Project would be a small contribution to the overall change in cumulative impact on cultural resources.

Biological Resources. Dismantlement, demolition, and removal of the observatories within or near areas of Wēkiu bug habitat has the potential to adversely impact some biological resources. It is unlikely that flora at or near the demolition sites would be subject to long-term adverse impacts. The former observatory sites will already have been disturbed by facility construction and operation, thus little flora would be directly impacted by on-site demolition activities. Nearby flora may be subject to fugitive dust. However, with careful attention to dust control measures, these resources should experience only small to negligible impacts.

Potential impact to Wēkiu bugs is less clear. Some Wēkiu bug habitat may experience ground vibration during the demolition phase of observatory removal. It is not known what effect, if any, intense and prolonged vibration of the habitat would have on the resident Wēkiu bugs or on habitat suitability. This may have to be carefully monitored during observatory removal. Removal of the Outrigger Telescopes Project, particularly the retaining walls at JB-5 and Outrigger Telescope 3, and the removal of Outrigger Telescope 1 could have substantial adverse impact on Wēkiu bug habitat in nearby areas. Removal would have to be carefully planned and suitable mitigation measures instituted to prevent sidecasting of cinder and destabilizing the cinder slope in these areas. Potential impacts to the Wēkiu bug and its habitat may be lessened if removal plans for the Outrigger Telescopes and other observatories accommodate leaving retaining walls in place. Biological resources in the areas of Hale Pōhaku and the construction staging areas near Hale

Pōhaku and the summit should not be substantially impacted by observatory removal. Other fauna near the observatory sites should not be adversely impacted.

Transportation. It is likely that mobilization and demobilization of contractor heavy machinery and workforces would occur a number of times over the period of phased observatory removal. In addition to transporting the heavy demolition machinery that would be needed at each removal site, heavy truck and water tanker traffic would increase on the Mauna Kea Access Road throughout the observatory removal process. There would be a further increase in traffic due to demolition crews commuting to and from the summit. Heavy trucks would be needed to remove the demolition debris from each observatory site and transport that debris to licensed disposal sites elsewhere on the island. The addition of a relatively large amount heavy truck and tanker traffic on the access road would at times adversely impact other traffic (e.g., recreational users, tourists, cultural practitioners), causing some delays and possibly increasing accident risks. This is likely to persist throughout the extended period required to complete the removal of all observatories. Heavy truck and equipment traffic throughout the observatory removal process would also adversely impact the Mauna Kea Access Road, leading to a requirement for increased maintenance. It is likely that Saddle Road improvements would have been completed well in advance of 2033. Thus it is unlikely that traffic on that road would be adversely impacted by the heavy truck and other traffic associated with observatory removal-. Overall, the cumulative impact on transportation on the Mauna Kea Access Road during demolition would be substantial, adverse, and significant. The incremental impact associated with removal of the Outrigger Telescopes Project would be a small contributor to the cumulative impact on transportation.

Socioeconomics. Substantial, adverse, and significant socioeconomic impacts on the local and State economies, employment, and education would occur with cessation of astronomy on Mauna Kea and removal of the observatories. As noted in 4.2.15.1 the State and local economies benefit from the over $270 million/yr flowing into the economies. This amount would likely increase between now and the year 2033, but would cease with this End-of-Lease outcome. The 500 long-term jobs created by astronomy on Mauna Kea along with many of the indirect jobs associated with astronomy would also cease. Many of those jobs are in highly skilled occupations that would be lost from the local and State job bases. Some of those jobs would be replaced in the short-term by job opportunities created by observatory removal activities. However, those jobs would end with completion of removal. The educational opportunities available to Hawaiians and Hawaiian students because of the presence of a large group of astronomers and world-class facilities would cease, as would the community programs conducted by the observatories. Mauna Kea would no longer be one of the world's premier locations for astronomy. The activities at Mauna Kea would probably move to locations elsewhere in the world. In addition, with astronomy no longer funding support activities on Mauna Kea, other funding sources would have to be found for activities such as maintenance of the Mauna Kea Access Road, operation of the Hale Pōhaku facilities, and the ranger force and cultural interpreters. The incremental impact of removing the Outrigger Telescopes Project would be a small contributor to the overall substantial, adverse, and significant cumulative impact

on socioeconomics from observatory removal.

Visual/Aesthetics. While the observatories are being removed, the impact on viewscapes from those areas on Mauna Kea where the observatories can be seen would be adverse, substantial and significant due to the presence of heavy equipment and demolition rubble. This would be the case for the duration of the removal activities. Observatory removal activities would also be somewhat visible from some off-mountain areas such as Hilo, Waimea, and Honoka‘a. With completion of observatory removal, the abandoned sites, while neat in appearance, would likely still show signs that they had been the locations of large structures. It is unlikely that the original topography of each of the observatory sites could be fully restored. Although greatly reduced from present levels, the visual impacts would likely remain moderate to substantial for viewers in the area of the summit. Completion of observatory removal would continue to have a small residual adverse visual impact from some off-mountain locations.

Noise. Removal of the observatories would also generate localized intense and sustained noise from demolition activities (e.g., wrecking balls and jack hammers) and the heavy equipment and associated traffic. This noise would be superimposed on an existing environment that is characterized by very low noise levels. It is expected that even with contractor compliance with OSHA standards and State of Hawaii Community Noise Standards, noise impacts during demolition would be substantial, adverse, and significant. The incremental impact associated with removal of the Outrigger Telescopes Project would be a small contributor to the cumulative noise impact associated with removal of the observatories. After observatory removal there will be a residual small to moderate adverse noise impact from recreational and other non-observatory users of the mountain.

Solid Waste. During observatory removal there should only be a minor adverse impact from solid waste on the summit if proper waste containers are used and effective housekeeping practiced by the removal contractors. There should be no to negligible impact from solid waste during transportation of demolition debris down the mountain if suitable mitigation measures, such as covering the debris with a tarp during hauling, are implemented. Because of the number and sizes of the observatories on Mauna Kea, demolition and removal would generate an extremely large amount of solid waste. While some of this material could be recycled, it is anticipated that a very large fraction would be disposed of at existing landfills. It is anticipated that removal of the observatories could have a substantial and adverse effect on landfill capacity.

Other Resources. Air emissions during removal of the observatories would be unlikely to exceed the SAAQS or the NAAQS and should result in a moderate, but not significant, impact on air quality. The incremental impact associated with removal of the Outrigger Telescopes Project would be a small contributor to the cumulative impact on air quality. Careful attention to appropriate dust control measures by the demolition contractors would preclude fugitive dust from significantly impacting local air quality or other resources.

Geology would not be impacted but slope stability could be adversely impacted, particularly in those areas where retaining walls and other slope stabilization measures had to be installed during construction of the observatories. The removal of these structures from observatory sites would have to be carefully planned and implemented to

prevent destabilization of slopes and eliminate potential for impacting existing Wēkiu bug habitat, for example at JB-5 and Outrigger Telescope 3. The incremental impact associated with removal of the Outrigger Telescopes Project would be a small contributor to the overall cumulative impact on geology and slope stability.

Hazardous waste management associated with removal of the observatories should not result in adverse environmental impact, given attention to use of proper waste containers and effective housekeeping practices by the removal contractors. Minimization of hazardous material storage and use at each work site, combined with adequate contractor spill control and response planning, should help ensure that no impacts would arise from these activities.

The currently designated land use for the Astronomy Precinct would no longer be necessary and could be revised accordingly. Existing uses of the mountain such as cultural practices, recreation, and tourism would be substantially and adversely impacted during observatory removal. Heavy truck activity, noise, and the need to establish exclusionary zones around demolition sites for safety purposes would contribute to these impacts. Over the long-term, tourism may experience a large decline with cessation of astronomy as an attraction. Utilities and services in the summit area could also be adversely impacted with removal of the observatories. Electric service to the summit would no longer be needed and would probably be decommissioned or removed. The substation at Hale Pōhaku would no longer be needed and could also be removed. The communication lines to the summit might be retained for use in emergencies.

For these environmental resources, the incremental impact associated with removal of the Outrigger Telescopes Project would be a negligible to small contributor to the overall cumulative impacts.

4.2.16 Cumulative Impacts Conclusions

From a cumulative perspective, the impact of past, present, and reasonably foreseeable activities on cultural and biological resources is substantial, adverse, and significant. The corresponding impact on socioeconomics is substantial and positive. In general, the Outrigger Telescopes Project would add a small incremental impact. Overall, past, present and reasonably foreseeable future actions have a significant impact on the quality of the human environment.

4.3 POTENTIAL ENVIRONMENTAL IMPACTS OF THE CANARY ISLANDS SITE ALTERNATIVE

NEPA and the Council on Environmental Quality (CEQ) implementing regulations apply to proposed Federal agency actions that may occur in or have environmental effects on the United States, its territories, and possessions. The Gran Telescopio Canarias (GTC) alternative site is located on the island of La Palma, Canary Islands, and is under the control of Spain. As a result, NASA need not comply with NEPA if it were to decide to locate the Outrigger Telescopes Project at the GTC alternative site. Rather, NASA must satisfy the requirements of Executive Order (EO) 12114, Environmental Effects Abroad of Major Federal Actions, prior to taking a final action concerning the GTC alternative.

While the purposes of NEPA and EO 12114 are very similar, there are far fewer procedural requirements under the Executive Order and the scope is much narrower. EO 12114, Subsection 2-3 describes the Federal actions covered by the Executive Order that necessitate the preparation of environmental

documentation to be considered by the decision maker before reaching a final decision. The actions specifically covered are:

"(a) major Federal actions significantly affecting the environment of the global commons outside the jurisdiction of any nation (e.g., the oceans or Antarctica);

(b) major Federal actions significantly affecting the environment of a foreign nation not participating with the United States and not otherwise involved in the action;

(c) major Federal actions significantly affecting the environment of a foreign nation which provide to that nation:

(1) a product or physical project producing a principal product or emission or effluent which is strictly prohibited or strictly regulated by Federal law in the United States because its toxic effects on the environment create a serious public health risk; or
(2) a physical project which in the United States is prohibited or strictly regulated by Federal law to protect the environment against radioactive substances.

(d) major Federal actions outside the United States, its territories and possessions which significantly affect natural or ecological resources of global importance designated for protection under this subsection by the President, or, in the case of such a resource protected by international agreements binding on the United States by the Secretary of State.…"

If a proposed Federal action falls within one of the above categories, the Federal agency must prepare either an environmental impact statement (EIS), a bilateral or multilateral environmental study, or a concise review of the environmental issues involved (including an environmental assessment, summary environmental analysis, or other appropriate document) depending on which category is applicable. An EIS is only required for an action falling under Subsection 2-3(a) (i.e., significant effects on global commons), and is discretionary for actions falling under Subsection 2-3(d) (i.e., significant effects on natural or ecological resources of global importance). It should also be noted that "actions not having a significant effect on the environment outside the United States as determined by the agency" are exempt from EO 12114 (see Subsection 2-5 (a)(i)).

While not necessarily required under EO 12114 to support a decision on the GTC alternative site, NASA has conducted an environmental analysis on the GTC site sufficient for a decision maker to make a meaningful comparison of the potential environmental impacts of siting the Outrigger Telescopes Project at the Mauna Kea and GTC sites. For purposes of analysis and comparison the ROI for each environmental medium relevant to the GTC site is generally the same as that for the Proposed Action on Mauna Kea. However, there is no equivalent to Hale Pōhaku along the road to the GTC site.

4.3.1 Cultural Resources

The earliest known inhabitants of the Canary Islands are a people who have come to be known as Guanches. This people is thought to have originated from the Berbers of the Atlas region in Africa (modern day Morocco). There appears to be no group or sub-population that considers the area within the Roque de los Muchachos Observatory (ORM) (an area that includes the GTC) to be sacred or of religious importance. However, there are a number of archeological sites along the rim of the caldera. The GTC has been surveyed for potential archeological properties to the extent necessary to accommodate the observatory and ancillary facilities. As a part of the environmental

assessment for the GTC, there are 7 sensitive archeological sites that are protected and/or will be relocated as a part of the construction effort. These sites are to be protected and/or relocated in accordance with Spanish regulatory requirements. The presence of these sites has not impeded construction. See Figure 4-5. The GTC site appears located at the 2,270-m (7,450-ft) contour at the ridge line denoted by the square denoted by Caseta.

On-site and Installation Impacts. Since there are no groups that consider the ORM to be sacred or of religious importance, on-site construction and installation will have no impact on traditional cultural values. The GTC site has been surveyed for archeological sites to the extent necessary to construct and operate the GTC. Certain configurations of the Outrigger Telescopes could be placed entirely within the zone that has been screened for archeological properties. However, from a scientific standpoint, the most advantageous configuration would likely involve the Outrigger Telescopes placed so as to "surround" the 10-m (33-ft) GTC telescope. In that event certain Outrigger Telescopes would likely be placed in areas not previously surveyed for archeological properties. For that scenario additional archeological surveys would be required. Based on prior GTC and other ORM telescope experience, there is a reasonable likelihood that one or more additional archeological sites would be discovered. However, again based on prior experience, suitable mitigation is likely available without undue effect on the siting and construction of the Outrigger Telescopes. In summary, the anticipated impacts on cultural resources are minor.

Operations Impacts. Since there is no traditional cultural value placed on the ORM or surrounding areas, operation of the Outrigger Telescopes would not impact traditional cultural values. Similarly, once the on-site construction and installation phases are completed, there is no potential for adverse effect on archeological resources. The anticipated adverse impact on cultural resources is zero.

Mitigation Measures. If the proposed layout of the Outrigger Telescopes places any of the telescopes in previously unsurveyed areas, an archeological survey would be conducted. If any archeological resources of consequence are discovered, NASA would ensure that all stipulations and conditions specified by Spanish authorities would be carried out.

4.3.2 Biological Resources and Threatened and Endangered Species

The area surrounding the GTC site is populated with a subalpine ground cover composed of mountain scrub that is easily damaged by foot or machinery traffic. There have been no protected plant species identified in the area surrounding the GTC. The only fauna species that is "of special interest" that may be encountered in the ORM is the vulgar kestrel (Falco tinnunculus), although no nesting sites were encountered in the environmental survey of the GTC site.

Los Tiles, which extends over four municipalities of La Palma, is a component of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) world network of Biosphere Reserves. Such reserves combine conservation of the natural environment with research and environmental monitoring, while balancing the need for sustainable development.

The island of La Gomera, approximately 80 km (50 mi) southeast of La Palma, is home

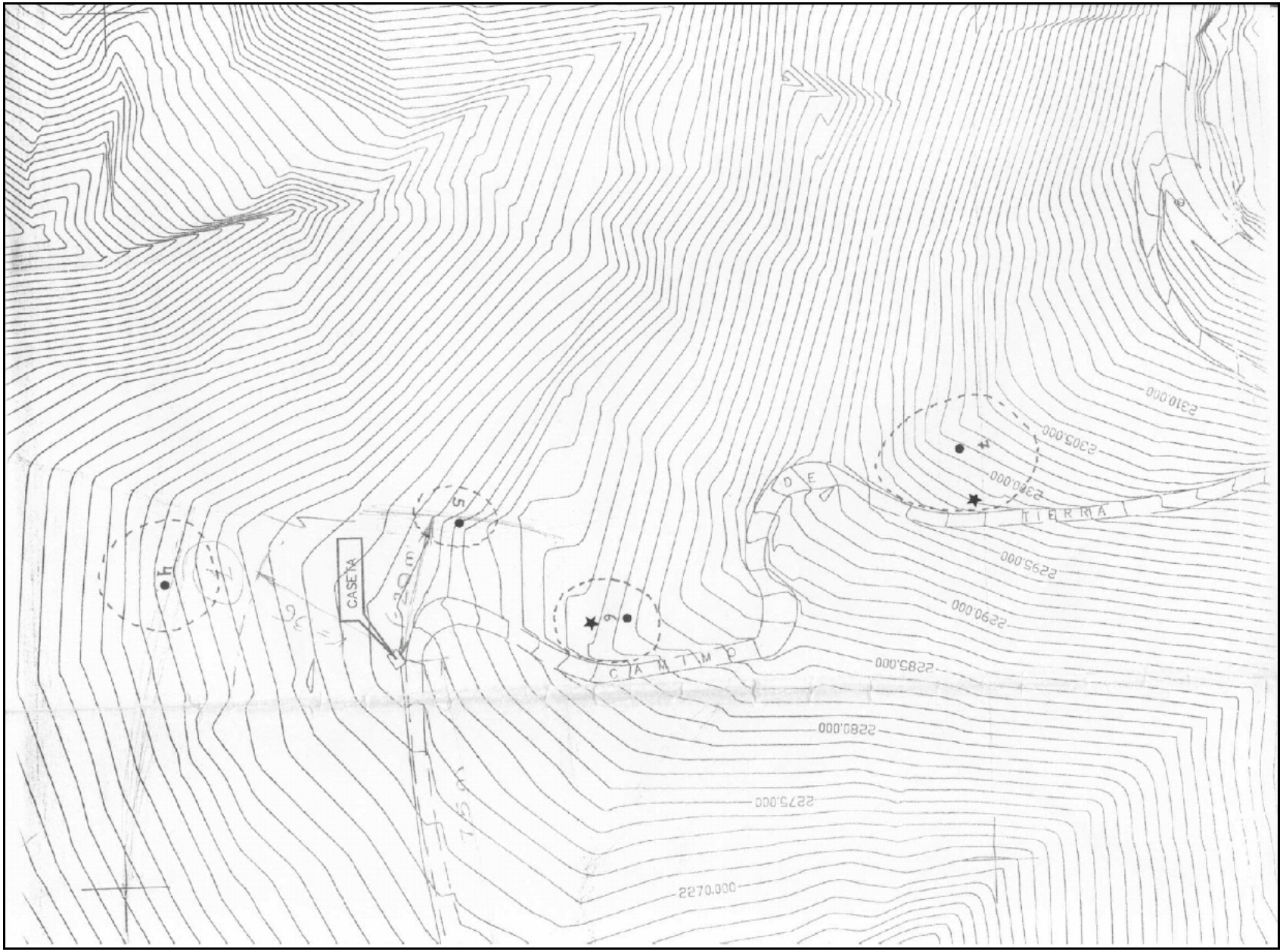


FIGURE 4-5. ARCHAEOLOGY MAP

to Garjonay National Park, which is a World Heritage site. World Heritage sites are places in nature and culture with a value and importance reaching far across geographical and political boundaries and are a heritage of the world in general. The Grand Canyon of the Colorado River, Galapagos Islands, and Taj Mahal are prominent examples of properties on the World Heritage list. The concept of World Heritage sites was first implemented by UNESCO in 1972, with new properties of nature and culture considered exceptional added to the list yearly. Garjonay National Park, almost 4,000 ha (10,000 ac) in size, is located in the center and highest part of La Gomera. The main purpose of creating this National Park was the protection of its exceptional vegetation, especially its bay-tree forests. Hardly any of these forests remain in the world, and they are a veritable relic of the past. In Garjonay National Park, 450 different plant species have been identified so far. Thirty-four of them are exclusive to La Gomera, while 8 of these are only found in the National Park. There are two species of mountain doves only found in the Canary Islands. In addition, early research indicates that among the numerous invertebrate species are several species that are only found locally.

On-Site Construction and Installation Impacts. A sizeable area adjacent to the GTC has been disturbed by material staging and construction activities. The relative impact of the Outrigger Telescopes Project would depend on the location of these telescopes in relation to the GTC. While it may be feasible to locate them wholly in previously disturbed areas, from a science and research perspective the optimal configuration would likely be similar to that on Mauna Kea (the Outrigger Telescopes placed in a configuration surrounding the GTC). Such a configuration would involve siting of some telescopes in previously undisturbed areas, leading to destruction of flora. Because of the nature of the site and flora involved, there would be difficulty in flora reestablishing itself. However, the relatively small size of the Outrigger Telescopes would necessarily limit the area of disturbance.

Animals temporarily may leave the immediate vicinity during the period of construction and installation. Noise may cause a startle response among certain species, although no bird nesting sites have been found in the vicinity of the GTC. It is reasonable that animal species would return after on-site construction and installation are complete.

The 1999 environmental survey for the GTC resulted in a finding of no impact to protected species within the GTC area. Since construction and installation activities associated with the Outrigger Telescopes would be similar to but smaller in scale than the GTC, no impact to protected species is anticipated.

Because of the localized nature of this construction and installation activities, there would be no biological impact on the Biosphere Reserve or on the World Heritage site of La Gomera.

In summary, the impact on flora and fauna would be minor. Impacts of fauna would be temporary, while it could take some period of time for flora to reestablish itself.

Operation Impacts. Operation of the Outrigger Telescopes would generate very little noise and little overall human activity. Human activity would be confined to the developed portion of the GTC site. Biological impact would be zero.

Mitigation Measures. During on-site construction and installation, a construction best management plan (BMP) would be implemented that would be similar to that

proposed for Mauna Kea. These practices would further limit impact to flora and fauna.

4.3.3 Hydrology, Water Quality, and Wastewater

No surface or subterranean water courses or aquifers cross the site. The GTC will use a septic tank and leech field to dispose of domestic wastewater.

On-Site Construction and Installation Impacts. There would be three principal sources of environmental impact during construction: (1) use of water for dust control, (2) accommodating the water supply and wastewater treatment and disposal needs of construction workers, and (3) alteration of runoff in previously undisturbed areas. Water would be trucked to the site. For purposes of analysis, it is assumed that water use would be roughly equivalent to that at Mauna Kea. While there may be more workers at certain time as at the site than under the Mauna Kea alternative, the large proportion of them would likely commute daily rather than reside near the construction site. This is in contrast to the Mauna Kea alternative where many workers may temporarily reside at Hale Pōhaku. The septic system and leech field at GTC have been approved by local authorities.

Some of the water applied for dust control would be lost to evaporation and the remainder would percolate downward. Since water action has resulted in two soil layers where the cinder has taken on a clay-like character, it is possible that there may be horizontal displacement of water while percolating downward. Otherwise, the percolation process should be similar to that on Mauna Kea. Minor hydrologic impact from dust control would be expected.

The presence of construction workers at the GTC site for Outrigger Telescope construction and installation would add domestic wastewater loading to the septic system, although within the capacity of the system. As an alternative, portable toilets with off-site disposal could be used. Impact from domestic wastewater on hydrology and water quality is expected to be small.

While construction activities may affect precipitation run-off from the site, it is anticipated that impacts to hydrology and water quality would be small. No water channels or drainages cross the site.

Operation Impacts. Potential impacts are limited to those arising from the generation of domestic wastewater. All personnel working on the Outrigger Telescopes during operations would use the GTC facilities. The number of such personnel would be very small. Mirror cleaning and resurfacing would be accomplished on site, with the wastewater collected, placed in containers and transported off site. The overall impact would be effectively zero.

Mitigation Measures. Implementation of a BMP would minimize alteration of drainage. Disposal of wastewater through use of septic systems and leech fields has been approved and of no particular concern for astronomy activities in the ORM. However, there is a Canary Island-wide concern over potable water source protection and enhancement. Such concerns arise from (1) increased population, and (2) local rainfall being the only source for potable water. While there is no current pressure to upgrade wastewater facilities at the observatories, it is conceivable that additional island-wide requirements could be imposed within the next several years. There also conceivably could be pressure for observatories at the ORM to collect some of the precipitation for on-site use.

4.3.4 Solid Waste and Hazardous Materials Management

On-Site Construction and Installation Impacts. The analysis of these impacts and mitigation measures for the W.M. Keck Observatory site in Section 4.1.5.2 generally applies to the GTC alternative. However, the mitigation applicable to the Wēkiu bug would not be relevant and, thus, not implemented. There would be a minor increase in solid waste but no impact with implementation of appropriate mitigation measures. With appropriate handling of hazardous materials, there would be effectively no impact arising from such materials.

Operation Impacts. The analysis of these impacts and mitigation measures described in Section 4.1.5.2 for the W.M. Keck Observatory site would generally apply to the GTC alternative. Operations at the GTC site would result in effectively no increase in hazardous materials use and disposal or solid waste.

4.3.5 Land Use and Existing Activities

Land Use Impacts. The GTC alternative site lies within the ORM which is a designated area within the National Park of the Caldera of Taburiente. By law astronomy activities have been declared compatible with traditional uses of the grounds within the ORM. Thus on-site construction, installation, and operation of the Outrigger Telescopes would be compatible with and not adversely affect land use designation.

Existing Activities

On-Site Construction and Installation Impacts. Activities associated with the on-site construction and installation of the Outrigger Telescopes Project would occasionally delay vehicular traffic along the northern road route to the ORM and temporarily increase noise levels and dust generation. See sections related to transportation (Section 4.3.8), noise (Section 4.3.12), and air quality (Section 4.3.11) impacts for additional information. Tourism activities primarily concentrated on the south rim of the caldera would not be affected. See Section 4.3.13 for more information on visual impacts. There are no activities of any note in the area of ORM other than astronomy, other than a relatively small number of tourists.

Operation Impacts. The Outrigger Telescopes Project would be consistent with the only use of any note, astronomy, in and in the vicinity of the ORM. There would be no impact.

4.3.6 Geology, Soils, and Slope Stability

The GTC site may be characterized as a broad plain sloping 18 percent downward towards the northwest. The upper 1 to 3 m (3 to 10 ft) of the surface soil is clay-like due to weathering. This layer has low compressive strength. Below this is a layer of basaltic lava 1 to 6 m (3 to 20 ft) thick that exhibits substantially higher bearing capacity. Beneath this layer is another stratum that also exhibits extreme weathering and low load bearing capacity.

On-Site Construction and Installation Impacts. The altered state due to weathering of the volcanic material in the upper soil layers results in a surface subject to erosion as a result of project related activities. Careful design would be implemented to ensure that the Outrigger Telescopes are placed on stable foundations. The BMP will need to include measures to minimize erosion. Such measures would likely need to be more extensive than at the W.M. Keck Observatory where the Outrigger Telescopes locations would be almost entirely on previously leveled land. Still with available mitigation methods the

adverse impacts to soils and slope stability are anticipated to be small.

Operation Impacts. Given the nature of Outrigger Telescope operations, adverse impacts would be zero.

4.3.7 Geologic Hazards

Earthquakes are very rare in the Canary Islands. Volcanic eruptions have occurred recently on the southern end of La Palma. There have been eight eruptions since 1470. The Spanish building code assigns the ORM area its lowest level of seismic risk and very low ground motion coefficient.

Outrigger Telescopes Impacts. On-site construction, installation, and operation would have no adverse impact on seismic and volcanic activity.

4.3.8 Transportation

Within the ORM, the road the GTC is two-way and entirely paved. The ORM itself is accessible via two routes, both of which are paved for their entire lengths. The southerly and more direct route from Santa Cruz de la Palma provides access through the National Park of the Caldera of Taburiente to the developed viewing points for tourists of the caldera. However, this route has many curves and precipitous sections. The longer and more forgiving route entails a circuitous route around the northern end of the island. While tourism is growing among the eastern islands of the Canaries, tourism is still not a major factor on the agriculturally based island.

On-Site Construction and Installation Impacts. The anticipated amount and mix of construction traffic during the on-site construction and installation stages would be roughly the same as for the Proposed Action. Therefore, one would expect the environmental impacts to be essentially the same with some exceptions. Since both routes to the ORM are entirely paved, there would be less dust generation for the GTC alternative. Also, since traffic can use two routes to the ORM and visitor activity is relatively small, there is likely to be much excess traffic capacity. Finally, movement of the largest components (e.g., telescopes and domes) would likely follow the northern route, and thus not delay the larger portion of tourist traffic to the southern edge of the caldera. Overall adverse transportation impact would be small and less than at Mauna Kea.

Operation Impacts. Even using a conservative assumption of 6 to 12 daily roundtrips, adverse transportation impact would be nearly zero. There are two routes to the ORM and no evidence that collectively these roads are heavily traveled.

Mitigation Measures. As for the Proposed Action, movement of large and over-sized loads along the circuitous northern route would be planned and coordinated to minimize traffic delays.

4.3.9 Utilities and Services

Water Supply and Communications. The analysis of impacts on water supply and communications in Section 4.1.9.2 for the W.M. Keck Observatory site is equally applicable to the GTC site. No on-site construction, installation, or operations impacts would occur.

Electrical Power. The primary feed is from a substation at about the 1,000 m (3,300 ft) level. This line runs mostly overhead to the vicinity of the ORM and GTC and then underground for the last 2 km (1.2 mi). The GTC itself has a feeder line that has a capacity of 1 megawatt, with an anticipated load of no greater than 850 kW. The GTC will have emergency generator capacity of 969 kW.

On-Site Construction and Installation Impacts. The analysis for the W.M. Keck Observatory site in Section 4.1.9.2 equally applies to the GTC alternative. There will be no adverse impact on electrical power.

Operation Impacts. Four Outrigger Telescopes would require 120kW, and six would require 180 kW. When combined with the anticipated load of the GTC itself, the maximum load would be either very near to or exceed capacity. The situation would be even more problematic for emergency generation. It is quite likely that capacity of the feeder line would need to be increased with attendant changes of equipment and potentially the need to install a new feeder line. An additional emergency generator is even more likely to be needed with accompanying expansion of on-site infrastructure. Overall adverse impact to electric power capacity would be substantial without the upgrades. With such additional infrastructure, the adverse impact would be small.

Emergency Services and Fire Suppression. The GTC facilities store about 30,000 l (7,900 gal) of water for fire suppression. There are four helipads within several hundred meters of the GTC. Thus, persons needing emergency treatment could be airlifted to the nearest hospital in Garafia at the northern base of the mountain.

Impacts on Emergency Services and Fire Suppression. The analysis for the W.M. Keck Observatory site provided in Section 4.1.9.2 equally applies to the GTC site. No adverse impacts are anticipated.

4.3.10 Socioeconomics

Excluding the need to add certain facilities at the GTC site that presently exist at the W.M. Keck Observatory (e.g., an interferometer and associated equipment, electric power upgrades, etc.), on-site construction, installation, and operations costs would be approximately the same: $13 million for on-site construction and installation and $5 to $7 million yearly for operations. The only difference would be slightly less expenditures on La Palma for construction due to labor costs that are essentially counterbalanced by higher transportation costs to deliver certain components (e.g., telescopes and domes) to La Palma. There would relatively be a greater socioeconomic benefit to La Palma and the Canary Islands than to the Island and State of Hawai‘i because of the relative sizes of the local economies. Overall, locating the Outrigger Telescopes Project would offer a moderate socioeconomic benefit to La Palma and small benefit to the Canary Islands.

4.3.11 Air Quality

A marine inversion layer occurs throughout the Canary Islands for 90 percent of the year. This inversion layer protects the ORM and high altitude portions of the caldera from any air pollution generated at lower elevations on La Palma. Generally air quality is very good at the ORM.

On-Site Construction and Installation Impacts. The analysis provided in Section 4.1.11.2 for the W.M. Keck Observatory is generally applicable to the GTC alternative, with one exception. Since the two highway routes to the GTC are entirely paved, there would be no dust generated by traffic to and from the GTC. With the implementation of the mitigation measures mentioned below, the adverse environmental impacts on air quality are expected to be small and slightly less than for the W.M. Keck Observatory site.

Operation Impacts. During operation of the Outrigger Telescopes, air quality would return virtually to the same levels as prior to construction. The only incremental impacts

would be the few additional vehicle round trips to the GTC site by operational personnel. Adverse impact to air quality would be zero.

Mitigation Measures. Construction activities would comply with Spanish and Canary Island air quality requirements. In addition, the specific mitigation measures described in Section 4.1.11.2 would be implemented.

4.3.12 Noise

The GTC is sufficiently below the north rim of the caldera that it cannot be viewed from the primary tourist overlooks, which are located on the south rim.

On-Site Construction and Installation Impacts. The analysis presented in Section 4.1.12.2 for the W.M. Keck Observatory site generally applies to the GTC site with certain exceptions. There are no religious practices conducted in the vicinity. There is little recreational use in the area. The great preponderance of tourism terminates along the south rim, where noise impacts are mitigated by distance 8 km (5 mi) and noise screening due to the GTC site being located below the caldera rim. However, buses also do frequently visit the ORM primarily to provide tourists views of the observatory. Construction noise should not be incompatible with such a purpose. Noise impacts would be small and less than at Mauna Kea.

Operation Impacts. The analysis presented in Section 4.1.12.2 for the W.M. Keck Observatory equally applies to the GTC alternative. Noise impacts would be effectively zero.

Mitigation Measures. Noise mitigation measures required by the pertinent regulatory authorities would be implemented.

4.3.13 Visual/Aesthetics

The GTC is on the north side of the north rim of the caldera.

On-Site Construction, Installation, and Operations Impacts. While some tourists visit the south rim of the caldera to view the existing observatories in the ORM, there is sensitivity that these structures may adversely effect the visual view plane. Approval of the GTC project by the National Park de la Caldera de Taburiente was dependent, in large part, upon the fact that it would not be visible from the south rim visual outlooks. Similarly, the Outrigger Telescopes that are much shorter than the GTC would not be visible from the south rim. Also, being on the north side of the north rim, the Outrigger Telescopes would be shielded from view from the major population centers, which are located to the south. The ORM is not visible from north shore island communities due to the steep slopes that make up the mountainous terrain. The Outrigger Telescopes would be compatible visually with the other telescopes and observatories in the ORM. Viewing the observatories themselves is the primary purpose of tourists visiting the ORM. The adverse impact would be effectively zero.

4.4 POTENTIAL ENVIRONMENTAL CONSEQUENCES OF THE NO-ACTION ALTERNATIVE

Under the No-Action Alternative, NASA would not fund on-site construction, installation, or future operation of the Outrigger Telescopes Project proposed for the W.M. Keck Observatory site at Mauna Kea. The potential environmental impacts described for the Outrigger Telescopes Project would not occur. If the Outrigger Telescopes are not constructed and installed at the W.M. Keck Observatory on Mauna

Kea, the facilities at the W.M. Keck Observatory site would consist of the two existing 10-m (33-ft) Keck Telescopes, which are capable of functioning as the Keck-Keck Interferometer. NASA would not be able to attain the four science objectives of the Outrigger Telescopes Project discussed in Section 1.3. In addition, the No-Action Alternative would result in economic losses to the State of Hawai‘i estimated at $13 million for the on-site construction and installation of six Outrigger Telescopes. The incremental revenues ($5 to $7 million annually) that would be associated with operation of the Outrigger Telescopes Project would also be lost to the State. NASA’s funding of the Wēkiu bug on-site mitigation, the autecology study, and the Wēkiu bug monitoring activities would not occur. NASA’s funding of the on- and off-site mitigation activities proposed by NASA in the NHPA Section 106 process would also not occur.

The environmental impacts attributed to the implementation of the Outrigger Telescopes Project would not occur. The impacts of past, present, and foreseeable future activities on Mauna Kea would be unchanged (see Section 4.2). Since the incremental impacts of the Outrigger Telescopes Project would be generally small, the overall cumulative impacts would generally be as described in Section 4.2.

5 SUMMARY OF MITIGATION AND MONITORING MEASURES FOR THE OUTRIGGER TELESCOPES PROJECT

This Chapter summarizes the most important mitigation and monitoring measures for the Outrigger Telescopes Project. NASA is committed to ensuring implementation not only of the mitigations described in this Chapter, but also those presented elsewhere in this EIS.

The mitigation and monitoring activities for the Outrigger Telescopes Project, provided below, are detailed in Chapter 4 and Appendices B, D, E, and F of this Environmental Impact Statement (EIS). The National Historic Preservation Act (NHPA) Section 106 Memorandum of Agreement (MOA) in Appendix B describes the mitigation and monitoring measures associated with historical and cultural resources. The Consulting Parties invited under the Section 106 MOA include the Advisory Council on Historic Preservation (ACHP), the Hawai‘i State Historic Preservation Officer (SHPO), the University of Hawai‘i (UH), the California Association for Research in Astronomy (CARA), the California Institute of Technology (Caltech), Ahahui Ku Mauna, Hawai‘i Island Burial Council, Hui Mālama I Nā Kūpuna O Hawai‘i Nei, Mauna Kea Anaina Hou, the Office of Hawaiian Affairs (OHA), Office of Mauna Kea Management (OMKM), and the Royal Order of Kamehameha I.

Appendices D and E describe mitigation and monitoring measures associated with the Wēkiu bug and its habitat. CARA would ensure that any of the MOA’s provisions that relate to on-site construction and installation of the Outrigger Telescopes would be included as provisions in any contracts for on-site construction and installation (see Appendix F).

CARA would implement all of these mitigation measures, and NASA would ensure they are carried out during on-site construction, installation, and operation of the Outrigger Telescopes.

5.1 HISTORIC/CULTURAL RESOURCE MITIGATION AND MONITORING MEASURES

- In consultation with NASA and the other Consulting Parties, CARA shall develop criteria for and select an individual to be the project’s Cultural Monitor. Any Consulting Party may submit the names of persons who they believe would be appropriate to serve as Cultural Monitor. This individual will have the knowledge or awareness of Mauna Kea’s cultural landscape, and traditions, practices, beliefs, and customs associated with Mauna Kea.
- This individual will be able to communicate cultural values and protocols to others, both within and outside of the culture.
- The Cultural Monitor will become aware of the general scope and requirements of the on-site construction and installation of the Outrigger Telescopes Project including, but not limited to, becoming familiar with: project boundaries, identified areas of historic/cultural sensitivity, the “Construction Best Management Practices Plan” (BMP), the construction worker responsibilities, responsibilities of the Archaeologist, and the sequence of operations to ensure that mitigation actions are implemented.

- A Cultural Monitor will be provided free access for monitoring activities during excavation, other on-site construction, and telescope installation.
- Prior to construction, a cultural monitoring plan will be developed by the Cultural Monitor in consultation with CARA. CARA shall submit the plan for review by NASA and all other Consulting Parties.
- The CARA Construction Manager shall encourage the Cultural Monitor and Archaeologist to work closely with one another.
- The CARA Construction Manager will provide to the Cultural Monitor a weekly schedule of all construction activities planned for the following week. Based on that schedule, the Cultural Monitor will determine his/her need to visit the site during construction and installation as deemed necessary by him/her. For safety purposes, prior to entering the site, the Cultural Monitor will meet and confer with the CARA Construction Manager.
- The site and grading development drawings and the BMP for the Outrigger Telescopes project site, the staging areas, and nearby areas of the summit region will be provided to the Cultural Monitor. The Cultural Monitor shall keep a log and map notes of every visit — noting date of visit; identifying work locations; noting findings date; and reporting on potential problems, if any. All findings identified and deemed to be significant by the Cultural Monitor shall be reported to the CARA Construction Manager and OMKM; in turn, CARA shall promptly notify NASA, the Council, the Hawai‘i SHPO, UH, and Caltech and any other Consulting Party that has requested to be notified of the Cultural Monitor’s findings. The Cultural Monitor will submit a final report to the CARA Construction Manager; CARA, in turn, will provide copies to NASA, the Council, the Hawai‘i SHPO, UH, OMKM, and Caltech and any other Consulting Party that has requested the report.

In Consultation with NASA and the other Consulting Parties, CARA shall select an individual to be a Cultural Monitor.

- The Cultural Monitor shall consult with the Construction Manager to determine what circumstances the Cultural Monitor should have direct authority to halt construction activities in a given area.
- The Cultural Monitor will provide cultural orientation to individuals who are associated with the on-site construction and installation of the Outrigger Telescopes and who will be on Mauna Kea. For safety purposes, all communication for the purpose of cultural orientation between project personnel and the Cultural Monitor will be scheduled and overseen by the CARA Construction Manager.
- The Archaeologist will be hired by CARA in consultation with the Hawai‘i SHPO and OMKM.
- The above monitoring plan (see I.B.2a) shall include burial and notification components that comply with Hawai‘i Revised Statutes (HRS) Title 6E-43.6 (Inadvertent Discovery of Burial Sites), and Hawai‘i Administrative Rules (HAR) Title 13-300-40 (Inadvertent Discovery of Human Remains) for the burial components;

and with applicable draft State Historic Preservation Division (SHPD) Rules (e.g., Sections 13-275-12, 13-279-1 *et seq.*, and 13-280-1 *et seq.*) for the archaeological components. The burial treatment component will reflect that the preferred treatment, in the absence of evidence to the contrary, and to the extent practicable, is for any human burial found to remain in place.

- As a minimum, if there were to be an inadvertent discovery of human remains, or an archaeological property, the Archaeologist has the authority to halt ground-disturbing activities in the immediate area of such remains or archaeological property until all parties identified in the plan have been notified, and the requirements of the appropriately approved plan have been carried out.
- As a minimum, if previously unidentified historic properties (e.g., deposits, artifacts, and stone alignments) were to be discovered during construction, the Archaeologist has the authority to halt ground disturbing activities in the immediate area of such properties until all parties identified in the plan have been notified, and the requirements of the appropriately approved plan have been carried out.
- The Archeologist shall familiarize him/herself with the W.M. Keck Observatory site before construction begins.
- The Archaeologist will become aware of the general scope and requirements for the on-site construction of the Outrigger Telescopes Project. This would include, but not be limited to becoming familiar with: project boundaries, identified areas of historic/cultural sensitivity, the BMP, construction worker responsibilities, responsibilities of the Cultural Monitor, and the sequence of operations to ensure that mitigation actions are implemented.
- The Archaeologist will monitor all excavation activities for on-site construction. The CARA Construction Manager will provide to the Archaeologist a weekly schedule of all construction activities planned for the following week. The Archaeologist will have access to the site and be present during all excavation activities. For safety purposes, prior to entering the site, the Archaeologist will meet and confer with the CARA Construction Manager.
- The site and grading development drawings and the BMP for the Outrigger Telescopes project site, the staging areas, and nearby areas of the summit region will be provided to the Archaeologist. The Archaeologist shall keep a log and map notes of every visit — noting date of visit; identifying work locations; noting findings date; and reporting potential problems, if any. All findings identified and deemed by the Archaeologist to be significant shall be reported to the CARA Construction Manager, the Hawai‘i SHPO, and OMKM; in turn, CARA shall promptly notify the NASA, the Council, UH, Caltech, and the Cultural Monitor of the Archaeologist’s findings. The Archaeologist will also notify the Cultural Monitor if a burial is involved so that he or she can assist in coordinating with lineal and cultural descendents and the Hawai‘i Island Burial Council. The Archaeologist will submit a draft report to the CARA

Construction Manager; CARA, in turn, will forward the draft report to the Hawai‘i SHPO for approval. The approved final report will be distributed by CARA, who will provide copies to NASA, the Council, UH, OMKM, and Caltech, and any other Consulting Party that has requested a copy of the report.

- Proposed grading and site development drawings will be provided to all the Consulting Parties for a 45-calendar day review and comment period to ensure that every reasonable effort has been made to reduce the adverse effects on Pu‘u Hau ‘Oki and on the summit region of Mauna Kea by minimizing disturbance from the on-site construction and installation of the Outrigger Telescopes. The goal of the grading and site development planning will be to minimize alteration of the cinder cone as it presently exists, maintain the general shape and form of the cinder cone as it presently exists, and to stabilize the cinder cone in the on-site construction and installation areas.
- When a Consulting Party provides comments to one of these plans, the party submitting the plan shall, to the extent practicable during a 45-day review period, enter into a dialogue with a commenter.
- The CARA Construction Manager will oversee the on-site professional personnel and all on-site construction and equipment installation. The CARA Construction Manager will schedule mutually agreed upon meetings with the Archaeologist, Cultural Monitor, and OMKM, to ensure that work is being carried out according to applicable terms of the MOA. The CARA Construction Manager, at the request of the Archaeologist or the Cultural Monitor or on his/her own initiative, has the authority to stop construction if the stipulations in the MOA are not being complied with.
- As part of an orientation process to ensure work is carried out in as sensitive and respectful a manner as possible, the CARA Construction Manager, the contractor(s), foremen, and all construction workers involved in this Undertaking will be required to view a specially scripted training videotape reviewing the historic and sacred qualities of Mauna Kea.
- This training videotape will be prepared by CARA in consultation with the Hawai‘i SHPO and OMKM. This training videotape will include a presentation on the history of Mauna Kea and its significance to Native Hawaiians, and an overview of what to do if human remains or archaeological properties are found. CARA shall provide the Consulting Parties an opportunity early in the videotape development process to provide ideas on subject matter that should be discussed and highlighted. CARA shall afford the Consulting Parties an opportunity to review the draft script and preview the videotape before the videotape is produced in final form. Should a disagreement arise, CARA will enter into consultation to resolve the disagreements. The time for such consultations shall cumulatively not exceed 45 days, unless CARA, at its sole discretion, agrees to a longer cumulative period.
- The CARA Construction Manager, contractor (s), foremen, and construction workers will also be briefed by the Archaeologist and

Cultural Monitor on Native Hawaiian objects, artifacts, and remains, and what to do if such materials are found during construction activities.

- The videotape will also advise the workers of the potential loss of their jobs on this Undertaking if they fail to comply with the conditions imposed by the Construction Best Management Practices Plan.
- In order to implement a series of precautions and procedures to be undertaken to avoid or minimize adverse effects and prevent or reduce adverse impacts to the cinder cone and inner crater slope during on-site construction and installation, the CARA Construction Manager and the on-site construction and installation contractor(s) will prepare a Construction "Best Management Practices Plan" (BMP) in consultation and coordination with OMKM and UH. The BMP will be finalized prior to the start of construction. This BMP will reference the MOA and include it as an appendix.
- Prior to the start of construction, CARA will submit the draft BMP to the Signatories and the Concurring Parties for review. Copies of all comments received will be provided to NASA. CARA will take those comments into account before its final approval of the BMP and prior to mobilization. CARA will take no more than 15 calendar days to conclude consultation on any issues stemming from the comments.
- On-site construction and installation activities related to the Outrigger Telescopes — from delivery of materials and equipment to the W.M. Keck Observatory site or one of the two construction staging areas, excavation and removal of excess cinder to the summit stockpile area through assembly of the domes and telescopes to clean up of the staging, stockpile and the W.M. Keck Observatory site — will be managed in accordance with the BMP. The CARA Construction Manager will be responsible for following the BMP.

The CARA Construction Manager, contractor(s), supervisors, and construction workers will be briefed by the Archaeologist and Cultural Monitor on Native Hawaiian objects, artifacts, and remains, and what to do if such materials are found during construction activities.

- To address the effects on historic properties, the BMP will include, but not necessarily be limited to, the following items:
  - The process to be followed if there were to be an inadvertent discovery of human remains or archaeological properties.
  - Site characterization, including the locations of all construction and laydown/stockpile areas on the site, and temporary on-site fill material stockpiles.
  - The sequence of construction activities will be designed to minimize potential adverse effects on historic properties and to allow efficient scheduling of appropriate monitoring times.
  - The specific methods needed to protect the attributes of the historic properties within the project site, staging areas, and within the immediate vicinity of the project area will include, but are not limited to:

- Installing a temporary silt fence along the crater rim to facilitate on-site containment of all material, including cinder, so that no such material will spill over the slope. A silt fence will be used whenever excavation occurs within six feet of the slope.
- Transferring all excavated material, to the extent not necessary for backfill or Wēkiu bug habitat restoration, to other locations accessible from the established roads on the summit of Mauna Kea. These locations will be identified after consultation with the Hawai‘i SHPO and OMKM prior to the start of construction.
- Following all applicable County of Hawai‘i and State Department of Health (DOH) regulations concerning dust control which include, but is not limited to, suspending all dust-generating activities, securing equipment and materials during high winds and storms, minimizing dust by spraying with water or other environmentally-acceptable soil stabilizers whenever necessary, and, if needed, covering excavated material with a tarp which is anchored down.
- Ensuring adherence to effective drainage and erosion control as provided for in the BMP.
- Ensuring that precautions are adopted to prevent potential adverse effects on the historic properties arising from use of the staging areas near the summit of Mauna Kea and at Hale Pōhaku.
- Providing an organizational chart that identifies project personnel with the responsibility for maintaining the integrity of the historic properties and the historic district.

- To reduce the visual impact on the cinder cone and the historic district, all structures or portions thereof will be of colors designed to blend in with the surrounding terrain; provided, however, that such colors would not adversely affect the operation and scientific capability of the Outrigger Telescopes. CARA will afford the Consulting Parties an opportunity to review and comment on the colors to be used.
- Characteristics of any discharge of a pollutant into the environment associated with the construction activity (including solid waste, sanitary waste, oily waste, or toxic/hazardous waste, if any) will be identified as soon as it is practicable. Proposed control measures and/or treatment methods for any unplanned or accidental discharge of pollutants associated with construction activity will be developed by the contractor(s) and managed in accordance with the BMP.
- During the construction and installation of the Outrigger Telescopes, OMKM, in consultation with the Hawai‘i SHPO, will develop and provide interpretative materials concerning the cultural significance of Mauna Kea.
- CARA shall report work stoppage to NASA and all the Consulting Parties within two working days.
- CARA shall make provisions for the Consulting Parties to monitor and review the work during on-site

construction and installation activities. However, for safety purposes, all construction site visits must be coordinated through the CARA Construction Manager's office. If it appears that the terms of this MOA are not being followed, Consulting Parties are encouraged to notify NASA, CARA, and the Hawai'i SHPO. NASA, in consultation with OMKM, will fund, out of funds for the Outrigger Telescopes Project, an initiative that deals with preservation and protection of historic/cultural resources on Mauna Kea and educational needs of Hawaiians as a mitigation component of the Outrigger Telescopes Project. Funding such an initiative, however, is conditioned on the approval of the Outrigger Telescope's being placed at the W.M. Keck Observatory site on the summit of Mauna Kea, Hawai'i. This initiative will be sensitive to Native Hawaiian culture, history, and institutions.

- The necessary first step is the formation of local citizens' working group. NASA and OMKM, in consultation with the other Consulting Parties will ensure the formation of this working group. OMKM will coordinate and manage the activities of this working group and provide administrative services.
- Once this working group is formed, its task will be to inform NASA as to what types of opportunities or goals will best benefit Hawaiians, including Native Hawaiians. The working group will be asked to prioritize their proposals.
- Funding will be subject to the availability of appropriated funds in accordance with Federal law (e.g., the Anti-Deficiency Act). Such funds will be allocated to the proposals as prioritized by the working group until available funds are exhausted.

CARA shall ensure that the plans and mitigation measures set forth in the MOA for adverse effects on historic properties, including, visual impacts, erosion control, permit requirements and conditions, and monitoring commitments are incorporated into the contract(s) with its contractors and subcontractors.

- CARA will ensure that all persons involved with the operations of the Outrigger Telescopes shall be required, within a thirty day period of commencing their job, to view as part of worker orientation the training videotape which addresses the cultural significance of Mauna Kea to Native Hawaiians. CARA will report to OMKM quarterly on the status of worker compliance with the viewing of the training videotape.
- In order to minimize negative effects, appropriate traffic control measures would be taken, and all trips of heavy oversized loads, such as those transporting the telescope components, would be scheduled during off-peak hours so as not to interfere with normal traffic flow in Hilo, Waimea, or along the Saddle Road.

5.2 WĒKIU BUG MITIGATION AND MONITORING MEASURES

- Wēkiu bug habitat will be restored in areas damaged by on-site Outrigger Telescope construction, and on the crater floor of Pu'u Hau 'Oki. Restored areas will total at least three times the total area damaged by new construction.

- Under no circumstances during construction, installation, and operation will cinder or other materials be deliberately side-cast into Wēkiu bug habitat. Temporary barriers will be built along the slope breaks above the inner slopes of Pu‘u Hau ‘Oki crater.
- Educational signs will be placed along the slope break above Wēkiu bug habitat, and at the service road adjacent to the crater floor.
- Potable water will be applied to excavation sites and cinder stockpiles as required to minimize dust during earthmoving activities.
- Only small or contained areas will be affected at any given time.
- Dust-generating activities will be suspended during high winds.
- Application of environmentally safe soil stabilizers may be applied to roads and parking areas to reduce dust during and after on-site construction. Environmentally safe soil stabilizers would only be used in situations where the application of potable water is inadequate for dust control. Soil-binding stabilizers will be used sparingly, and will never be applied to Wēkiu bug habitat. Soil stabilizers will be applied under light wind conditions to prevent cinder dust drift due to wind into Wēkiu bug habitat. Products considered for use will be reviewed by an entomologist familiar with Wēkiu bug ecology prior to being considered for use.
- The W.M. Keck Observatory staff will continue to follow Federal guidelines specifying the use and disposal of substances used in the washing and recoating of observatory mirrors.
- Contractors will be required to minimize the amount of on-site paints, thinners, and solvents. Painting and construction equipment will not be cleaned on-site. Contractors will be required to keep a log of hazardous materials brought on-site and report spills immediately to a designated W.M. Keck Observatory representative.
- The amounts of such substances transported to the summit will be those required to support the current activity. The amount required for the entire project will not be stockpiled at the summit. Painting equipment would be cleaned off site to reduce the risk of a spill.
- Construction trash containers will be tightly covered to prevent construction wastes from being dispersed by wind.
- Construction materials stored at the site will be covered with tarps, or anchored in place, and not be susceptible to movement by wind.
- If construction materials and trash are blown into Wēkiu bug habitat, they will be collected to the extent practicable, with a minimum of disturbance to the habitat and cultural properties.
- Earthmoving equipment will be free of large deposits of soil, dirt, and vegetation debris that could harbor alien arthropods.
- Contractors will be required to pressure-wash earthmoving equipment to remove alien arthropods.
- Contractors will be required to inspect large trucks, tractors, and other heavy equipment before proceeding up the observatory access road.

- All construction materials, crates, shipping containers, packaging material, and observatory equipment will be free of alien arthropods when delivered to the summit.
- Contractors will be required to inspect shipping crates, containers, and packing materials before shipment to Hawai‘i.
- Contractors will be required to inspect construction materials before transport to the summit area.
- Outdoor trash receptacles will be secured to the ground, have attached lids and plastic liners, and be collected frequently to reduce food availability for alien predators.
- New alien arthropod introductions (ants, yellow jackets, and spiders) detected during monitoring will be eradicated.
- Construction contracts will ensure that compliance violations are corrected.
- Cinder or ash will be moved to temporary stockpile areas and covered with tie-down tarps. Permanent placement of any excavated cinder fill and ash from the project area during on-site construction will be determined in consultation with SHPD and OMKM.
- Educational signs will be placed along the slope break above Wēkiu bug habitat, and at the service road adjacent to the crater floor. Attractive, non-intrusive, educational signs will be installed to inform people about the Wēkiu bugs, their habitat, and the historic/cultural significance of the area.
- Strict adherence to precautions and procedures outlined in the construction Best Management Practices Plan (BMP’s) will be required to maintain slope stability.

Two types of Wēkiu bug monitoring will be implemented: (1) compliance monitoring to investigate the extent to which contractors, operators, managers, and visitors comply with Wēkiu bug protection guidelines and rules; and (2) effectiveness monitoring to investigate the changes in Wēkiu bug habitat and population that may happen concurrent with and/or subsequent to construction of the Outrigger Telescopes.

- As part of project implementation, NASA will fund a graduate student to study Wēkiu bug autecology, and to gather more information about habitat requirements, life cycle, nutritional requirements, and breeding behaviors.
- If construction materials and trash are blown into Wēkiu bug habitat or fall onto the surrounding slopes of Pu‘u Hau ‘Oki, they will be collected to the extent practicable, with minimum disturbance to the habitat and cultural properties.
- Contractors will properly maintain construction vehicles and equipment to minimize combustion emissions. Engine emissions would be controlled by the use of functional emission devices as required by law. Equipment idling would be kept to a minimum when not in use.

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6 REDUCED SCIENCE OPTIONS

Chapter 6 provides information on the Reduced Science Options. Should NASA decide not to fund the Outrigger Telescopes Project at either the proposed Mauna Kea site, or at the alternative site in the Canary Islands, it may choose to implement a Reduced Science Option.

6.1 BACKGROUND AND PURPOSE AND NEED FOR THE REDUCED SCIENCE OPTIONS

6.1.1 Background

Of the four scientific objectives identified for the Outrigger Telescopes Project, three require the use of an 8 meter (m) (26 foot (ft)) or larger telescope. One objective, precision astrometry of nearby stars to search for planets, can be accomplished using only the Outrigger Telescopes. The astrometry survey is a key part of NASA's Origins Program and would complement the scientific results that other projects, such as the Space Interferometer Mission and the Terrestrial Planet Finder, will provide. NASA has investigated alternative site locations for the Outrigger Telescopes (four Outrigger Telescopes combined) to accomplish the astrometry program. Because location at an alternative site would accomplish only one of four scientific objectives, NASA considers this a *Reduced Science Option*.

6.1.2 Purpose and Need

Astrometry involves measuring the precise position of stars in the sky. A planet orbiting a star exerts a gravitational force on that star, causing it to sway slightly as the planet orbits. This is called the star's reflex motion. By measuring the precise position of the star, the astronomer can infer the presence of the planet from this reflex motion. The actual size of the motion is much smaller than the diameter of the star as seen from Earth. The larger the orbiting planet and the farther it is from the star, the larger the corresponding reflex motion. The period of the motion is equal to the orbital period of the planet.

For planets that are in orbits close to a star and whose orbital period is therefore relatively short (a few months to a few years), scientists can detect motion in a fairly short time. These planets in close orbits cause a relatively small reflex motion, requiring a measurement precision that can be achieved only from space, where the effects of the Earth's atmosphere are eliminated. The Space Interferometer Mission is designed to conduct a five-year astrometric survey of nearby stars for planetary companions, with an emphasis on terrestrial planets in relatively short-period orbits.

For planets with long orbital periods (e.g., Saturn's 29-year orbital period), astronomers require a series of measurements over a long period to detect the corresponding reflex motion. Collecting these data would take longer than a single space mission; therefore, a ground-based observatory is the best location for obtaining data. In addition, if the system contains several planets of different masses and different orbits (as our own solar system), the corresponding motion of the star is very complex and would require additional years of measurement.

NASA needs the Outrigger Telescopes to obtain the data necessary to complete our

understanding of the composition of planetary systems around nearby stars. It is envisaged that the Outrigger Telescopes would be required to collect data for at least 20 years to accomplish the survey for long-period planets.

6.2 SCREENING CRITERIA AND ALTERNATIVES

6.2.1 Reduced Science Options Site Screening

Because the astrometry science objective does not require a large telescope and can be accomplished with four Outrigger Telescopes, the combined telescopes can be placed in any location that has acceptable site-observing quality and adequate land. Generally, sites that already host observatories are good candidates, because they have good observing quality.

NASA identified six candidate sites for the Reduced Science Options. Five of the six sites already host or are scheduled to host an interferometer array of some type. The sixth site is home to the National Optical Astronomy Observatory (NOAO). The six reduced science sites are:

- Anderson Mesa, Arizona
- Mount Hopkins, Arizona
- Kitt Peak, Arizona
- Magdalena Ridge, New Mexico
- Palomar Mountain, California
- Mount Wilson, California.

The screening criteria were applied to each site and filtered through two tiers.

Tier 1 criteria address whether the Outrigger Telescopes can be built at a particular site as well as and the site's atmospheric observing quality. Tier 2 criteria address the practical difficulties or challenges of building the Outrigger Telescopes at that site.

6.2.1.1 Tier 1 Screening Criteria

Adequate Land for Four Outrigger Telescopes. The site must have adequate land to locate four Outrigger Telescopes and a beam-combining facility. It must support, at a minimum, two orthogonal (within +/- 15 degrees) baselines, approximately 100 m (328 ft) in length. The site must have unobscured views of the sky from each telescope within a zenith angle of 60 degrees. The beam-combining facility should be within the polygon defined by the locations of the Outrigger Telescopes. Otherwise, an additional building would be required to house a central hub, where a number of relay mirrors would be placed. All buildings, including the combiner facility, should be at the same elevation or altitude above sea level within approximately 6 m (20 ft).

Adequate Site Atmospheric Observing Quality. The site should have adequate atmospheric seeing conditions and good weather most nights, with no season of poor observing conditions. Sites are awarded points for seeing quality and clear nights, as shown in Table 6-1.

The maximum possible score for Tier 1 is 14 points. Sites scoring 6 points or higher in Tier 1 will be evaluated against Tier 2 criteria.

6.2.1.2 Tier 2 Screening Criteria

Technical Considerations. Sites that are deemed relatively straightforward to develop will be awarded an additional 4 points. Sites that are deemed difficult or challenging to develop (e.g., sites with uneven topography), unfavorable local conditions, or other negative factors, will not be awarded additional points.

TABLE 6-1. TIER 1 SCREENING CRITERIA SCORING

Atmospheric Seeing Criterion (arcseconds)	Comments	Point Score Assigned
0.5” seeing	Full astrometric program capability.	10
0.5” – 0.75” seeing	Possible small impact to astrometric program.	8
0.75” – 1.0” seeing	Some degradation to astrometric program.	6
1.0” seeing	Moderate degradation to astrometric program.	4
1.0” – 1.5” seeing	Further degradation to astrometric program.	2
Not possible to predict accurately	Potential for poor seeing.	0
Clear Night Criterion	**Comments**	**Point Score**
Greater than 180 nights/year	Usable more than ½ the year.	4
Less than 180 nights/year	Usable less than ½ the year.	0

Programmatic Considerations. Because the astrometry program would be expected to involve operations every clear night of the year, proximity to the Jet Propulsion Laboratory (JPL) in Pasadena, California (which would develop the interferometer), and the Michelson Science Center at Caltech (which would operate the interferometer) is considered a practical advantage. Sites within 241 kilometers (km) (150 miles (mi)) of JPL will be awarded an additional 2 points.

The maximum possible score for Tier 2 is 6 points.

6.2.2 Reduced Science Site Descriptions and Screening Criteria Evaluations

6.2.2.1 Anderson Mesa, Arizona

Site Description. Anderson Mesa, located on the Colorado Plateau, approximately 16 km (10 mi) from Flagstaff, Arizona, is part of the Lowell Observatory in an area known as the Dark Site. The Dark Site is home to the Navy Prototype Optical Interferometer (NPOI) project, a joint venture between the U.S. Naval Observatory, the Naval Research Laboratory, and the Lowell Observatory.

Screening Criteria Evaluation. Anderson Mesa has adequate land to accommodate the Outrigger Telescopes.

Atmospheric seeing is estimated to fall in the range of 1.0 to 1.5 arcseconds (2 points). The site is reported to have good atmospheric seeing conditions on 60 percent of nights over the year (4 points).

Tier 1 Criteria (score = 6 points)

Anderson Mesa is a straightforward site for development with good access and relatively level terrain.

Tier 2 Criteria (score = 4 points)

6.2.2.2 Mount Hopkins, Arizona

Site Description. Mount Hopkins is in the Santa Rita Mountains within the Coronado National Forest in southeastern Arizona. The Smithsonian Astrophysical Observatory, a research bureau of the Smithsonian Institution, began development of the site in the 1960s. The site is home to several telescopes, including

the 6.5-m (21-ft) MMT and the Infrared Optical Telescope Array.

Screening Criteria Evaluation. Mount Hopkins is a rugged mountain site characterized by steep slopes and sheer cliffs. The site could marginally accommodate the Outrigger Telescopes, with the removal of a hard granite knoll to provide level ground.

Atmospheric seeing is estimated to fall in the 1.0 arcseconds category (4 points). This site has acceptable weather and cloud cover (4 points).

Tier 1 Criteria (score = 8 points)

Mount Hopkins would be a relatively difficult site to develop. Road cuts and natural rock outcrops indicate the site has a minimal soil profile and a monolithic, fractured bedrock pattern. Removal or modification would require heavy equipment (e.g., coring, air ram, blasting). A steep unpaved road, portions of which require radio communication between uphill and downhill traffic, provides the only access to the site.

Tier 2 Criteria (score = 0 points)

6.2.2.3 Kitt Peak, Arizona

Site Description. Kitt Peak National Observatory resides on land leased from the Tohono O'odham Tribal Nation. Located about 90-km (56-mi) southwest of Tucson, Arizona, Kitt Peak houses several telescopes, including the 4-m (13-ft) Mayall Telescope and the McMath-Pierce Solar Telescope (1.6 m (5.5 ft)). Kitt Peak also houses the 3.5-m (11-ft) telescope owned and operated by the WIYN Consortium, which consists of the University of Wisconsin, Indiana University, Yale University, and the NOAO.

Screening Criteria Evaluation. The summit area of Kitt Peak is densely developed with structures and access roads. Several possible sites for the Outrigger Telescopes were identified, most of which would require routing the various light paths across roads. Further, given the density of structure in the summit area, location of the Outrigger Telescopes would involve considerable risk of wake-induced turbulence from existing structures, as well as vibration caused by vehicle travel to other facilities. The site most suitable for development is at a slightly lower altitude, to the side of the main developed area, in a local depression. Atmospheric seeing data collected from observatories that occupy premium locations on the mountain could not be relied upon because the data is not likely to be representative of the most amenable site for the Outrigger Telescopes. Considerable risk would be involved in accepting such data without further testing at the site. For this reason this site is being classified with seeing as being "not possible to predict accurately" (0 points).

The average number of nights available for astronomical viewing is estimated at 255 per year (4 points).

Tier 1 Criteria (score = 4 points)

Kitt Peak did not proceed to Tier 2 criteria screening evaluation.

Tier 2 Criteria (no score)

6.2.2.4 Magdalena Ridge, New Mexico

Site Description. Magdalena Ridge, located near Socorro, New Mexico, on land leased by New Mexico Tech, is the site selected for development of the Magdalena Ridge Observatory Interferometer. The site is currently undeveloped except for the Langmuir Lightning Laboratory, an unoccupied balloon hanger, and the Joint Observatory for Comet Research.

Screening Criteria Evaluation. Ample land exists to locate the Outrigger Telescopes at Magdalena Ridge.

Very little atmospheric seeing data exists for this site, and significant risk would be incurred without additional testing. For this reason, the seeing is classified as "not possible to predict accurately" (0 points).

Magdalena Ridge experiences an average of 60 thunderstorms per year. A high percentage of cloud cover at the site means that more than half of the nights during the year would be unsuitable for observing.

Tier 1 Criteria (score = 0 points)

Magdalena Ridge did not proceed to Tier 2 criteria screening evaluation.

Tier 2 Criteria (score = 0 points)

6.2.2.5 Mount Wilson, California

Site Description. Mount Wilson, located in the San Gabriel Mountains overlooking Pasadena, California, is leased from the U.S. Department of Agriculture (USDA) by the Carnegie Institution of Washington and is managed by the Mount Wilson Institute. It houses the 254-centimeter (cm) (100-inch (in)) Hooker Telescope, the 152-cm (60-in) Hale Telescope, the CHARA Interferometer, and the ISI Interferometer, among others. The site has been in use as an astronomical observatory since 1904.

Screening Criteria Evaluation. The observatory is heavily developed, but at least one location has been identified that could accommodate the Outrigger Telescopes.

Atmospheric seeing is estimated to fall in the 1.0 arcsecond category, with periods during the summer better than 1.0 arcseconds. Weather and cloud cover are not issues at this site (4 points).

Tier 1 Criteria (score = 8 points)

Mount Wilson would be reasonably straightforward to develop and is close to Pasadena. Tier 2 Criteria (score = 6 points)

6.2.2.6 Palomar Mountain, California

Site Description. Palomar Mountain, located in northern San Diego County, California, within the Cleveland National Forest, is owned and operated by Caltech and houses the 508-cm (200-in) Hale Telescope, the 102 cm (40-in) Oschin Telescope, and the Palomar Testbed Interferometer. The site has been in use as an astronomical observatory since the mid-1930s.

Screening Criteria Evaluation. Palomar Mountain has ample land to accommodate the Outrigger Telescopes.

Atmospheric seeing is estimated to fall in the range of 1.0 to 1.5 arcseconds (2 points). The site is reported to have 70 percent viewable nights over the year (4 points).

Tier 1 Criteria (score = 6 points)

Palomar Mountain is a straightforward site for implementation. Access is good and two potential locations have been identified for the Outrigger Telescopes. Palomar Mountain is approximately 177 km (110 mi) from JPL.

Tier 2 Criteria (score = 6 points)

6.2.2.7 Summary of Reduced Science Site Scoring

Tables 6-2, 6-3, and 6-4 summarize the final evaluations for the Reduced Science Option sites when filtered through the Tier 1 and 2 criteria.

TABLE 6-2. REDUCED SCIENCE OPTIONS TIER 1 CRITERIA SCORES

Site	Atmospheric Seeing Score	Clear Night Score	Total Tier 1 Criteria Score
Magdalena Ridge	0	0	0
Kitt Peak	0	4	4
Anderson Mesa	2	4	6
Palomar Mountain	2	4	6
Mount Hopkins	4	4	8
Mount Wilson	4	4	8

TABLE 6-3. REDUCED SCIENCE OPTIONS TIER 2 CRITERIA SCORES

Site	Technical Considerations Score	Programmatic Considerations Score	Total Tier 2 Criteria Score
Mount Hopkins	0	0	0
Anderson Mesa	4	0	4
Mount Wilson	4	2	6
Palomar Mountain	4	2	6

TABLE 6-4. REDUCED SCIENCE OPTIONS FINAL SCORES

Site	Tier 1 Criteria Score	Tier 2 Criteria Score	Final Point Score
Kitt Peak	4	---	---
Magdalena Ridge	0	---	---
Mount Hopkins	8	0	8
Anderson Mesa	6	4	10
Palomar Mountain	6	6	12
Mount Wilson	8	6	14

Among the six Reduced Science Options sites evaluated, Mount Wilson is ranked first, followed by Palomar Mountain, Anderson Mesa, and Mount Hopkins. Kitt Peak and Magdalena Ridge were not subjected to Tier 2 criteria because they lacked representative data on atmospheric seeing quality at the site where the Outrigger Telescopes would be placed.

The two sites selected for more detailed study are Mount Wilson and Palomar Mountain, both in California. Sections 6.3 and 6.4 address the on-site construction and installation of the Outrigger Telescopes at Mount Wilson and Palomar Mountain, respectively.

Most of the information in this chapter is extracted from the following documents:

- *Draft Environmental Impact Report for Palomar Mountain Subdivision*
- *A Supplement to the Environmental Impact Report for Palomar Mountain Subdivision*
- *Final Environmental Impact Statement for the Cleveland National Forest*
- *Draft Environmental Assessment for the CHARA Array Mount Wilson California*
- *Draft Southern California Land Management Plan Revisions*
- *SeaWest, Inc. Alternative Site Assessment Phase 1 and 2 Reports.*

6.3 MOUNT WILSON OBSERVATORY

6.3.1 Mount Wilson, California

The Mount Wilson Observatory (MWO) is located in the Angeles National Forest on top of Mount Wilson, northeast of Los Angeles. The site is approximately 38 hectares (ha) (95 acres (ac)). Carnegie Institute of Washington leases the site from the U.S. Department of Agriculture renewed the lease in 2003 for an additional 100 years. The lease "*provides for the land to be used as an astronomical observatory and authorizes the construction of additional structures consistent with this purpose.*"

Figure 6-1 illustrates the proposed layout for the Outrigger Telescopes on Mount Wilson.

6.3.1.1 Proposed Facilities

Telescope Piers and Light Pipes. See Section 2.1.2 for a detailed description of the Outrigger Telescopes facility. Each proposed telescope would be supported by a telescope instrument room acting as a telescope pier. The telescope room would house the mirrors that inject the starlight beams into the light pipes. These light pipes would bring starlight beams into the interferometer beam-combiner room. Depending on the topography of the site and the locations of the telescopes, the light pipes could be above or below grade. Also, depending on the details of the site, the locations of the telescopes, and the optical requirements for the starlight beams to maintain symmetry, light-beam junction boxes may be required to join multiple light pipes or change the direction the light beams.

6.3.1.2 On-site Construction and Installation of the Outrigger Telescopes at Mount Wilson

Schedule. Construction operations at the 1,737-m (5,700-ft) elevation in the San Gabriel Mountains can occur only nine to ten months of the year. Freezing and/or muddy conditions make the mountain roads impassable to large construction and delivery vehicles and the sites more susceptible to erosion and general degradation. Site grading and earthwork activities would require several months to complete; construction for this project would require about 24 months. As a result of both seasonal and unanticipated weather, this probably would require three building periods (spring, summer, and fall) for three consecutive calendar years.

Estimated Excavation. Construction of the Outrigger Telescopes Project would require building pad earthwork and preparation as well as foundation excavations for each of the four telescopes, each of the enclosures, approximately 40 light beam tube support structures, and the beam-combiner facility.

The canyon terrain within the Museum Quadrant site would require a cut-and-fill

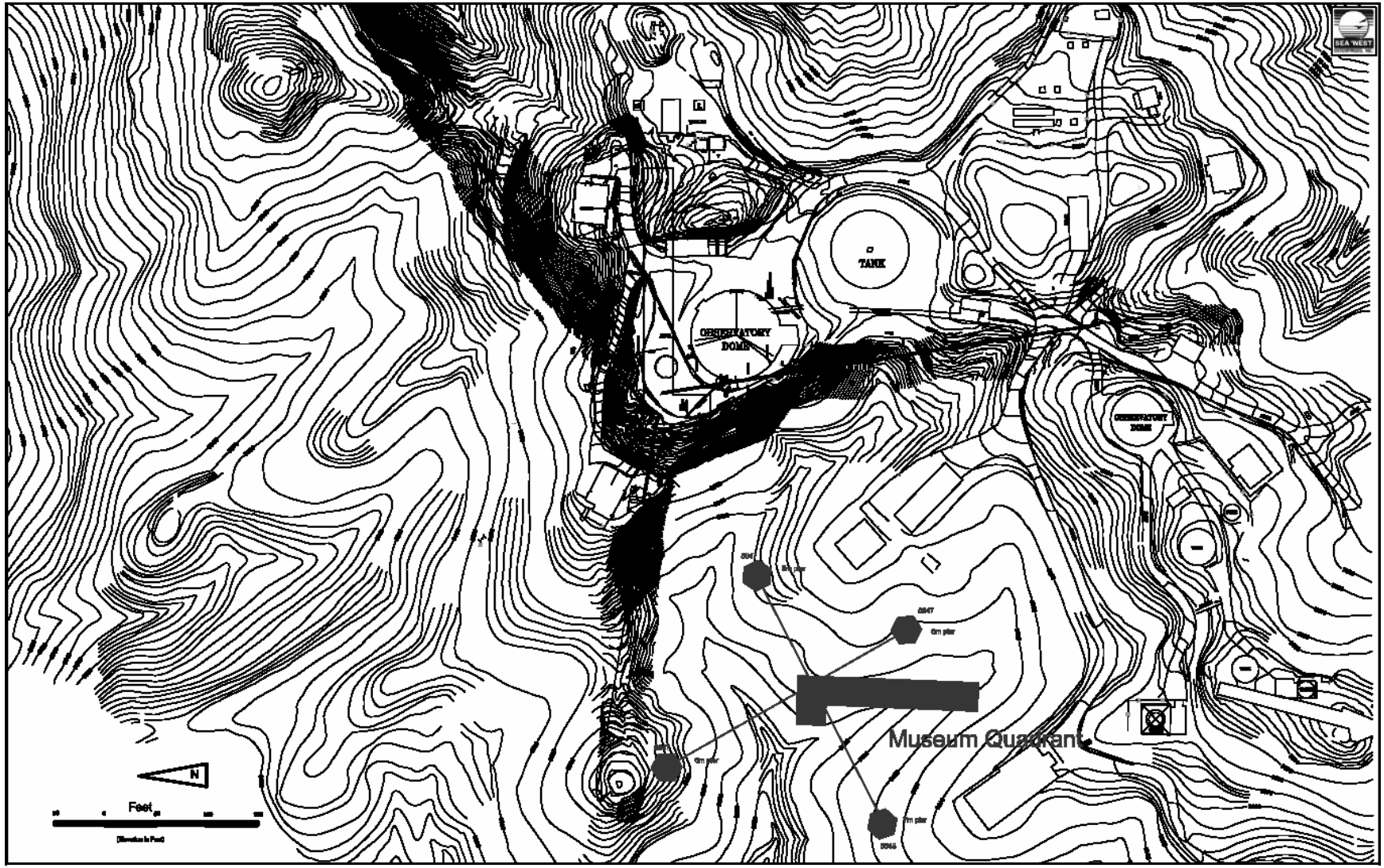

FIGURE 6-1. LAYOUT OF THE OUTRIGGER TELESCOPES AT MOUNT WILSON

operation involving more earthwork than a project of equal square footage on a level site. The pads for the four telescope buildings—approximately 93 square meters (m^2) (1,000 square feet (ft^2))—and the beam-combiner building—approximately 743 m^2 (8,000 ft^2)—would be about 1, 987 cubic meters (m^3) (2,600 cubic yards (yd^3). The Outrigger Telescopes Project would balance the amount of required cut or excavated material and the amount of required backfill to minimize the need to transport soils or aggregate to and from the site.

The foundation systems include the enclosure and combiner buildings, the large mass piers for the telescopes, inertia pads for the delay lines, optics tables, and combiner instrument stands within the combiner facility. The volume of earth excavated for these elements would be about 2,141 m^3 (2,800 yd^3).

The access trail needed to enter the site for construction activities would remain in use for the life of the Outrigger Telescopes Project. As such it would be designed to handle the traffic and loads anticipated as a part of the operations and maintenance of this facility over an extended period of time. Current designs include an access trail of about 244 m (800 ft) beginning west of the project site at a point of connection to the Observatory Road and diverging downslope to the Museum Quadrant site. Additionally, it would be necessary to implement access to each of the four telescope sites. One or more of these locations might be accessible via existing roads and trails within the observatory. All road cuts and fills would be designed so as to minimize the potential for erosion and concentrated runoff. Based on the current design criteria and configurations, it is estimated that approximately 1,070 m^3 (1,400 yd^3) of material would be involved in the excavation and earthwork operation for these access ways.

Grading Plans. The Outrigger Telescopes foundation would be set as close to the existing grade as possible using a balance cut-and-fill method to achieve an elevation for optimal interferometric measurements.

Each of the four telescope enclosures would sit on Mount Wilson between the 1,713 and 1,716 m (5,620 and 5,630 ft) AMSL contour. From a pad at or near this elevation, the piers would be constructed to allow for adjusting the final telescope mount elevations to create a planer array (at an elevation of about 1,721 m (5,647 ft) AMSL).

Foundations and Footings. Developing a four-aperture array within the museum quadrant at the MWO would require the delivery of up to 600 truckloads of concrete, sufficient for building both foundations/slabs interferometer inertia pads and telescope mounts. Delivery of premixed concrete to the observatory site would minimize the on-site water demand.

Installation of Telescopes and Dome Enclosures. The Outrigger Telescopes constructed within the museum quadrant at the MWO under the current design configuration would consist of four 1.8-m (6-ft) telescopes/enclosures arranged around a central combiner facility. The final collective footprint of the four telescope enclosures, light beam foundations, and combiner building would be approximately 1,300 m^2 (14,000 ft^2). The access trail (suitable for light vehicular traffic) would involve a terrain disturbance of approximately an additional 1,115 to 1,394 m^2 (12 to 15,000 ft^2) from the intersection with the existing observatory access road to the array site. The total project site would require approximately 1 ha (2.5 ac) of land to construct the

telescope enclosures, the light-beam paths, access trails, and the beam-combiner building. It is anticipated that the necessary Outrigger Telescopes staging and laydown areas would be located within the 1-ha (2.5-ac) plot. In those cases where deliveries and or staging requirements require off-site holding, it is anticipated that the USFS parking area to the west of the observatory could be used as a temporary staging area.

On-Site Construction Facilities/Equipment. The soil and rock types found within the MWO area consist, for the most part, of a range of soils from decomposed granite soils to chemically weathered granites and granodiorites. Excavation of these types of friable soil may be accomplished using conventional equipment. It is anticipated that all excavations would be completed without blasting or using special hardrock equipment. Rubber mounted backhoes, articulated loaders, track mounted excavators and drill rigs would likely be among the earth removal/moving equipment involved in this type for this earth-removal project. During the earthwork, transport vehicles, including 11,793-kilogram (kg) (26,000-gross pound vehicle weight (GVW)) bobtail trucks and 22.7-metric ton (mt) (25-ton) capacity truck and trailer combination rigs, to would be used for the transport, handling, disposal and delivery of soil and aggregate as required.

On-Site Construction Employment and Costs. The work force for the Outrigger Telescopes Project would vary from an average of 25 to 35 workers to up to 60 workers. Fifteen or fewer workers would be on site during the initial phases of work for site preparation and grading. The limited access, terrain, and staging areas require a project schedule that relies on consecutive rather than concurrent execution of activities. Throughout the concrete/foundation portions of the project and into the rough construction of the buildings and enclosures, the crew size will be restricted by the limited space for staging equipment and delivering material. Once the building "shells" are complete, it is possible that additional specialty contractors and technicians would increase the size of the project crew to 50 to 60 individuals for a short time. Final installation of building both facilities and telescope/delay line systems would require a smaller, focused effort and a substantially reduced project crew.

Construction Management. It is assumed that the contractor would follow an approved construction Best Management Practices Plan (BMP) during all on-site construction and installation activities and that the final BMP would be incorporated into the construction contract.

Construction Traffic. During construction of the Outrigger Telescope Project, it is anticipated that the average daily construction related vehicular trips (average daily trips (ADT)) may vary from 50 to 75 (work force size and equipment/material delivery dependent). At peak periods of activity the ADT could reasonably exceed 100 vehicles. This traffic volume would be much lighter than the 730 ADT for Red Box Road (the final 8 km (5 mi) of access way to the site) and the 3,400 ADT for the intersection of Highway 2 and Angeles Forest Highway to the high desert communities to the north.

It is anticipated that most of the construction work would occur during the dry months when road conditions are best. Most of the traffic to the site would occur before 7:00 a.m. during weekdays, before the start of commuter traffic from the Mojave Desert communities into Los Angeles. Traffic leaving the site would

likely peak around 3:30 p.m., before the start of return commuter traffic. Commuter traffic along this highway would primarily flow in the opposite direction from construction vehicle traffic.

6.3.1.3 Operations of the Outrigger Telescopes at Mount Wilson

Employment and Economics. The current daily operational workforce level at the MWO averages from 12 to 14 individuals, including technicians, science team members, and facilities staff.

The Outrigger Telescopes would be both locally and remotely operated during its multiyear science mission. The primary on-site activities require a staff of trained individuals—a mechanical engineer, electrical engineer, optics specialist, software specialist, two technicians, and a supervisor. The resident science team would include two or three individuals, depending on the activity and programs underway. Based on current plans, the average workforce would be six staff per day.

Traffic. According to ADT counts conducted by the California Department of Transportation in 2002, current traffic along the Red Box Road access to the MWO is approximately 730 vehicles. The operation of the Outrigger Telescopes at the MWO would be expected to add 6 to 12 vehicular trips from the LA basin to this road and Highway 2.

Infrastructure and Utilities. All utilities, including water, power, communications, and sewage facilities, would be provided from existing Mount Wilson infrastructure.

Southern California Edison (SCE) currently supplies 14,000 kilowatts of electrical power to Mount Wilson, with a considerable portion of that wattage going to the neighboring broadcast antennae group. SCE is *attempting* to implement a three-phase plan beginning in 2004, to improve electrical service on the mountain.

The observatory has a fiber optic network within its boundaries linking many of its facilities; however, the telecommunications network beyond its periphery is limited to copper wire.

Maintenance. The ramp-up phase of the Outrigger Telescopes Project would primarily involve commissioning the interferometer. The staff would focus on calibration and integration activities associated with the telescopes: pointing and tracking tests, encoding enclosure domes, and generally establishing control systems to coordinate the simultaneous operation of the four telescopes, their domes, and the delay line systems. In parallel with these efforts, the staff would align delay line, meteorology, and beam-combiner systems in the main building. These activities require the collaborative participation of engineers and scientists to achieve "first light." Once the staff has completed initial testing and calibration of the interferometer, they would refine the instrumentation with further calibration and troubleshooting, possibly incorporating spectrographs, CCD cameras, and infrared equipment into the Outrigger Telescopes.

These activities would require personnel to move between the control room, combiner facility, and individual telescope locations to conduct necessary installations and testing. These activities would not require the use of heavy equipment or generate noise above normal levels associated with pedestrian traffic at the site and occasional vehicular arrivals and departures from the mountain. Once the ramp-up is completed, the level of activity around each telescope site and within the delay line/beam-combiner facility would decrease sharply because the interferometer would be

operated by a high-speed data connection, from a remote site.

During the lifetime of the Outrigger Telescopes, ongoing activities would include scheduled equipment and facility maintenance, re-instrumentation and calibration, periodic optics recoating activities, and system monitoring.

During the operation of the Outrigger Telescopes, lubricants and mirror-care chemicals would be the only frequently used hazardous materials. No airborne pollutants would be associated with the operation of an optical interferometer.

6.3.2 Affected Environment of Mount Wilson

This section describes the existing environment in and around Mount Wilson and serves as a baseline from which to identify and evaluate environmental impacts of activities associated with the Reduced Science Options.

6.3.2.1 Land Use and Existing Activities

Land Use. Mount Wilson Institute (MWI) operates the Observatory, under agreement with the Carnegie Institution of Washington, since 1986. MWI's mission *"focuses on scientific research, historic preservation, astronomical education and public outreach"* (Mount Wilson 2003f).

The USFS Dark Sky Observations guidelines, as established in the 1987 Land Management Plan (Forest Plan), require sensitivity to light pollution, and mitigation of new lighting sources and electronic interference around existing observatories; coordination with an affected observatory regarding any planned activity that generates dust or smoke; and preparation of an environmental assessment before adding night skiing activities.

Construction of new facilities and infrastructure are subject to review and inspection by the County of Los Angeles Department of Public Works as part of the USFS-adopted approval process.

Existing Activities. The MWO complex includes the following major facilities for astronomy and astrophysical research: a 254-cm (100-in) telescope; a 152-cm (60-in) telescope; a 46-m (150-ft) solar tower; the Snow solar telescope; a 61-cm (24-in) telescope; a 18-m (60-ft) solar tower; the University of California Berkeley Interferometer; and the U.S. Naval Research Interferometer.

Lodging accommodations and support facilities available within the lease boundary include:

- Astronomical Museum
- Michelson 6-m (20-ft) Stellar Interferometer (display)
- Eleven residences
- The 14-room Monastery dorm
- Galley and restroom
- Vehicular storage and maintenance garage(s)
- Machine shop(s) and woodworking/ storage areas
- 151-kl (40,000-gal) potable water storage tank
- 1,900-kl (500,000-gal) fire suppression water tank.

The current MWO daily operational workforce averages from 12 to 14 individuals, including technicians, science team members, and facilities staff (SeaWest, Inc. 2004b).

The MWO hosts public tours and attracts tourists during the summer and for special

events. The MWO is frequented by hikers, backpackers, and mountain bikers over the network of primitive forest trails that traverse the mountains. This area of the Angeles National Forest is also a popular film/camera location for both amateurs and major film companies. The Angeles National Forest offers additional opportunities for recreational users and tourists, including hiking, camping, fishing, picnicking, hunting and target shooting, and off-highway vehicle use.

The village of Mount Wilson, California, the site of several television and radio antennas that broadcast to the entire Los Angeles Basin, is located near the WMO.

6.3.2.2 Cultural Resources

Resource Definition. See Section 3.1.2.1 for cultural resource definitions.

Cultural Environment. The two cultural resources within an 0.8-km (0.5-mi) radius of the project area are: (1) remnants of the Mount Wilson Toll Road, and (2) remains of the Steil's/Martin's amp (NSF 1996).

"The Mount Wilson Toll Road played a crucial part in the Observatory's construction and early days, functioning as the main connecting road to the Observatory until the completion of the Angeles Crest Highway. Currently, the road is a fairly well maintained dirt road leading from the base of Mount Wilson (in the community of Altadena) to the radio towers at the crest and is still used by hikers and mountain bikers. There are seven sections of retaining wall south of Mount Wilson that appear to date to the road's original construction in 1907" (NSF 1996).

"Steil's/Martin's Camp originally consisted of a number structures and tents to provide accommodations for travelers/campers; however the site has been greatly disturbed and now only consists of several pads where the structures once stood" (NSF 1996).

A reconnaissance survey conducted in 1998 on the observatory grounds found no archaeological sites within the Mount Wilson ridge top system. However, on the basis of the geographical setting, water sources, plant, and animals that exist in the area, this report concluded that it probably contains prehistoric sites. It further stated that historic uses and Observatory construction had greatly altered the mountain surface. Any prehistoric cultural resources would have been destroyed, altered, or buried.

6.3.2.3 Biological Resources and Threatened and Endangered Species

Biological resources include the native and introduced plants and animals within the area potentially affected by the proposed activity.

Biological Resources. Mount Wilson is dominated by canyon live oak and sections of coniferous forest separated by shrubs and small clearings. The coniferous forest evergreens include primarily Coulter pine, Ponderosa pine, and big cone Douglas fir. The forest floor is generally covered with a duff of fallen and decomposing leaves with little or no vegetation except for some small grasses and herbs.

The Observatory area shrubs include scrub oak and Manzanita chaparral, deer brush, California buckwheat, Our Lord's Candle, and Spanish broom. Herbs and grasses in the area include beardtounge, California milkweed, eriastrum, and lupine. Three small flowering plants—the Rock Creek broomrape (*Orobanche valida* ssp. *valida*), Peirson's spring beauty (*Claytonia lanceolata*), and the Laguna Mountains

jewel flower (*Streptanthus bernardinus*.)—are listed as sensitive and may potentially be found within the lease parcel, although they have never been documented in the Observatory area.

A variety of wildlife can be found in the Observatory area and throughout the Angeles National Forest, including mountain lion, black bear, mule deer, coyote, western gray squirrel, brush rabbit, lodgepole chipmunk, Merrian's chipmunk, badger, skunk, raccoon, pocket gopher, longtailed gopher, broadfooted mole, and various other rodents.

The Observatory area is also home to the following amphibians and reptiles and can be found in the Angeles National Park include but are not limited to the California newt, Monterey ensatina, black bellied slender salamander, Pacific slender salamander, arboreal salamander, sagebrush lizard, western fence lizard, western whiptail, gilberts and western skinks, and the southern alligator lizard.

Various snakes are also found in the area: common and California king snakes western and speckled rattlesnake, gopher snake, common garter snake, and night snake. The San Diego horned lizard is a Category 2 Federally protected reptile that potentially could inhabit the Observatory area, although there were no sightings of the lizard at or near the Observatory area during the CHARA Environmental Assessment biological survey (NSF 1996).

The northern spotted owl is prevalent throughout mountainous regions of western North America. At Mount Wilson, it potentially may nest in lower elevation canyons and forage in the Observatory area; however, to date, its presence at or near the Observatory has not been documented. The most recent biological survey evaluations for the MWO, including the Biological Evaluation for the Infrared Spatial Interferometer and for the Abbot Solar Tower site, did not identify any Federally listed or endangered species within the boundaries of the MWO (NSF 1996).

Bird species that have been observed or are expected to be present are listed in Table 6-5.

Threatened and Endangered Species. In 2003, Northrop Grumman conducted a biological evaluation/assessment of an area within the MWO complex. Table 6-6 identifies those threatened, endangered, or sensitive species that may occur in Angeles National Forest. A survey completed in 2003 found no threatened, endangered, or sensitive species on or near the MWO complex (Northrop Grumman 2003).

6.3.2.4 Hydrology, Water Quality, and Wastewater

Regulatory Framework. The State Water Resources Control Board (SWRCB) and the Regional Water Quality Control Board (RWQCB) administer the CWA and State water regulations in California. The Los Angeles RWQCB is the local agency responsible for the Mt. Wilson Observatory area. The RWQCB is responsible for management of the NPDES permits process for California. State regulations require a Waste Discharge Requirement (WDR) for permitting discharge. A Report of Waste Discharge (RWD) is required for actions that would involve discharge of waste to surface and/or groundwater. The California Porter-Cologne Water Quality Act implements the NPDES program for the State (USAF 1998).

Surface Water. Water runoff in the San Gabriel Mountains is rapid, and most of the streams are dry through the summer.

TABLE 6-5. BIRD SPECIES OBSERVED OR EXPECTED TO OCCUR ON MOUNT WILSON, CALIFORNIA

Scientific Name [1]	Common Name
Cathartes aura	Turkey Vulture
Haliaeetus leucocephalus	Bald Eagle
Accipiter striatus	Sharp-shinned Hawk
Accipiter cooperii	Cooper's Hawk
Buteo jamaicensis	Red-tailed Hawk
Aquila chrysaetos	Golden Eagle
Falco sparverius	American Kestrel
Falco columbarius	Merlin
Oreortyx pictus	Mountain Quail
Zenaida macroura	Mourning Dove
Columba fasciata	Band-Tailed Pigeon
Bubo virginianus	Great Horned Owl
Strix occidentalis	Spotted Owl
Otus flammeolus	Flammulated Owl
Glaucidum gnoma	Northern Pygmy Owl
Aegolius acadicus	Northern Saw-Whet Owl
Phalaenoptilus nuttallii	Common Poorwhill
Caprimulgus vociferous	Whip-Poor-Will
Chaetura vauxi	Vaux's Swift
Aeronautes saxatalis	White-throated Swift
Cypseloides niger	Black Swift
Calypte anna	Anna's Hummingbird
Selasphorus rufus	Rufous Hummingbird
Melanerpes formicivorus	Acorn Woodpecker
Sphyrapicus rubber	Red-breasted Sapsucker
Sphyrapicus thyroideus	Williamson's Sapsucker
Picoides albolarvatus	White-Headed Woodpecker
Picoides nuttallii	Nuttall's Woodpecker
Colaptes auratus	Northern Flicker
Melanerpes lewis	Lewis Woodpecker
Picoides villosus	Hairy Woodpecker

TABLE 6-5. BIRD SPECIES OBSERVED OR EXPECTED TO OCCUR ON MOUNT WILSON, CALIFORNIA (CONTINUED)

Scientific Name [1]	Common Name
Contopus borealis	Olive-sided Flycatcher
Contopus sordidulus	Western Wood-Pewee
Empidonax hammondii	Hammond's Flycatcher
Empidonax oberholseri	Dusky Flycatcher
Empidonax wrightii	Gray Flycatcher
Myiarchus cinerascens	Ash-throated Flycatcher
Tachycineta thalassina	Violet-green Swallow
Stelgidopteryx serripennis	Northern Rough-winged Swallow
Hirundo pyrrhonota	Cliff Swallow
Aphelocoma coerulescens	Scrub Jay
Cyanocitta stelleri	Stellar's Jay
Corvus brachyrhynchos	American Crow
Corvus corax	Common Raven
Parus inornatus	Plain Titmouse
Parus gambeli	Mountain Chickadee
Sitta Canadensis	Red-Breasted Nuthatch
Sitta carolinensis	White-Breasted Nuthatch
Sitta pygmaea	Pygmy Nuthatch
Certhia Americana	Brown Creeper
Regulus satrapa	Golden-Crowned Kinglet
Regulus calendula	Ruby-crowned Kinglet
Myadestes twonsendi	Townsend's Solitaire
Sialia mexicana	Western Bluebird
Sialia currucoides	Mountain Bluebird
Catharus guttatus	Hermit Thrush
Turdus migratorius	American Robin
Vireo solitarius	Solitary Vireo

TABLE 6-5. BIRD SPECIES OBSERVED OR EXPECTED TO OCCUR ON MOUNT WILSON, CALIFORNIA (CONTINUED)

Scientific Name [1]	Common Name
Vermivora ruficapilla	Nashville Warbler
Dendrocia coronata	Yellow-rumped Warble
Dendrocia occidentalis	Hermit Warbler
Geothylypic tolmiei	MacGillivray's Warbler
Piranga ludoviciana	Western Tanager
Pheucticus melanocephalus	Black-headed Grosbeak
Pipilo chlorurus	Green-tailed Towhee
Spizella passerina	Chipping Sparrow
Chondestes grammacus	Lark Sparrow
Paserella iliaca	Fox Sparrow
Junco hyemalis	Dark-eyed Junco
Molothrus ater	Brown-headed Cowbird
Carduelis pinus	Pine Siskin
Carduelis psaltria	Lesser Goldfinch
Carduelis lawrencei	Lawrence's Goldfinch
Carpodacus purpureus	Purple Finch
Carpodacus purpureus	Cassin's Finch
Loxia curvirostra	Red Crossbill

[1] Nomenclature follows American Ornithologists' Union. 1983. Checklist of North American Birds. 6th ed. American Ornithologists' Union, Baltimore, MD and American Ornithologists' Union. 1985. Thirty-fifth supplement to the American Ornithologists' Union Checklist of North American Birds. Auk 102:680-686.

The Observatory is not located on a 100-year flood plain, nor are there any wild and scenic rivers at or near the Observatory.

Groundwater in the Mount Wilson Area. There are no designated sole-source aquifers at or near the proposed site. The closest sole-source aquifers are the Campo/Cottonwood Creek Aquifer located near the San Diego/Mexico border and the Fresno County Aquifer to the north.

Domestic Wastewater Collection, Treatment, and Disposal. On the mountain wastewater/effluent is treated through septic tank/leach field systems. In this system, waste flows into a septic tank where bacteria break down much of the solid components into a liquid form. The produced liquid is gradually displaced from the septic tank and flows to a leach field where it percolates into the mountain soil. As the liquid percolates, the soil filters out the biological components from the liquid and eventually only water and minor dissolve components remain. This water commingles with other groundwater and is available to wells further down-slope.

Mount Wilson uses about 16.6 kl (4,400 gal) of water per week, and it is assumed that the resulting wastewater is disposed of through the septic system.

TABLE 6-6. FEDERALLY THREATENED, ENDANGERED OR SENSITVE SPECIES KNOWN IN THE ANGELES NATIONAL FOREST

Scientific Name	Common Name	Likelihood of Occurrences
Plants		
Astragalus brauntonii	Braunton's milk-vetch	Unlikely to occur
Berberis nevinii	Nevin's barberry	Unlikely to occur
Dodecohema leptoceras	Slender-horned spineflower	Unlikely to occur
Rorippa gambellii	Gambel's watercress	Unlikely to occur
Birds		
Empidonax traillii extimus	Southwestern willow flycatcher	Unlikely to occur
Amphibians		
Bufo microscaphus californicus	Arroyo southwestern toad	Possible occurence
Federally Listed Threatened Species		
Plants		
Brodiaea filifolia	Thread-leaved brodiaea	Unlikely to occur
Birds		
Haliaeetus leucocephalus	Bald Eagle	**Unlikely to occur**
Amphibians		
Rana aurora draytoni	California red-legged frog	**Unlikely to occur**
U.S. Forest Service Sensitive and Watch List Species		
Plants		
Arenaria macradenia var. kuschei	Forest Camp sandwort	Unlikely to occur
Astragalus bicristatus	Crested milk-vetch	Unlikely to occur
Astragalus lentiginosus var. antonius	San Antonio milk-vetch	Unlikely to occur
Calochortus striatus	Alkali mariposa lily	Unlikely to occur
Calochortus palmeri var palmeri	Palmer's mariposa lily	Unlikely to occur
Calochortus plummerae	Plummer's mariposa lily	Unlikely to occur
Canbya candida	Pygmy poppy	Unlikely to occur
Castilleja gleasonii	Mount Gleason Indian Paintbrush	Unlikely to occur
Claytonia lanceolata var. peirsonii	Peirson's spring beauty	Unlikely to occur
Eriogonum kennedyi var. alpigenus	Southern alpine buckwheat	Unlikely to occur
Eriogonum microthecum var. johnstonii	Johnston's buckwheat	Unlikely to occur
Frasera neglecta	Pine swertia	Unlikely to occur
Galium grande	San Gabriel bedstraw	Unlikely to occur
Lilium parryi	Lemon lilly	Unlikely to occur
Linanthus concinnus	San Gabriel linanthus	Unlikely to occur

TABLE 6-6. FEDERALLY THREATENED, ENDANGERED OR SENSITVE SPECIES KNOWN IN THE ANGELES NATIONAL FOREST (CONTINUED)

Scientific Name	Common Name	Likelihood of Occurrences
Monardella macrantha ssp. Hallii	Hall's monardella	Unlikely to occur
Monardella viridis ssp. Saxicola	Rock monardella	Unlikely to occur
Opuntia basilaris var. brachyclada	Short-joint beavertail cactus	Unlikely to occur
Oorbanche valida ssp. Valida	Rock Creek broomrape	Unlikely to occur
Birds		
Accipiter gentiles	Northern goshawk	Unlikely to occur
Buteo swainsonii	Swainson's hawk	Unlikely to occur
Strix occidentalis ssp. Occidentalis	California spotted owl	Possible occurence
Reptiles		
Lichanura trivargata ssp. Roseofusca	Coastal rosy boa	Possible occurrence
Phrynosoma coronatus blainvillii	San Diego Horned Lizard	Possible occurrence
Mammals		
Perognathus alticola ssp. inexpectatus	Tehachapi pocket mouse	Unlikely to occur
Perognathus alticola ssp. alticolo	White-eared pocket mouse	Unlikely to occur

Source: Northrop Grumman 2003

6.3.2.5 Waste and Hazardous Materials Management

Potentially hazardous materials stored on the Observatory grounds include:

- Fifteen 1,900-kl (500-gal) propane tanks
- One oxygen/acetylene torch stored in the main observatory
- Carbon dioxide and helium gas canisters stored in the optical path building
- 11 l (3 gal) of paint stored in the machine shop
- Motor oil and hydraulic fluid stored in the machine shop
- Two 19-l (5-gal) gasoline cans stored in the carpenter shop
- Two 160-l (42-gal) liquid nitrogen tanks
- Two 208-l (55-gal) drums (one containing gasoline, one containing diesel fuel) stored in the tractor shed
- About 950-ml (1-qt) hydrochloric acid stored in the machine shop

The MWO recoats telescope optics on site. The facility has the capacity to handle all mirrors up to and including the large 254-cm (100 in) primary mirror for the Hooker Telescope. The process involves the acid etch removal of old reflective coatings and re-application of a molecular aluminum coating in a vacuum chamber. HCl is brought to the Observatory grounds as needed for mirror treatment.

Solid waste (i.e., trash) is stored in two dumpsters that are emptied once a week by a contractor. Waste oil is stored in a 208-l (55-gal) drum on site and is taken down the mountain once a year to be recycled. The acid solution used for mirror coating removal is neutralized with lime or

powered calcium carbonate and water prior to disposal.

The Mt. Wilson Observatory has an emergency action plan, which includes contact numbers for emergency situations. The Observatory staff is trained and drilled annually in first aid.

6.3.2.6 Geology, Soils, and Slope Stability

MWO is located in the San Gabriel Mountains within the Transverse Range Province. This range extends from the Santa Monica Mountains and offshore Channel Islands to the west through the San Bernardino Mountains to Yucca Valley in the east. Most of these mountains consist of Mesozoic granitic rock and pre-Cambrian anorthosite with some pre-Cretaceous shist. A majority of the Mount Wilson area consists of metamorphosed and weathered granodiorite.

The primary geomorphic processes are mass wasting and fluvial erosion. The Mount Wilson summit bedrock is overlain with decomposing coarse-sand size granitic soils. The depth of these in-place weathered soils varies from a few inches to several tens of feet. In most locations, contact between the surficial soils and the quartz diorite bedrock is gradational over several feet. Soils are mostly lithic and shallow Typic Xerorthents, shallow Entic Haploxerolls; and Calcic Haploxerolls, most of the soils are leached free of carbonates. The soils are well drained. Soil temperatures are mostly thermic, with some mesic on north-facing slopes at higher elevations. Soil moistures are xeric (Miles and Goudey 1997a).

The flanks of the MWO are steeply sloped; eroding rock faces to the northeast, east, and southeast. Along the northwest and southwest perimeters, the mountain supports substantial growths of live oak and scrub oak on slopes less steeply inclined and able to retain suitable soil profiles. Access to the site is via the roadway to the west that winds up to the mountain along the steep flanks of the north face before crossing to the top of the north-south trending ridge where the observatory sits.

6.3.2.7 Geologic Hazards

Seismic Activity. Earthquakes are a major hazard in California. See Section 3.1.7 for general information about earthquakes.

Although steep terrain and weathered rock outcrops characterize the area, it is stable geologically. The tectonically active San Andreas fault zone is to the north; Mount Wilson is located in Seismic Risk Zone 4, which corresponds to intensity VIII on the Modified Mercalli Scale (MM Scale) (NSF 1996). The Observatory site is not on top of any known fault or located within an Alquist-Priolo Earthquake Fault Zone. The closest mapped fault, the Lowe fault zone, is approximately 2.4 km (1.5 mi) from the site (Tsai and Carnegie 2001).

6.3.2.8 Transportation

Access to the Observatory is via Angeles Crest Highway (SR-2), designated as a Scenic State Highway, to Mount Wilson Road, which ends on the Mount Wilson plateau and serves the Electronics Site and the MWO. Existing traffic volumes on Mount Wilson Road are very light. Access to the Mount Wilson plateau is controlled; visiting hours are limited. Vehicular traffic from the plateau to the MWO complex is further limited and controlled. Visitor parking is provided on the plateau, about one-half mile west of the MWO. Parking within the MWO complex is provided only for MWO staff.

The ADT for traffic on the main roads connecting the MWO to the greater Los Angeles area are:

- On Interstate 210 at the East SR-2 exit, the 2002 ADT was 115,000 vehicles.
  I-210 is a major highway that skirts the southern edge of the San Gabriel Mountains connecting Sylmar (in the northern San Fernando Valley) to I-15 in San Bernardino and carries a large volume of commuter and freight traffic.
- On SR-2 at the I-210 junction, the 2002 ADT was 15,700 vehicles.
- At the SR-2 and Angeles Forest Highway junction, the 2002 ADT was 3,400. Many residents of the Palmdale/Lancaster area (approximately 64 km (40 mi)) north of Mount Wilson) use the Angeles Forest Highway and SR-2 as an alternative to commute to the greater Los Angeles area.
- At the SR-2 and Mount Wilson Red Box Road junction, the 2002 ADT was 730 vehicles.

6.3.2.9 Utilities and Services

Water Supply. The MWO has its own wells for water supply. Three water tanks are located within the observatory site—1,892-kl (500,000-gal), 625-kl (165,000-gal) and 151-kl (40,000-gal) capacity tanks. The 1,892-kl (500,000-gal) water tank is stored on site for fire suppression and is located southeast of the 254-cm (100-in) telescope (SeaWest, Inc. 2004a).

Estimated water consumption for the mountain is 4.2 kl (1,100 gal) per day (SeaWest, Inc. 2004b). The MWO is totally dependent on the limited local groundwater resource for its water supply. The current potable water supply network, including source wells, storage tanks, and distribution systems, need renovation and repair (SeaWest, Inc. 2004b).

Electrical Power and Communications. SCE supplies the 14,000 kilowatts (kW) of power available on Mount Wilson, much of which is used by the neighboring Electronics site that broadcasts television and radio to the Los Angeles Basin. At this time, the capacity of the existing extended power grid from the foot of the mountain to the MWO, and adjacent broadcast facilities sites, is near, (or over), capacity (SeaWest, Inc. 2004a).

SCE is attempting to implement a three-phase plan to improve the electrical service on the mountain beginning the first phase this year. However, no schedules, timelines, or project start dates have been set as of this date. The plan would be subject to USFS approval (SeaWest, Inc. 2004a and 2004b).

Current telecommunication uses copper wire. Fiber optic connectivity is available approximately 1.6-km (1-mi) west of the site within the Electronics site. The MWO has a fiber network within its boundaries that links many of the existing facilities (SeaWest, Inc. 2004a).

Emergency Services and Fire Suppression

Emergency Services. An updated Emergency Services plan is available at the MWO.

Because Mount Wilson has no emergency medical facilities and the MWO is isolated and many miles from the nearest emergency medical service (EMS), the employees at the Observatory have the primary responsibility for first aid assistance. 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 available equipment. In addition, the plan recommends that each facility should establish regular first aid drills and test emergency and safety equipment.

The hospital nearest the Observatory is the Verdugo Hills Hospital in Glendale, approximately 31 km (19.5 mi) away. The Los Angeles County Sheriff's Department provides law enforcement through its Crescenta Valley Station. This station also is responsible for the communities of La Cañada Flintridge, La Crescenta, Montrose, Lake View Terrace, and much of the Angeles National Forest.

Fire Suppression. The MWO fire suppression equipment consists of widely available handheld fire extinguishers, dry chemical (A-B-C) types. Personnel are trained in their use. In addition, a 1,892-kl (500,000-gal) water tank, located southeast of the 254-cm (100-in) telescope, is stored on site for fire suppression (SeaWest, Inc. 2004a).

In addition, the USFS provides fire protection for the Mount Wilson area and the Angeles National Forest (NSF 1996).

6.3.2.10 Socioeconomics

The total population of Los Angeles County as of 2003 was 10,047,300 in a land area of 10,578 m^2 (4,084 mi^2) (including the Santa Catalina and San Clemente Islands). Demographics from 2000 data show the median household income in the county is $52,100 and the unemployment rate is 5.4 percent.

The closest community to Mount Wilson is the town of La Cañada Flintridge, approximately 31 km (19 mi) to the west/southwest of the Observatory. For the year 2000, La Cañada Flintridge had a population of 20,318, a median household income of $109,989, and an unemployment rate of 1.9 percent. There are no mountain communities in the near vicinity of the MWO. Mount Wilson has no public amenities—restaurants, stores, gas stations, or lodgings.

6.3.2.11 Climate/Meteorology/Air Quality

Climate/Meteorology. The MWO, located at 1,742 m (5,715 ft) above sea level, has a mean annual precipitation (mostly rain) of approximately 51 to 76 cm (20 to 30 in). The mean annual temperature varies between 7° and 16° C (45° and 60° F). The mean freeze-free period is approximately 200 to 275 days. Wind patterns run predominantly from west-southwest, especially in the spring through mid-fall.

Air Quality. Air quality at Mount Wilson is regulated by 40 CFR 50 (National Ambient Air Quality Standards (NAAQS)), 40 CFR 51 (Implementation Plans), 40 CFR 61 and 63 (National Emission Standards for Hazardous Air Pollutants (NESHAP)), and 40 CFR 70 (Operating Permits). Table 6-7 compares Federal and California regulatory standards.

Regulations. See Section 3.1.11.2 for an explanation of air standards. Table 6-8 compares the South Coast Air Basin (SCAB) air quality concentrations to the NAAQS and the California State Ambient Air Quality Standards (CAAQS) (PCR 2002).

Air Quality Monitoring. Air quality in California is assessed on a county and regional basis. The San Gabriel Wilderness Area, a Class I Air Quality area under the Federal Clean Air Act, is approximately 4 km (2.5 mi) northwest of the Observatory. The closest sources of air pollutants are Scenic Highway 2–(Angeles Crest Highway) located approximately 4.8 km (3

TABLE 6-7. NATIONAL AND CALIFORNIA AMBIENT AIR QUALITY STANDARDS[ab]

Pollutant	Averaging Time	California Standards	NAAQS	
			Primary[a]	Secondary[b]
Ozone	8 Hour	No Standard	157 µg/m3 (0.08 ppm)	No Standard
	1 Hour	180 (0.09 ppm)	235 µg/ m3 (0.12 ppm)	No Standard
Carbon Monoxide	8 Hour	10 mg/m³ (9.0 ppm)	10 mg/m³ (9.0 ppm)	No Standard
	1 Hour	23 mg/m³ (5.1 ppm)	40 mg/m³ (35 ppm)	No Standard
Nitrogen Dioxide	Annual (Arithmetic Mean)	No Standard	100 µg/m³ (0.05 ppm)	Same as Primary
Sulfur Dioxide	Annual Average	No Standard	80 µg/m³ (0.03 ppm)	No Standard
	24 Hour	105 µg/m³ (0.04 ppm)	365 µg/m³ (0.14 ppm)	No Standard
	3 Hour	No Standard	No Standard	1,300 µg/m³ (0.5 ppm)
	1 Hour	655 ug/m³ (0.25 ppm)	No Standard	No Standard
Particulate Matter (PM_{10})[c]	Annual (Arithmetic Mean)	30 µg/m³	50 µg/m³	Same as Primary
	24 Hour	50 µg/m³	150 µg/m³	Same as Primary
Particulate Matter ($PM_{2.5}$)[c]	Annual	12 µg/m³	15 µg/m³	No Standard
	24 Hour	No Standard	65 µg/m³	No Standard
Lead	Calendar Quarter	1.5 µg/m³	1.5 µg/m³	Same as Primary
Hydrogen Sulfide	1 Hour	42 µg/m³ (30 ppb)	No Standard	No Standard

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

b. Designated to protect public welfare.

c. PM_{10} refers to particulate matter sized 10 microns or less. $PM_{2.5}$ refers to particulate matter sized 2.5 microns or less.

mi) north of the Observatory lease land; lower elevation campgrounds located within 3 km (2 mi) of the Observatory lease land; and the greater Los Angeles urban area which starts approximately 6.4 km (4 mi) south of the Observatory lease land. Located in the SCAB, the Los Angeles urban area is a Class II Air Quality area under the Federal Clean Air Act.

Air quality in the SCAB is generally very poor and is one of the most heavily impacted in the nation. However, the Observatory lease land is located in a high-

TABLE 6-8. MAXIMUM CRITERIA POLLUTANT CONCENTRATIONS IN LOS ANGELES COUNTY, CALIFORNIA

Pollutant Averaging Time	State Standard	Federal Standard	Maximum Concentrations			
			ppm/µg/m^3	% State Standard	% Federal Standard	Location
Ozone 1-Hour 8-Hour	> 0.09 ppm	> 0.12 ppm > 0.08 ppm	0.06 0.055	60%	48% 65%	Several Locations Banning Airport
Carbon Monoxide 8-Hour	> 9.0 ppm	> 9.0 ppm	8.40	92%	88%	South Central Los Angeles County
Nitrogen Dioxide 1-Hour 24-Hour	> 0.25 ppm		0.10 0.069	38%		Southwest Coastal Los Angeles County South San Gabriel Valley
Sulfur Dioxide 1-Hour 24-Hour	> 0.25 ppm > 0.04 ppm	> 0.14 ppm	0.02 0.010	8% 24%	7%	South Coastal Los Angeles County North Coastal Orange County
Particulate (PM10) 24-Hour	> 50 µg/m^3	> 150 µg/m^3	95	186%	63%	Metropolitan Riverside County
Particulate (PM 2.5) 24-Hour		> 65 µg/m^3	55.4		85%	South Coastal Los Angeles County
Sulfates 24-Hour	>=25 µg/m^3		4.7	19%		South Central Los Angeles County
Lead[a] 30-Day 30-Day[a]	>=1.5 µg/m^3		0.03 0.19	2% 13%		Central Los Angeles Several Locations

Source: SCAQMD 2003

a. Maximum monthly average concentration recorded at special monitoring sites in the immediate vicinity of major lead sources.

elevation rural area of the SCAB, and air quality at this elevation is generally expected to be better than in the nearby urban areas.

6.3.2.12 Noise

The MWO is located in an isolated, rural area with moderate daytime traffic and very light nighttime traffic. The major noise sources within the Observatory site are occasional motor vehicles traveling at low speeds, human conversations, animal sounds and occasional aircraft ascending out of the Los Angeles Basin on eastbound and northbound flight tracks. On-site mechanical noise includes heating and ventilation equipment, vacuum pumps, and small electric motors used to actuate the astronomy domes and telescopes.

The prevailing noise environment is not pristine due to the current development and level of activity on the Observatory grounds. The presence of a significant number of broadcast facilities within one-half mile of the site creates an environment outside the Observatory area with a significantly higher background noise level than that directly on site. Background noise levels within rural areas such as the

Observatory typically range between 35 and 45 A-weighted decibels (dBA).

6.3.2.13 Visual/Aesthetics

MWO sits at an elevation of 1,742 m (5,715 ft) above sea level, along the southern flank of the San Gabriel Mountains. The southern boundary of the Observatory is clearly visible from many locations throughout the Los Angeles Basin and particularly within the San Gabriel Valley, the City of Pasadena, and the surrounding municipalities. The Observatory is also visible along many portions of the 210 freeway. This major southern California artery runs east-west along the southern foothills of the San Gabriel Mountains from San Bernardino County in the east to the northwestern corner of Los Angeles County near the Ventura County line in the west. The State of California has classified the section of this freeway between the Interstate 5 Freeway to the west to Interstate 134 east of La Cañada-Flintridge as an Eligible State Scenic Highway. The Angeles Crest Highway (SR-2), providing access to the Angeles National Forest and Mount Wilson, is classified as a State of California Officially Designated State Scenic Route (see Figure 6-2).

The location and elevation of the Observatory allow views of several of the more prominent structures within the complex by the population in the southern California urban areas.

The 254-cm and 152-cm (100-in and 60-in) telescopes, housed within large white domes set on asphalt pads surrounded by trees, are the most visible structures within the Observatory. These structures can be seen among the trees and their tops can be seen towering over the trees from many viewpoints within the Observatory. These are also the most visible structures from urban areas (NSF 1996).

The north-south-oriented Mount Wilson ridgeline is highly visible from regional viewpoints such as urban areas to the south and Angeles Crest Highway to the north. Individual Observatory facilities are visible from local areas such as Mount Wilson Road and on-site areas such as Skyline Park picnic area.

From a distance, Mount Wilson appears to be a natural landscape with little modification; however, its moderate to substantial modification is obvious onsite (NSF 1996).

6.3.3 Potential Environmental Impacts of the MWO Reduced Science Option

6.3.3.1 Land Use and Existing Activities

ROI for Land Use and Existing Activities. The ROI for assessing land use and existing activities includes the MWO, the Angeles National Forest, and the travel routes used by construction and operation vehicles.

<u>Land Use</u>. *On-Site Construction and Installation Impacts.* The construction and installation of the Outrigger Telescopes at the MWO is consistent with the land use designation in the current lease that "*provides for the land to be used as an astronomical observatory and authorizes the construction of additional structures consistent with this purpose"* (NSF 1996).

Construction of the telescope enclosures, the light beam paths, access trails, and the beam combiner building would occur within the approximately 1-ha (8.5-ac) site. It is anticipated that the project staging and laydown areas would be located within the project site. If deliveries and/or staging

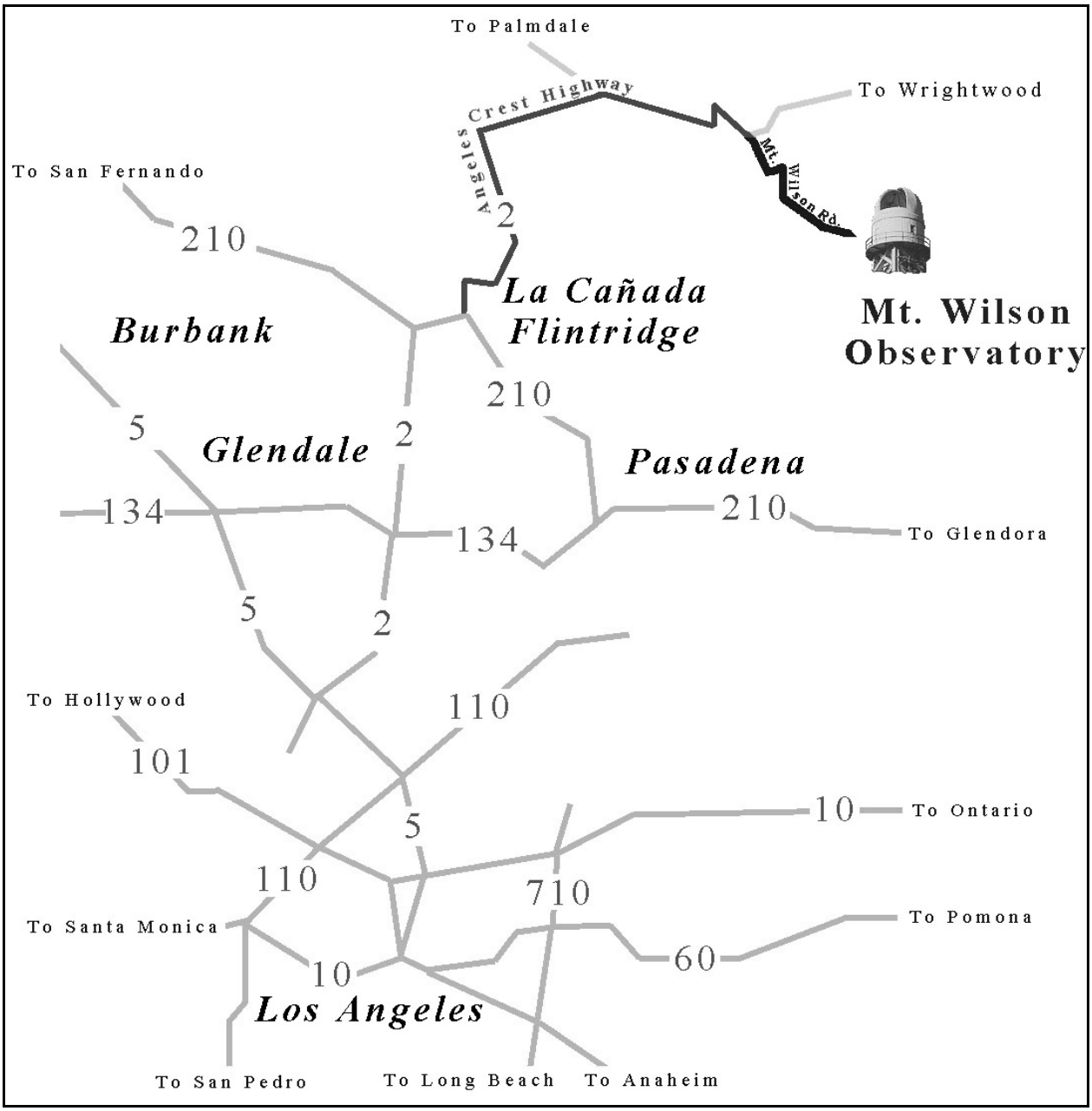

FIGURE 6-2. REGIONAL MAP OF MOUNT WILSON, CALIFORNIA

areas must be off site, the USFS parking area to the west of the Observatory could be used as a temporary staging area.

Construction of the Outrigger Telescopes would be subject to review and inspection by the County of Los Angeles Department of Public Works as part of the USFS-adopted approval process. It is anticipated that there would be no land use impact associated with this phase of the Outrigger Telescopes Project.

Operation Impacts. The operation of the Outrigger Telescopes would be consistent with the current designated land use. There

would be no land use impact associated with this phase of the Outrigger Telescopes Project.

Existing Activities. *On-Site Construction and Installation Impacts*. Activities associated with the on-site construction and installation of the Outrigger Telescopes Project would occasionally delay traffic along the Angeles Crest Highway (SR-2) and Mount Wilson Road and temporarily increase noise levels. See sections related to transportation (Section 6.3.3.7) and noise (Section 6.3.3.12) impacts for additional information. It is also anticipated that the viewscape of the proposed site and construction staging areas at the MWO would be temporarily impacted by the presence of large construction equipment, materials, and telescope components. See Section 6.3.3.13 for more information regarding visual impacts.

Although some transportation, noise, and visual impacts would occur, it is anticipated that the Outrigger Telescopes Project would not result in a long-term conflict with or have a substantial impact on existing activities in the ROI. The ability to use the land within the ROI for astronomical and other scientific research, and a variety of recreational activities would remain consistent with the current use. In conclusion, all construction and installation activities on Mount Wilson would be conducted in a manner that would allow the surrounding area to remain accessible for all existing activities.

Operation Impacts. It is anticipated that operation of the Outrigger Telescopes would encompass both on-site and off-site activities. The primary on-site activities would require a crew of trained individuals, including a mechanical engineer, electrical engineer, optic specialist, software specialist, two technicians, and a supervisor. The resident science team would be two or three individuals, depending on the activity and programs underway. Based on current plans, the average daily workforce would be six people.

All telescope and facility operations associated with the Outrigger Telescopes Project would be conducted in a manner that would preserve access to the surrounding area for all existing activities. The only continuing impact of the Outrigger Telescopes operations on existing activities would be the visual presence of the telescope enclosures. Thus, the impacts associated with this project phase would be small.

Mitigation Measures. Refer to the following sections of this chapter for mitigation measures associated with transportation (Section 6.3.3.7), noise (Section 6.3.3.12), and visual impacts (Section 6.3.3.13).

6.3.3.2 Cultural Resources

ROI for Cultural Resources. The ROI for the proposed Outrigger Telescopes Project in the "Museum Quadrant" of Mount Wilson is defined as the footprint of project facilities and any access roads, trails, and construction staging areas required for on-site construction and installation.

On-Site Construction and Installation Impacts. No previously recorded cultural resources were found within the ROI. Records in the South Central Coastal Information Center, University of California at Los Angeles, Institute of Archaeology, identified the following cultural resources within an 0.8-km (0.5-mi) radius of the project area:

"One multi-component site, CA-LAN-2343/H—Remnants of the Mount Wilson Toll Road, containing no artifacts but having both prehistoric and historic use

histories. This site currently consists of a fairly well maintained dirt road leading from the base of Mount Wilson to the radio towers at the crest. In addition to the road, there are seven remaining sections of retaining walls south of Mount Harvard. Some of these are made of sandbagged concrete and appear to date to original road construction in 1907. According to ethnohistorians, the Mount Wilson Road was originally built up over an Old Native Californian trail that also ran to the crest of Mount Wilson" [NSF 1996)].

"One historic site, CA-LAN-2342/H—Remains of Steil's/Martin's camp has been subjected to a great deal of disturbance and currently consists of several pads where former structures and tents once stood. Steil's camp had been outfitted with tents in 1889 and 1890. Martin added a single story, L-shaped, frame dining room at the west side of the camp area, opposite the entrance of the trail from Eaton Canyon. Later its south wing was extended to the west over the edge of a dry masonry terrace wall" (NSF 1996).

An archaeological reconnaissance report conducted in 1998 on Observatory grounds indicated there were no known sites within the Mount Wilson ridge top system. However, on the basis of the geographical setting, water sources, plants, and animals that exist or were known to exist in the area, the report concluded that it was very likely that the area had a high probability of containing prehistoric sites. Further, the mountain surface had been altered greatly by historic uses and construction of the Observatory. Any prehistoric cultural resources would have been destroyed, altered, or buried.

On-site construction and installation are not likely to adversely impact any cultural or archaeological resources within the ROI. A cultural artifacts survey would be required by the USFS, as part of the approval process should the museum quadrant of the MWO be selected as the location for the Outrigger Telescopes Project.

Operation Impacts. Because the proposed site is within yards of the CHARA Array, the comments and conclusions presented in the 1996 Draft Environmental Assessment for the CHARA Array, Mount Wilson, California may also apply to archaeological, historical, and/or cultural resources at the current proposed museum quadrant site:

- The National Register of Historic Places lists no properties within a 0.8-km (0.5-mi) radius of the project area.
- There are no California Historic Landmarks within a 0.8-km (0.5-mi) radius of the project area.
- There are no California points of historic interest within a 0.8-km (0.5-mi) radius of the project area.

Operation of the Outrigger Telescopes at the museum quadrant site would not impact cultural and historic resources within the project area.

6.3.3.3 Biological Resources

ROI for Biological Resources. The ROI for assessing impacts to biological resources would be the Mount Wilson summit and any areas where construction and laydown activities would occur.

On-Site Construction and Installation Impacts. The most recent biological survey evaluations for the MWO, including the biological evaluation for the Infrared Spatial Interferometer and for the Abbot Solar Tower site, did not identify any Federally listed or endangered species within the boundaries of the MWO (SeaWest, Inc. 2004b). Within the

proposed site for the Outrigger Telescopes, no critical habitat exists for any of the species identified in Section 6.3.2.3 (Northrop Grumman 2003).

The northern spotted owl is prevalent throughout mountainous regions of western North America. However, to date there is no documentation of its presence at or near the Observatory.

The Outrigger Telescopes Project would require the removal of trees in the immediate vicinity of the dome enclosures and combiner facility and along the access trail to the site.

Operation Impacts. No substantial biological impacts would occur as a result of operating the Outrigger Telescopes in the proposed project area.

6.3.3.4 Hydrology, Water Quality, and Wastewater

ROI for Hydrology, Water Quality, and Wastewater. The ROI for hydrology, water quality, and wastewater is defined as the Mount Wilson summit and any areas where construction laydown activities would occur.

Water Use and Wastewater Treatment and Disposal for Construction Workers. Separate work crews would be required to prepare the Mount Wilson site for installation and erection and testing of the Outrigger Telescopes and related components. The workforce would vary in size from between 25 and 35 workers to 50 to 60 workers during short-term peaks. The overall term of construction would be approximately 24 months, and it is assumed all workers would commute to the site daily (SeaWest, Inc. 2004b). Portable facilities would handle water supply and wastewater collection and disposal for construction workers. These portable facilities would be completely self-contained and serviced on a routine basis. As such, they would create no hydrologic or water quality impacts.

The requirement to wash down trucks, tools, forms, and equipment during concrete placement, however, could account for 38 to 76 kl (10,000 to 20,000 gal) of water during the construction period. If the contractor needs to mix concrete on site, the amount of water could substantially increase. Wash down basins and containers would be used to contain the wash water, which would be allowed to evaporate. The remaining solid residues would be disposed of off site (SeaWest, Inc. 2004b).

Surface Runoff from the MWO. On-site construction and installation of the Outrigger Telescopes would require the contractor to employ approved runoff and erosion controls. Impacts from surface runoff would likely be low and would continue through completion of construction. This small increase in runoff from impervious areas created by the Outrigger Telescopes at the MWO would likely be directed to existing drainage courses and would not result in increased soil erosion.

Subsurface Disposal of Domestic Wastewater. The problem with domestic wastewater that Mount Wilson faces - especially when considering the rapid growth of the broadcast facilities - is that at some point the rate of effluent injection into the mountain may become so great that it will not allow the soil to fully filter the wastewater before it reaches the down-slope wells. Determination of when this imbalance could occur would require extensive research and testing. In the long run, a pipe sewer system would seem to be the best option, but at this time there does not seem to be any set plans of action for upgrades. There is no quantitative analysis available at this time.

To evaluate wastewater increment added by implementing the Outrigger Telescopes, it is assumed that the volume of water trucked to the MWO approximates the volume of domestic wastewater generated. Based on available information, this figure is about 16.6 kl (4,400 gal) per week. It is estimated that operation of the Outrigger Telescopes Project would add about 9.5 kl per month (2,500 gal per month). This is the same amount of wastewater projected for operation of the Outrigger Telescopes on Mauna Kea and is used as an approximation for this evaluation. This would be a 57 percent increase in flow to the existing wastewater system at the MWO. Operation of the Outrigger Telescopes could potentially adversely impact wastewater operations of the MWO.

Mitigation Measures. The existing MWO septic system may need to be upgraded or an additional system installed to manage the additional wastewater generated by the Outrigger Telescopes operation.

6.3.3.5 Solid Waste and Hazardous Materials Management

ROI for Waste and Hazardous Materials. The ROI for waste and hazardous materials is defined as the Mount Wilson summit and any areas where construction laydown activities would occur.

Solid Waste. *On-Site Construction and Installation Impacts*. On-site construction activity would generate debris consisting of wood, scrap insulation, packaging material, concrete, and other construction-related wastes. This construction debris would be disposed of in large roll-off containers sized to accommodate debris generated over several days of construction. No other waste resulting from the construction process would be disposed of in these containers. Occasional high winds potentially could disperse construction debris, unsecured building materials, and equipment about the site and onto the surrounding area. Suitable containment would be used by the contractor to prevent this from occurring. With suitable attention from the construction contractor and enforcement by the Outrigger Telescopes Project construction manager, trash and debris should have little or no impact on the MWO site. The contractor would also be required to provide suitable containers for housekeeping trash (lunch wrappers, etc), and would be required to remove construction debris and trash from the site on a frequent and regular basis throughout the construction period in accordance with best construction management.

*Operation Impacts***.** Operation of the Outrigger Telescopes would not substantially add to solid waste (trash) currently generated by the MWO.

As an approximation, it is assumed that the amount of trash generated by the additional personnel required to operate the Outrigger Telescopes would increase proportionately with the increase in staff and visitors. It is anticipated that operation of the Outrigger Telescopes would require additional daily average of four staff, an increase of about 7 percent over the current 13 staff and 45 daily visitors. It is assumed there would be no increased traffic to transport this small amount of additional solid waste away from the site for disposal.

Because the Outrigger Telescopes are designed as instruments without any habitable spaces, they would not involve any new trash containment systems. The existing infrastructure at the MWO would be used to collect trash resulting from operation of the Outrigger Telescopes.

*Mitigation Measures***.** It is assumed that the Outrigger Telescopes on-site construction

and installation contract(s) would contain provisions regarding the management of solid wastes similar to those provided in Appendix F of this EIS.

Hazardous Materials Management. *On-Site Construction and Installation Impacts*. Diesel fuel and motor oil(s) for construction equipment are anticipated to make up the bulk of on-site hazardous materials during the construction effort for the Outrigger Telescopes. No mercury would be used for the Outrigger Telescopes (CARA 2001d). During the earthwork phase, it is anticipated that up to several hundred gallons of fuel for excavation equipment may be stored within skid-mounted or truck-mounted transfer tanks for short periods of time. Following adopted best management practices, all such fuels and oil would be provided with Material Safety Data Sheet (MSDS) information and warning labels. The storage of all hazardous liquids would be restricted to protected locations within the project site. Spill containment facilities would be provided for all such storage areas to avoid the potential contamination of soils in or around the construction zones. (Typically, such containment systems provide a capacity of 150 percent of all stored liquids). An adopted program of regular inspections of containers and reviews of handling procedures would ensure compliance. A program of spill containment and reporting would be submitted to the site authority prior to the delivery or offloading of any hazardous materials (SeaWest, Inc. 2004b). The handling guidelines and reporting procedures for other construction-related hazardous materials such as paints, solvents, and lubricants, would also follow best management practices.

Operation Impacts. Operation of the Outrigger Telescopes would require periodic maintenance activities similar to those associated with the MWO telescopes.

The Outrigger Telescopes would have few hazardous materials. The lubricants and cleaning solutions used to service and maintain the interferometer would be purchased and stored in limited quantities. MSDS information, and warning and handling data sheets will be on file at the Observatory, and storage would be in compliance with MWI and Los Angeles County Fire Department policy. The interferometer does not use internal combustion engines or turbines; therefore, the need for fuels and motor oils would be limited (primarily for the personal automobiles of the staff). It is anticipated that existing MWO maintenance equipment and vehicles would service this site. Operation of an optical interferometer does not generate airborne pollutants.

The optics surfaces for the telescopes and the light beam paths are most often composed of a molecular aluminum coating and as such degrade or oxidize over time. Based on historical evidence, it is anticipated that mirror-recoating operations would be necessary on a 1- or 2-year cycle. Hydrochloric acid (HCl) is used to clean the substrate. The quantity of acid required is limited (several gallons, diluted) and is delivered to the site on an as needed basis for scheduled cleaning/coating operations. Waste HCl is neutralized using a calcium carbonate powder. The MWO has conducted optics-coating operations on site and has both the cleaning facilities and vacuum chambers to accomplish these tasks. A small quantity, (typically about 950 ml (1 qt)) of HCl is stored at the observatory machine shop.

Chapter 4 describes other maintenance and operations activities for the Outrigger Telescopes. Table 6-9 compares current hazardous materials use at the MWO with

TABLE 6-9. EFFECT OF OUTRIGGER TELESCOPES ON HAZARDOUS MATERIALS USE AT THE MOUNT WILSON OBSERVATORY

Material Class	Current Use at Mount Wilson Observatory	Anticipated Requirements of Outrigger Telescopes
Cooling	No glycol used	No glycol used
Fuel	Gasoline (208 l (55 gal)), Diesel (208 l (55 gal)), Propane (28 kl (1,000 ft^3))	No fuel required; emergency power provided by existing infrastructure
Hydraulic Fluid	In use (19 l (5 gal))	No hydraulic fluids used
Lubricants	Motor oil, in use	Gear oil (66 l (17-gal) for each Outrigger Telescope) and grease used; no additional lubricants stored on site
Mercury	In use with 1.5 m (60 in) and 2.5 m (100 in) telescopes	No mercury used
Mirror De-coating & Re-coating	Hydrochloric acid (0.95 l (1 qt))	Up to four mirrors de-coated with hydrochloric acid every two years; no additional chemicals stored on site
Other Compressed Gases	Carbon dioxide, Helium, Nitrogen (160 l (42 gal)), Oxygen/Acetylene	Carbon dioxide used for snow cleaning monthly; 8.6-kl (205 ft^3) bottle stored in each Outrigger Telescope
Paints & Related Solvents	Paint (11 l (3 gal))	Used as needed; no additional paint and solvents stored on site

Source: SeaWest, Inc. 2004b

the anticipated requirements of the Outrigger Telescopes Project.

For operation of the Outrigger Telescopes appropriate hazardous waste management and spill control plans would be developed in accordance with Federal and State regulations.

Mitigation Measures. It is assumed that all on-site construction and installation contract(s) would contain provisions regarding the management of hazardous materials similar to those described by Appendix F of this EIS.

6.3.3.6 Geology, Soils, and Slope Stability

ROI for Geology, Soils, and Slope Stability. The ROI for accessing the potential impacts from implementing the Outrigger Telescopes Project on geology, soils, and slope stability would the Mount Wilson summit and at any areas where construction staging and laydown activities would occur.

On-Site Construction and Installation Impacts. Installation of the access trail and pad development for the combiner building and the four telescope enclosures within the Museum Quadrant site would involve terrain modification.

Excavate of the types of friable earth found on the MWO site may be accomplished using conventional equipment. During construction of the CHARA Array on Mount Wilson, all excavations were completed without the aid of blasting or special hardrock equipment (NSF 1996). Rubber-mounted backhoes, articulated loaders, track-mounted excavators, and drill rigs would be used for earth removal in this

project. During the earthwork, transport vehicles, including 26,000 GVW bobtail trucks, a 25-ton capacity truck, and trailer combination rigs would be used to transport, handle, dispose of, and deliver soil and aggregate, as required. Similar construction vehicles would be used for on-site construction and installation of the Outrigger Telescopes.

Under the current design configuration, the Outrigger Telescopes would consist of a set of four 1.8-m (6-ft) telescopes/enclosures arranged about a central combiner facility. The final collective footprints of the four telescope enclosures, light beam foundations, and the combiner building would be approximately 1,301 m^2 (14,000 ft^2). The access trail (suitable for light vehicular traffic) would involve a terrain disturbance of an additional 1,115 to 1,394 m^2 (12,000 to 15,000 ft^2) from the point of connection with the existing Observatory access road to the Outrigger Telescopes site. Overall, the total project site of approximately 1 ha (2.5 ac) of land would include the telescope enclosures, the light beam paths, access trails, and the beam-combiner building locations. It is anticipated that necessary project staging and laydown areas would be located within the 1-ha (2.5-ac) plot. If deliveries and/or staging require off-site holding, it is anticipated that the USFS parking area to the west of the Observatory could be used as a temporary staging area.

It is anticipated that on-site construction and installation of the Outrigger Telescopes would not have a small impact on geology at the site. Site soils in unexcavated areas would be compacted by heavy machinery and other construction activities. This would be relieved at the end of the construction during final site clean-up and contouring.

Operation Impacts. There would be no geology, soils, or slope-stability impacts associated with operation of the Outrigger Telescopes within the Museum Quadrant site.

6.3.3.7 Transportation

ROI for Transportation. Transportation refers to the movement of vehicles along roads. The ROI for assessing transportation impacts includes the MWO and other areas affected by on-site construction, installation, and operations including the Angeles National Forest and vehicle travel routes.

On-Site Construction and Installation Impacts. The daily workforce anticipated for the construction and installation phase of the Outrigger Telescopes Project varies between an average of 25 to 35 workers and a peak of 60 workers (SeaWest, Inc. 2004b). During construction of the Outrigger Telescopes it is anticipated that the average daily construction related vehicular trips ADT would vary from 50 to 75 depending on the size of the workforce and the amount of equipment and material delivered. At peak periods of activity the ADT might exceed 100 vehicles. This traffic volume would be much lighter than 730 the ADT for Red Box Road —the final 8 km (5 mi) of access to the site— and the 3,400 ADT for the intersection of Highway 2 and the Angeles Forest Highway to the high desert communities to the north (SeaWest, Inc. 2004b).

Most of the construction work would occur during the dry months when road conditions are best. Most of the traffic to the site would occur before 7:00 a.m. during weekdays, before start of commuter traffic from the Mojave Desert communities into Los Angeles. Traffic leaving the site would likely peak around 3:30 PM, before the start of return

commuter traffic. The primary flow of commuter traffic along this highway would be opposite to the flow of construction vehicles (SeaWest, Inc. 2004b).

The access trail needed to enter the site for construction activities would remain in use for the life of the Outrigger Telescopes and would be designed to handle the traffic and loads anticipated as a part of the long-term operations and maintenance of this facility. Current design concepts include an access trail of about 244 m (800 ft) beginning west of the project site at a point of intersection to the MWO road and diverging downslope to the museum quadrant site. Additionally, each of the four telescope sites must be accessible. One or more of the four sites might be accessible by existing MWO roads and trails. Based on the current design criteria and configurations, it is estimated that approximately 1,070 m^3 (1,400 yd^3) of material would be excavated and moved for these access ways.

Vehicular traffic associated with construction and installation activities would occasionally delay traffic along the Angeles Crest Highway (SR-2) and Mount Wilson Road, especially when the telescopes and domes are transported to the mountain. This would occur only intermittently and would not regularly interfere with normal traffic flow. Construction vehicles are slow and difficult to maneuver, but they would not have any long-term impact on the traffic flow.

Construction traffic within the ROI would create minor short-term increases in dust and emissions and temporarily increase noise levels. See Section 6.3.3.11 for impacts associated with air quality and Section 6.3.3.12 for information on noise impacts.

It is also anticipated that the current viewscape of the proposed site and construction staging areas at Mount Wilson would be temporarily impacted by the presence of large construction vehicles. See Section 6.1.13 for more information regarding visual impacts. Overall, short-term minor impacts would occur during this phase of the Outrigger Telescopes Project.

Transportation of minimal quantities of hazardous materials (e.g., diesel fuel, motor oil(s), paints, and solvents) and wastes would be expected throughout the course of constructing, installing, and operating additional facilities on Mount Wilson. Handling of these materials would be guided by best management practices. No impact is anticipated.

Operation Impacts. Operation of the Outrigger Telescopes at the MWO would add 6 to 12 vehicular trips per day along the Red Box Road access and Highway 2 from the Los Angeles Basin (SeaWest, Inc. 2004b). This slight increase in traffic associated with this project phase would create a very small impact on transportation.

Mitigation Measures. During the construction and installation phases of the Outrigger Telescopes Project, heavy truck trips will be scheduled during off-peak hours to avoid interfering with normal traffic flow along the Angeles Crest Highway (SR-2) and Mount Wilson Road.

All road cuts and fills will be designed to minimize the potential for erosion and concentrated runoff.

6.3.3.8 Utilities and Services

ROI for Utilities and Services. The ROI for assessing utilities and services impacts of the Outrigger Telescopes Project includes the MWO, the Angeles National Forest, and vehicle travel routes used by construction and operation vehicles.

This section analyzes potential impacts on water supply, electrical supply and communications, and emergency services and fire suppression.

Water Supply**.** *On-Site Construction and Installation Impacts*. The Outrigger Telescopes Project would result in an increase in the demand for potable water due to the increased number of workers at the site and the implementation of dust controls. The construction contractor(s) would transport this additional water to the summit area. Therefore, there would be no impact on the existing water supply at the MWO.

Operation Impacts. Because of the limited amount of available potable water on site, a new well and storage tank may be required to accommodate the additional Outrigger Telescopes workers and the increased demand on firefighting water systems and supply.

Mitigation Measures. The Outrigger Telescopes project may need to consider installation of a new walk and storage system, and possibly importing water for at least part of operational needs.

Electrical Power and Communications.

On-Site Construction and Installation Impacts. On-site generators provided by the construction contractor would provide power needs. Only a minor increase in demand for electrical power on the existing distribution system would occur during this period. This increase would have no impact on the existing electrical supply system.

Operation Impacts. The electrical power requirement of each Outrigger Telescope is estimated to be 30 kW (UH IfA 2001a). At this time, the available 14,000 kW of power on Mount Wilson is near, or over, capacity and would not be able to accommodate the additional operation of all four Outrigger Telescopes. In addition, the existing communications system for MWO is limited to copper wire. In conclusion, the Outrigger Telescopes Project could have a substantial impact on the electrical and communications supply systems.

Mitigation Measures. Within the next year, the current electrical supplier, SCE, will attempt to implement a three-phase plan to improve electrical service on the mountain.

It may be possible to connect the fiber optic network that exists within the boundaries of the MWO with the local telecommunications facility at the neighboring antennae farm underground fiber optic connections.

Emergency Services and Fire Suppression

On-Site Construction and Installation Impacts. The need for emergency services is related to the number of personnel at the summit and the types of work or activities they perform. As described in Section 6.3.1.2, the workforce anticipated for this project varies from an average of between 25 to 35 workers and a peak of 60 workers.

The construction contractor would have the primary responsibility for ensuring worker safety. If an injury or accident occurs, the existing emergency service plan that applies to the MWO would be adequate to provide on-site treatment or evacuation off the summit. No additional equipment, personnel, or modification of emergency procedures would be required during on-site construction. There would be no impact associated with this phase of the Outrigger Telescopes Project.

Operation Impacts. As described in Section 6.3.1.3, based on current plans the average daily workforce would be six people. Existing emergency services and procedures would be adequate to

accommodate this small increase in personnel. In addition, the Outrigger Telescopes Project would not require additional fire response capabilities by the USFS.

The Outrigger Telescopes would include fire alarm systems and suppression equipment. The additional personnel would follow established procedures and would be included in MWO fire drills and safety training. In conclusion, there would be no impact associated with this phase of the Outrigger Telescopes Project.

6.3.3.9 Socioeconomics

ROI for Socioeconomics. The ROI for assessing impacts to socioeconomics from implementation of the Outrigger Telescopes Project is the area at and near the MWO.

On-Site Construction and Installation Impacts. On-site construction and installation would generate about 25 to 35 construction jobs over the 24 month construction period, possibly peaking at 60 jobs. A number of these workers may come from nearby local communities which would have a moderate but beneficial impact on construction jobs in those areas for the 24 month construction periods. Some highly specialized workers needed to perform highly skilled activities during commissioning of the Outrigger Telescopes may originate from locations for removal from Mount Wilson. The local communities would be likely to benefit temporarily from even these jobs through worker expenditures for lodging and subsistence in those communities.

Operation Impacts. It is anticipated that the construction of the Outrigger Telescopes would not substantially impact the level of activity at the MWO and would have minimal long-term positive impacts on local/regional socioeconomics. Some of the 8 jobs created by operation may be filled locally. Some operation workers may also move into the local area purchasing or renting homes establishing themselves and their immediate families in the local communities.

Mitigation Measures. Given the relatively limited workforce involved in construction and operation, no socioeconomic mitigation measures would be necessary.

6.3.3.10 Air Quality

ROI for Air Quality. During the construction of the CHARA Array on Mount Wilson, all excavations were completed without the aid of blasting or special hardrock equipment. Rubber-mounted backhoes, articulated loaders, track-mounted excavators, and drill rigs would likely be among the earth removal/moving equipment involved in the Outrigger Telescopes Project.

On-Site Construction and Installation Impacts. The proposed project site would be located in a high-elevation rural area where there is no monitoring of air pollutants but the air is substantially better than in adjacent urban areas to the west of the proposed site. No major sources of air pollutants would be located in the vicinity of the proposed site; the closest sources of air pollutants are Angeles Crest Highway, about 4.8 km (3 mi) to the north, the Los Angeles urban area, about 6.4 km (4 mi) to the south, and campgrounds at lower elevations within 3.2 km (2 mi). The proposed site is about 4 km (2.5 mi) to the southwest of the San Gabriel Wilderness Area, the Class I Air Quality area closest to the proposed site.

The project would comply with State and Federal air quality standards and regulations. Truck and worker trips to the site during on-site construction and installation would not add appreciably to

the existing traffic levels or to vehicle emissions on Mount Wilson Road.

Excavation for building and pipe support footings and trenching for conduit sections would not exceed particulate standards, because the disturbance would be small, and to suppress dust emissions and control exhaust emission from construction machinery standard best management practices would be used. For example, if high wind conditions are present, best practices could include wetting down the disturbed area to contain fugitive dust.

The workforce anticipated for this project varies from between 25 to 35 workers and a peak of 60 workers (SeaWest, Inc. 2004b). Additional traffic to the Observatory would add to vehicle emissions, but resulting in little impact on existing air quality. Small impact on ambient air quality would be expected.

Operation Impacts. Air quality at Mount Wilson would return virtually to existing conditions once the Outrigger Telescopes are installed. A slight increase in vehicular traffic and emissions would be associated with scientists traveling to the project site. Overall air quality at Mount Wilson is good; the Outrigger Telescopes operation would not change these conditions.

The project would not include any point sources of air pollutant emissions, and staff and visitors to the facility would generate few additional vehicle trips, so project operations would have no impact on existing air quality.

Mitigation Measures. The construction contractor(s) would be required to institute appropriate dust control measures and abide by applicable vehicular emissions standards.

6.3.3.11 Noise

ROI for Noise Impacts. The ROI for assessing noise impacts from the Outrigger Telescopes Project includes the MWO and other areas affected by on-site construction, installation, and operations including the Angeles National Forest and vehicle travel routes.

On-Site Construction and Installation Impacts. Noise would result from excavation, trenching, grading, installation of sheet piling for utility protection, installation of junction boxes, construction of light and air pipes, construction of telescope dome foundations, and installation of telescopes and domes.

Noise levels would depend on the mix and duration of construction equipment use and construction methods. The vibrating hammer, used to install the sheet piling required for utility protection, would most likely be the loudest piece of equipment used during construction (approximately 95 dBA at 15 m (50 ft)). Use of this equipment likely would be short term, lasting 1 or 2 days. Blasting would not occur during the construction process. Rubber-mounted backhoes, articulated loaders, track-mounted excavators, and drill rigs would likely be the earth removal/moving equipment involved in this type and scale of project.

Transport of materials and equipment and daily construction traffic would also create noise. Increased noise levels would occur intermittently along routes used by construction and operation equipment. Most heavy construction equipment would be stored on site during the construction period. See Section 6.3.3.7 for additional transportation information.

This intermittent and short-term noise could result in minor disturbances to scientists, staff, recreational users, and

other visitors within the ROI. However, noise disturbances or interruptions would end once on-site construction and installation ends. Intermittent, short-term noise increases would create a moderate impact.

Operation Impacts. Operation of the Outrigger Telescopes would result in a negligible increase in noise and a minor increase in vehicular traffic noise along the Mount Wilson Road. See Section 6.3.3.7 for additional vehicular traffic information. In conclusion, there would be no impact associated with this phase of the Outrigger Telescopes Project.

Mitigation Measures. Any noise impacts on construction workers would be mitigated by adherence to appropriate Occupational Safety and Health Administration (OSHA) standards.

6.3.3.12 Visual/Aesthetics

ROI for Visuals/Aesthetics Resources. The ROI for visual impacts is primarily Mount Wilson and any other area where the Outrigger Telescopes would be visible.

On-Site Construction and Installation Impacts. Portions of the MWO have been designated for modification (per the USFS's visual quality objective (VQO) designations). The proposed Museum Quadrant site is located within this designated area and would be subject to that objective. A review of the USFS's definition of modification, however, shows that the existing Observatory structures do not comply strictly with VQO because they do not use naturally established form, line, color, and texture that are compatible with the natural surroundings.

The Outrigger Telescopes Project Museum Quadrant site is southwest of the CHARA Array, spanning a small canyon. For best astronomical viewing, the proposed telescopes would sit at a slightly higher elevation than the currently positioned CHARA W1 telescope.

The Outrigger Telescopes situated within the Museum Quadrant site would not be visible from points to the east or south of the Observatory or from any vantage point in the Los Angeles Basin due to adjacent terrain and tree stands. The Outrigger Telescopes enclosures would be visible from the north along sections of SR-2 and to the west, within the telecommunication broadcast facility development area.

The transport of construction equipment and machinery to the proposed site and the small amount of additional vehicular traffic necessary for transporting the workforce to the site would cause additional impacts. Construction activities and machinery would be visible from the Mount Wilson site; however, below Mount Wilson, the existing topography of the mountain would preclude view of those construction activities and machinery movement.

Operation Impacts. Operations of the Outrigger Telescopes would have a small incremental impact on visual resources from the view plane on the summit. The Outrigger Telescopes would not be seen below the mountain.

Mitigation Measures. The Outrigger Telescopes facilities would employ color schemes and design criteria established for observatories on the mountain.

6.3.3.13 Environmental Justice

Onsite construction, installation, and operation of the Outrigger Telescopes at the MWO site would not result in disproportionately adverse impacts on minority or low-income populations.

Past Activities

Astronomers have been interested in Mount Wilson for more than 100 years. The MWO was preceded by a 33-cm (13-in) refractor telescope located on Mount Harvard, southwest of the present site. That telescope was installed in 1889 and operated for 18 months. In 1904, the Carnegie Institution of Washington established the current Mount Wilson Solar Observatory under a 99-year lease agreement with the U.S. Department of Agriculture Forest Service. Astronomer George Ellery Hale planned to build a 102-cm (40-in) telescope, soon to be replaced by a 152-cm (60-in) and then the 254-cm (100-in) Hooker Telescope. Currently, the site is home to eight prominent observatories operated by universities and research centers throughout the United States.

6.3.3.14 Cumulative Impacts

Past and Present Activities on Mount Wilson. Before Spanish arrival, the Gabrielinos (Shoshonean-speaking natives) had a thriving culture in the Los Angeles Basin and San Gabriel Valley, extensively using the resources of the San Gabriel Mountains for food and materials and to trade with tribes across the mountains. With the earliest Spanish explorers—Portola in 1769 and Fages in 1776—Spanish missionaries founded several missions, gathered some of the native peoples into mission communities, taught them Christianity, and had them tend the mission orchards. This missionization resulted in the natives' loss of their own culture and practices, so that by the early 1800s, these native cultures had been assimilated into the Spanish political, economic, and religious systems.

The Spanish also relied on the San Gabriel Mountains (calling them the Sierra Madre during the early 1800s) for raw materials and grazing. After the United States took possession of California, the San Gabriel Mountains were used for mining, travel, homesteading, recreation, scientific observatories, and as a timberland preserve. The Angeles National Forest was established in December 1892 by Executive Order.

Benjamin D. Wilson started constructing a pack trail to the mountain summit in 1864 to harvest timber to make wine barrels. However, the timber was found to be unsuitable, and the trail was abandoned. As the local area population increased, the number of hikers and campers using the trail increased. Often, hikers lit a large bonfire at the summit after sunset to signal their safe arrival to those below.

The Mount Wilson area was first used for astronomical observations in 1889, when the first telescope was installed on the southwestern edge of the summit. The telescope remained for only 18 months before its removal.

In 1904, the Carnegie Institution of Washington entered into a 99-year lease with the National Forest Service to use Mount Wilson for astronomical study of our closest star, the Sun. The Mount Wilson Solar Observatory was founded, and the Snow Solar Telescope was relocated from the Yerkes Observatory to Mount Wilson (the telescope is named after its benefactor, Helen Snow). In 1908, the 8-m (60-ft) Solar Tower was built; the 46-m (150-ft) Solar Tower was built in 1910.

The first reflector deep-sky telescope, the 152-cm (60-in) telescope, was completed in 1908, establishing the basic design for future observatory telescopes. The 254-cm (100-in) Hooker Telescope, completed in 1917, remained the largest telescope in the world until 1948, when the 508-cm (200-in) Hale Telescope was built on Palomar

Mountain near San Diego. The Observatory changed its name to MWO after the completion of the Hooker Telescope.

Other astronomic observational equipment added to the Observatory's inventory includes the Berkeley Infrared Spatial Interferometer (ISI) in 1988 and the more recent Georgia State University CHARA Array.

Table 6-10 outlines the history of Mount Wilson.

Reasonably Foreseeable Future Activities. The MWO is administered by the Mount Wilson Institute (MWI), a non-profit corporation. The future uses and growth of the observatory depend on current funding, future funding for new science research projects, and available space on the mountain to support such efforts. MWI Director Dr. Harold McAlister states:

> "Because Mount Wilson is run by a non-profit organization whose major goal is to maintain the status quo, there is no long-range plan of growth at the Observatory. As in the past, MWI will respond to specific requests for new facilities on the site, and we have no idea of what might be proposed to us [or] on what time scale. My own feeling is that from the point of view of available acreage on the present leasehold, there is room for one or two more telescopes in the range of 2 to 4 m (6.6 to13 ft) aperture, placed on high ground that might be expected to enjoy good seeing conditions. Any additional expansion would… require extending the site boundary. That option is highly limited by the mountainous terrain. "

Summary of Cumulative Impacts There are no known plans for construction and operation of any additional telescopes at the MWO site for the foreseeable future.

On-site construction, installation, and operation of the Outrigger Telescopes at the MWO site would have little incremental impact on the whole. Construction would, even at the estimated 24 months, would have little adverse impact on the MWO site and Mount Wilson. Visitors and staff on the mountain would experience minor inconveniences at various times during construction. From an environmental impact perspective, construction of the Outrigger Telescopes would not combine with past and present sources of environmental impact sufficient to result in exceedances of existing environmental standards, either Federal or State.

Operation of the Outrigger Telescopes may incrementally impact the existing wastewater treatment system at MWO and possibly even the current MWO potable water supply capability. These potential adverse impacts, if verified during more detailed planning and design of the Outrigger Telescopes Project, can be avoided by upgrading or supplementing the existing systems.

6.3.4 Adverse Environmental Impacts That Cannot Be Avoided for Mount Wilson

Adverse impacts are divided into short- and long-term effects. Short-term effects are generally associated with construction and prevail only for the duration of the construction period. Long-term effects generally follow completion of the improvements and are permanent. Effects that can be considered both adverse and unavoidable are described below for both short- and long-term effects.

TABLE 6-10. MOUNT WILSON HISTORY

Year	Event
1864	Benjamin D. "Don Benito" Wilson hires Mexicans and Indians to transform an old Indian path up Little Santa Anita Canyon into a trail in order to cut down the trees on top of Mount Wilson to build fences and wine barrels. This was the first modern trail in the front range. Wilson builds a Halfway House at what is now called Orchard Camp, consisting of a three-room cabin, a stable, a blacksmith's shop and a chicken house. When Wilson got to the top, he discovered the remains of two log cabins, whose builders are lost to history. Wilson abandoned logging after a few weeks, perhaps because he didn't like the wood.
1866	George Islip takes over the Halfway House, and plants fruit trees, giving rise to the name Orchard Camp.
1877	John Muir climbs to a point near Mount Wilson.
About <1880	Islip abandons Orchard Camp.
1880s	Up to 70 hikers and horse-riders climb the trail to camp at Mount Wilson on weekends, building huge bonfires at the peak to signal their safe arrival.
1887	Government surveyors attempt to change the name of Mount Wilson to Mount Kenneyloa. Harrison Gray Otis wrote a scathing editorial in the L.A. Times, and the name wasn't changed. (The editorial is in SG, p. 115.)
1889	Harvard Professor William Pickering and telescope maker Alvan Clark use a 4" telescope and determine that Mount Wilson would be an excellent site for an astronomical telescope. A 13" telescope from Harvard weighing 3700 pounds is carried up the Mount Wilson Trail by six men and two horses, with the trail being "improved" by dynamite where needed. Within a year, a "star map of the heavens" is completed which included "many objects never heretofore viewed". Peter Steil opens a tent camp in the Harvard - Wilson Saddle. The Pasadena & Mount Wilson Toll Road Company was incorporated to build a wagon road to Mount Wilson.
1890	The wagon road to Mount Wilson proves too costly, and a 4' wide trail is proposed instead of a 12' roadway. 1000 people stay at Steil's camp in the summer. The *Mount Wilson War* begins when A.G. Strain erects a fence across the Mount Wilson Trail, which was ripped down by Steil. The War caused only property damage and a lawsuit.
1891	The Court rules that the Mount Wilson Trail is a "public highway, and cannot be closed against travel". Strain opens a tent camp near the summit, which also becomes popular, to a capacity of 60 people. Steil sells to Clarence S. Martin, who builds a frame dining room, enough tents for *Camp Wilson*, better known as *Martin's Camp*, to sleep 40 people, and a water tunnel below Mount Wilson with pipes to bring water to his camp. The 13" telescope is removed, probably in part due to a dispute with USC over land ownership of its site. Pasadena Contractor Thomas Banbury with a crew of 25 men builds the 10 mile "New Mount Wilson Trail", aka the Toll Road, in five months. It opens in June with a toll of 25 cents round trip for hikers and 50 cent for horseback riders. Its maximum 10 percent grade makes it more popular than the steeper Mount Wilson Trail.
1890s	Both Martin's and Strain's camps are full nearly every summer weekend. Hundreds of people use the Toll Road on weekends, stopping at Captain Henninger's house and George Schneider's Halfway House near the Idlehour Trail junction.
1892	President Charles W. Eliot of Harvard visits Mount Wilson. Martin offers him 10 acres on the unnamed high point south of the saddle for a 24" telescope, and christens it "Mount Harvard". Despite that offer and honor, the 24" telescope went to Peru.
1895	Mount Wilson Toll Road Company purchases Henninger Flats.
1896	Mount Wilson Toll Road Company purchases Martin's and Strain's camps.
1901	Mount Wilson Toll Road Company purchases 640 acres on the mountaintop for $800 from the U.S. Land Office, eventually expanding its holdings to 1050 acres.

TABLE 6-10. MOUNT WILSON HISTORY (CONTINUED)

Year	Event
1903	Mount Wilson determined to be one of the five best sites in southwestern California for an astronomical telescope by Professor W.J. Hussey of Lick Observatory. George Ellery Hale visits Mount Wilson for the first time on June 25, is "ecstatic" over the excellent observing conditions, and decides to build his observatory at Mount Wilson.
1905	Carnegie Institute granted a 99-year lease for 40 acres for telescopes. Toll Road Company constructs the first Mount Wilson Hotel.
1905	Snow Solar Telescope temporarily relocated from Yerkes Observatory to Mount Wilson
1907	Carnegie Institute widens Toll Road to 10' so that larger telescopes can be transported. The work is done by 200 Japanese laborers using mule-drawn scrapers and plows. Sandbags are used to build retaining walls.
1908	60' Solar Tower Telescope completed. 60" reflector operational and becomes world's largest telescope for almost 10 years until surpassed by the Mount Wilson 100" telescope.
1910	150' Solar Tower Telescope completed.
1913	First Mount Wilson Hotel burns down.
1913	Second, larger, Mount Wilson Hotel built, lasts for 53 years until it is demolished in 1966.
1917	100" Hooker Reflector telescope operational and becomes world's largest telescope for 31 years until surpassed by the 200" Palomar Telescope in 1948. The 200" telescope was built directly as a result of the stunning achievements of the Hooker Telescope.
1912	Toll Road opens to public automobiles until 1936.
1935	Angeles Crest Road / Red Box road to Mount Wilson completed.
1936	Toll Road closed to public travel and given to Forest Service.
1948	First TV / radio antenna installed, followed quickly by many more.
1964	Metromedia purchases the 720 acres of the Mount Wilson Hotel Company.
1966	Mount Wilson Hotel razed for Skyline Park.
1967	Skyline Park opens with the Pavilion, picnic plazas and Children's Zoo.
1976	Skyline Park closes after losing money for 8.5 years. Metromedia deeds its 1100 acres to The Nature Conservancy, who deeds it to the Forest Service, except for two small parcels of private land.
1984	Carnegie Institute plans to close Mount Wilson observatories to focus its resources on its telescopes in Chile.
1985	Hooker telescope closed. The other telescopes remain operational.
1986	Mount Wilson Institute formed.
1988	UC Berkeley's Infrared Spatial Interferometer, consisting of two 65" telescopes mounted in semi-trailers, begins operation.
1989	Mount Wilson Institute begins operation of the Carnegie Mount Wilson telescopes, and the 100" is opened sometime before 2000.
1996	Construction begins for six 1 m telescopes by the Center for High Angular Resolution Astronomy at Georgia State University. This will be the largest optical interferometric array ever built. Mount Wilson was chosen on the basis of the excellent atmospheric stability, the number of clear nights available, and the infrastructure available here. The Telescopes were installed in 1999. The facility should be operational by the end of 2000

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6.3.4.1 Unavoidable Adverse Short-Term Effects

- Operation of construction equipment, trucks, and worker vehicles would temporarily increase traffic along the roads serving Mount Wilson during the construction period. This minor impact would be intermittent and temporary and would occur only during construction. The transport of large machinery and large Outrigger Telescope components could temporarily impede traffic flow and result in temporary traffic delays on the Angeles Crest Highway (SR-2) and Mount Wilson Road. These impacts would be limited to brief periods at the beginning and end of construction.
- Increased vehicular traffic and heavy equipment internal combustion engines would generate air emissions. These emissions would be localized and would not impact the overall air quality on Mount Wilson. Emissions from road construction-related vehicles and equipment would cease once construction is completed.
- Heavy construction equipment operations on site would temporarily generate small dust particles. Although workers would take measures daily to mitigate and reduce these impacts, some soil would occasionally erode during periods of high winds.
- Heavy construction equipment operations on site and the transport of large machinery along the roads serving Mount Wilson would lead to intermittent and temporary increases in noise levels. The transport of large machinery would be limited brief periods at the beginning and end of construction.
- Construction equipment, related materials, and temporary structures, located on site during the construction phase of the project would affect the visual quality of the area for some viewers. Any changes to the visual quality of the area would be temporary, since all equipment and excess materials would be removed at completion of construction.

6.3.4.2 Unavoidable Adverse Long-Term Effects

- The presence of the Outrigger Telescopes would affect the visual quality of the area for some viewers using the area around the Observatory. To minimize this visual impact, the Outrigger Telescopes would be painted to blend into the natural surroundings to the extent possible.
- Workforce traffic associated with the Outrigger Telescopes would result in very minor increases in noise levels along the roads serving Mount Wilson, including the Angeles Crest Highway (SR-2) and Mount Wilson Road.

6.3.5 Incomplete or Unavailable Information

Sufficient information exists at this stage in development of the Reduced Science Option at Mount Wilson to determine whether or not significant environmental impacts would occur as a result of implementation of the Outrigger Telescopes Project.

Assuming the Reduced Science Option were to move forward at Mount Wilson two areas would require particular attention

in facility design and planning: (1) determination of the capability and capacity of the existing MWO wastewater system; and (2) determination of the capability of the existing MWO potable water supply system to meet the needs of an operational Outrigger Telescopes Project. While both areas would need attention, there are no indications at this time that any environmental conditions exist which would preclude assuring adequate wastewater management and potable water needs can be met.

6.3.6 Relationship Between Short-Term Uses of the Human Environment and the Maintenance and Enhancement of Long-Term Productivity

The Outrigger Telescopes Project would be an important addition to California's research and development industry, which can provide broadened employment opportunities for State residents. The productivity of Mount Wilson, however, cannot be measured in purely traditional economic ways. Mount Wilson is a natural and scientific resource that belongs to all State residents and future generations. The use of the mountain as an astronomical observatory need not be incompatible with its use by recreational users and tourists.

Any assessment of Mount Wilson's role as an astronomical observatory versus its role as a natural laboratory for other scientists or an aesthetic and recreational resource, should recognize that astronomy and other activities on Mount Wilson are not mutually exclusive. Upon removal, long-term productivity would not be affected.

6.3.7 Irreversible and Irretrievable Commitment of Resources

The Outrigger Telescopes Project would require a commitment of natural, physical, and human resources causing an irreversible and irretrievable commitment of resources in all these categories. A commitment of resources is irreversible when primary or secondary impacts limit the future options for a resource. An irretrievable commitment refers to the use or consumption of resources neither renewable nor recoverable for future use.

Construction of the Outrigger Telescopes would consume energy and building materials. In general, construction equipment would consume natural and propane gas and diesel fuel and these fuels would generate electrical power and heat. The electrical power requirement of each Outrigger Telescope is estimated to be 30 kW (UH IfA 2001a). The electrical utility supplying the observatories would supply additional electrical demand largely through fossil-fuel power. The consumption of petroleum products during operation would be significantly less than during construction. Although construction material such as steel, cement, and aggregate would also be expended, these physical resources are generally in sufficient supply, and their consumption would not have an adverse effect on availability. In some instances, some material resources such as structural steel and copper wiring could be reclaimed, recycled, and reused.

Trade and unskilled laborers would be employed during the development, construction, and operation of the Outrigger Telescopes. Labor is generally not in short supply, and commitment to the project would not have an adverse effect on its continued availability.

6.4 PALOMAR OBSERVATORY

Millions of San Diego and Riverside County residents regard Palomar Mountain as a historic mountain. Home to the

Palomar Observatory, the mountain is well known for its star-gazing opportunities and dark-night skies (USDA 2004).

6.4.1 Palomar Mountain, California

6.4.1.1 Proposed Facilities

See Section 2.1.2 for a detailed description of the proposed facilities for the Outrigger Telescopes. Figure 6-3 illustrates the proposed site layout for the Outrigger Telescopes on Palomar Mountain.

6.4.1.2 On-Site Construction and Installation of the Outrigger Telescopes at Palomar Mountain

Schedule. Construction operations at the 1,674-m (5,500-ft) elevation in the area around Palomar Mountain are possible during for most months throughout the year. The mountain roads' southern exposure allows rapid melting during the short-lived snowstorms that occur during the winter months. The relatively gentle site terrain and access road grades allow year-round access for large construction vehicles. The time required for construction of this project would probably be 20 to 24 months. Based on an average annual rainfall of approximately 76 cm (30 in), construction activities would be completed in slightly more than 2 calendar years.

Estimated Excavation. Construction of the Outrigger Telescopes Project would require building pad earthwork and preparation and foundation excavations for each of the four telescopes, each of the enclosures, the light beam tube support structures, and the beam-combiner facility.

The ridge-top terrain in the Long Canyon site would require a cut-and-fill operation involving more earthwork than a project of equal square footage on a level site. The pads for the four approximately 93-m^2 (1,000-ft^2) telescope buildings and the approximately 743 m^2 (8,000-ft^2) beam-combiner building would be about 1,835 m^3 (2,400 yd^3). This work would be related to creating a level pad on the crest of an existing knoll and establishing the four telescope enclosure pads on equal contour lines around this "center." The Outrigger Telescopes Project would balance the amount of cut or excavated material required with the amount of backfill to minimize the transportation of soils or aggregate to and from the site.

The access trail to the site for construction activities would remain in use for the life of the Outrigger Telescopes Project. Designed to handle the traffic and loads anticipated as a part of the operations and maintenance of this facility over an extended period of time, it would follow the ridgeline from the existing observatory corridor to the array site, a distance of 37 m (120 ft). The design of the trail would minimize the potential for erosion and concentrated runoff. Based on the current design criteria and configurations, between 229 and 153 m^3 (300 and 500 yd^3) of material would be excavated and moved for this access trail.

Grading Plans. The Outrigger Telescopes foundation would be set as close to the existing grade as possible, using a balance cut-and-fill method to achieve the desired elevation for optimal interferometric measurements. On the Long Canyon Ridge site, a concentricity concept about the knoll would allow the construction of each of the telescope piers between the 1,692- and 1,700-m (5,550- and 5,575-) amsl contours. The pier construction might allow each of the telescopes atop its concrete mount to sit at an elevation of 1,700-m (5,576-ft) amsl.

Foundations and Footings. Estimated concrete volumes for development of a

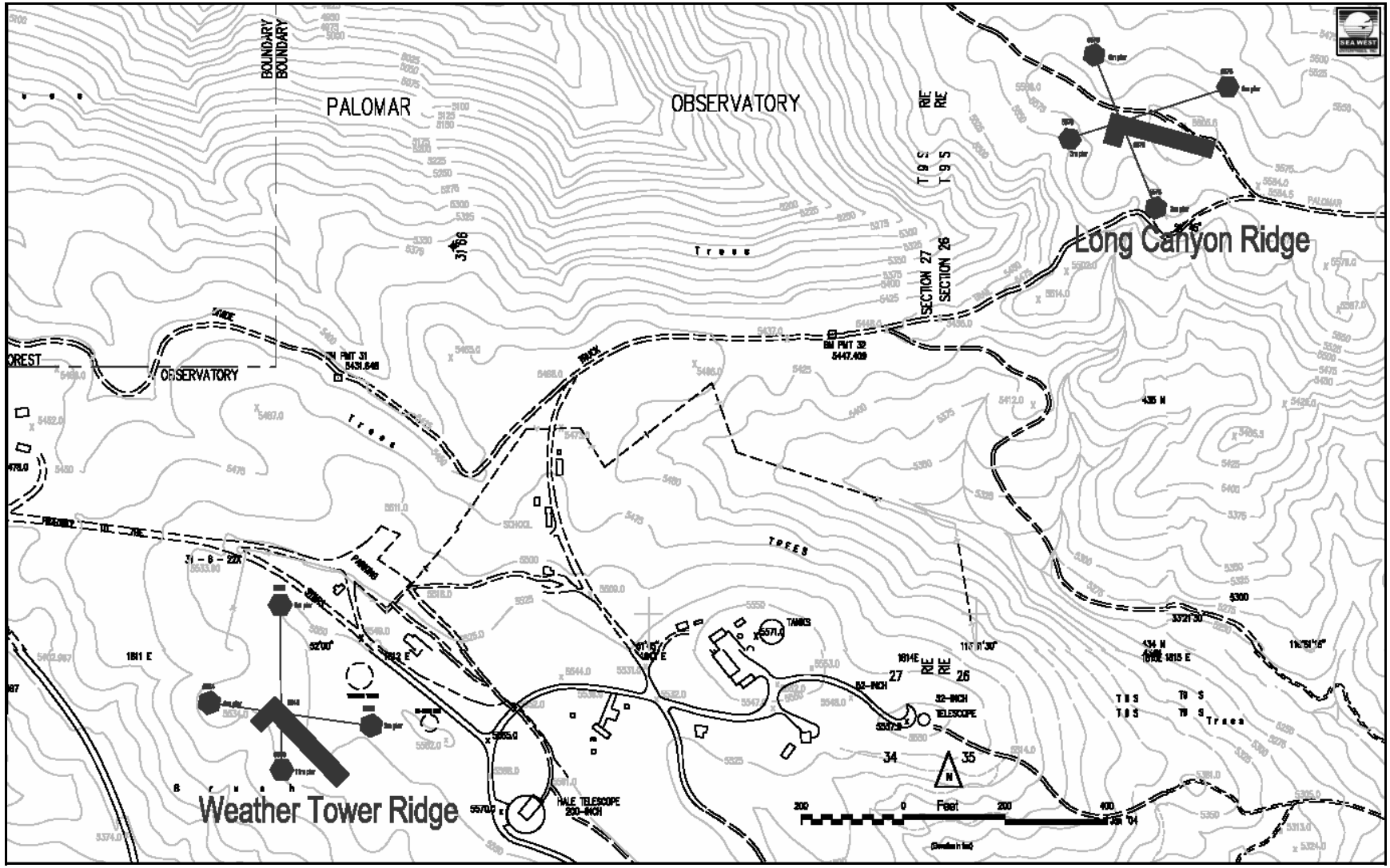


FIGURE 6-3. PROPOSED SITE LAYOUT OF THE OUTRIGGER TELESCOPES ON PALOMAR MOUNTAIN

four-aperture array on the Long Canyon Ridge site at Palomar Observatory would require the delivery of up to 600 truckloads of concrete both for building foundations/slabs, interferometer inertia pads, and telescope mounts. Premixed concrete could be delivered to the observatory site to minimize the on-site water demand.

Installation of Telescopes and Dome Enclosures. The Outrigger Telescopes Project, constructed within the Long Canyon Ridge site at the Palomar Mountain Observatory, under the current design configuration would consist of four 1.8-m (6-ft) telescopes/enclosures arranged around a central combiner facility. The final collective footprints of the four telescope enclosures, light beam foundations, and the combiner building would be approximately 1,301 m^2 (14,000 ft^2). The access trail, suitable for light vehicular traffic, would disturb approximately 836 m^2 (9,000 ft^2) of additional terrain, most of which would be within the site occupied by the array itself. Overall, the total project site would encompass approximately 5 ha (2 ac) of land in and among the telescope enclosures, the light beam paths, access trails, and the beam-combiner building locations. Necessary project staging and laydown areas would be located within this 5-ha (2-ac) plot. If deliveries and/or staging requirements require off-site holding, Palomar Observatory administration would identify suitable locations with both environmental sensitivities and observatory operations in mind.

On-Site Construction Facilities/ Equipment. The soil and rock types found within the boundaries of the Palomar Observatory appear to be friable and would require the use of conventional earthwork and grading equipment. Rubber-mounted backhoes, articulated loaders, track-mounted excavators and drill rigs would likely be among the earth removal/moving equipment involved in the construction activities for the Outrigger Telescopes Project. During the earthwork, transport vehicles, including 12 metric tons (mt) (26,000 lb GVW) bobtail trucks and 23 mt (25-ton) capacity truck and trailer combinations rigs would be used to transport, handle, dispose of and deliver soil and aggregate, as required.

On-Site Construction Employment and Costs. The workforce anticipated for this project would vary from an average of 25 to 35 workers to a peak of 60 workers. Throughout the concrete/foundation portions of the project and into the rough construction of the buildings and enclosures, the limited space to stage equipment and material deliveries, for the most part, would limit crew size. Once the building shells are completed, additional specialty contractors and technicians might increase the peak crew 50 to 60 individuals for the short term. Final installations for both the building facilities and telescope/delay line systems would once again require a smaller focused effort and result in a substantial reduction in personnel and equipment.

Construction Management. The contractor would be required to follow the approved construction Best Management Practices Plan (BMP) during all on-site construction and installation activities. The final BMP will be incorporated into the construction contract.

Construction Traffic. During construction of the Outrigger Telescopes Project, the ADT may vary between 50 and 75, (depending on the workforce size and equipment/material delivered). At peak periods, the ADT could reasonably exceed 100 vehicles, but is small compared to the

ADT for Palomar Mountain Road intersection with CA Highway 76 (the estimated closest monitored site to the CA-76/South Grade Road intersection). The California Highway Patrol recently estimated the ADT at about 10,000 vehicles. The closest regional artery to the Palomar Observatory is Interstate 15. The 2002 ADT volume for I-15 at the point of intersection with CA-76 was 117,000 vehicles. The paved sections along the State routes provide sufficient durability to handle traffic associated with this construction project.

6.4.1.2 Operations of the Outrigger Telescopes Project on Palomar Mountain

Employment and Economics. The current daily operational workforce at the Palomar Observatory is about 24 technicians, science team members, and facilities staff.

The Outrigger Telescopes would be operated both locally and remotely during its multi-year science mission. The primary on-site activities would require a staff of trained individuals; mechanical engineer, electrical engineer, optics specialist, software specialist, two technicians, and a supervisor. The resident science team would be two or three individuals, depending on the ongoing activity and programs underway, with an average daily workforce of six people.

Traffic. Operation of the Outrigger Telescopes at the Observatory would add 6 to 12 vehicular trips daily to Palomar Mountain Road and to South Grade Road that provides vehicular access to the Palomar Observatory.

Infrastructure and Utilities. All utilities—water, power, communications and sewage facilities—would be fully provided from existing infrastructure on Palomar Mountain.

San Diego Gas & Electric provides 12 kW at 480 volts to the Palomar Observatory. The Observatory infrastructure includes an underground power grid and backup generator that is near capacity with about 50 KVA available. If the Outrigger Telescopes were placed here and current electrical supply deemed insufficient, additional power could be made available with the installation of another transformer

The Observatory's telecommunication infrastructure includes an underground fiber optic backbone supported by two T1 lines serviced by Cox Communications and regular telephone service provided by SBC, with an Ethernet radio link equivalent to a T3 line.

Maintenance. During the ramp up phase of the Outrigger Telescopes Project, the on-site staff would focus on commissioning the interferometer, specifically on calibrating and integrating the telescopes, pointing and tracking tests, encoding enclosure domes, and generally working out control systems needed to coordinate the simultaneous operation of the four telescopes, their domes, and the delay line systems. Alignment of delay line, meteorology, and beam-combiner systems within the main building would also be underway. These activities require the participation of engineers and scientists in a collaborative effort to achieve first light. After the staff completes initial testing and calibration of the interferometer, they would focus on instrumentation, and further calibration and troubleshooting, possibly incorporating spectrographs, CCD cameras, and infrared equipment into the array.

During these activities personnel would move between the control room, combiner facility, and individual telescope locations to conduct the necessary installations and testing. These activities would probably not

require the use of heavy equipment or generate noise above normal operating levels associated with pedestrian traffic at the site and occasional vehicular arrivals and departures from the mountain. Once completed, the level of activity in and around each telescope sites and within the delay line and beam-combiner facility would decrease dramatically. The interferometer is intended to be operated via a high-speed data connection, ultimately from a remote site.

During the lifetime of the Outrigger interferometer, ongoing activities would include scheduled equipment and facility maintenance, re-instrumentation and calibration, periodic optics recoating activities, and system monitoring.

The quantities and use frequency of materials deemed hazardous during the operation of the Outrigger Telescopes are limited to lubricants and mirror-care chemicals. There are no airborne pollutants associated with the operation of an optical interferometer.

6.4.2 Affected Environment

This section describes the existing environment in and around Palomar Mountain, California, which serves as a baseline from which to measure environmental impacts resulting from activities associated with the reduced science alternative. Figure 6-4 shows a regional map of Palomar Mountain.

6.4.2.1 Land Use and Existing Activities

Land Use. The Palomar Observatory is located in northern San Diego County, approximately 26 km (16 mi) east of Interstate 15 and 8 km (5 mi) north of State Route 76. This region of California's Peninsular Range is characterized by low rolling mountaintops, approximately 1,676 m (5,500 ft) at msl, interlaced with isolated alpine meadows.

The Observatory occupies the summit area of Palomar Mountain and is surrounded by rural and wilderness lands under both private and government ownership.

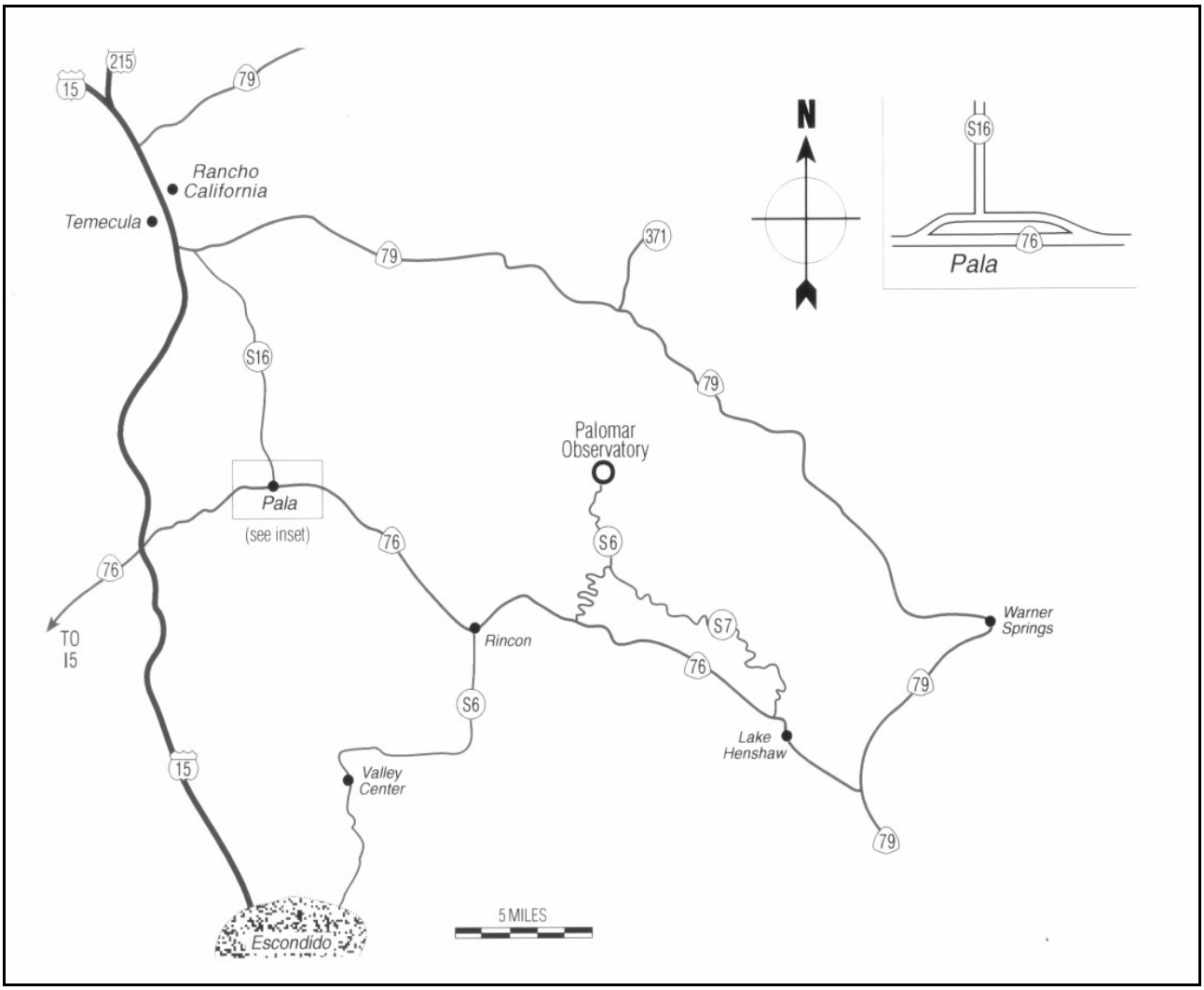
Surrounded by more than 23,472 ha (58,000 ac) of the Cleveland National Forest's Palomar Mountain Planning Unit, the 815 ha (2,013 ac) that comprise the Observatory were purchased by the California Institute of Technology (Caltech) beginning in November 1934 (Assessors Parcel Numbers 112-180-14, 112-230-21, 112-110-07, & 112-130-18).

The USFS lands surrounding the Palomar site include more than 6,070 (15,000 ac) of the Agua Tibia Wilderness, over 8,095 ha (20,000 ac) of undeveloped and no-road-access land and more than 2,020 (5,000 ac) of potentially unique vegetation. There are no classified Special Interest Areas, Research Natural Acres, or Experimental Forests within the immediate vicinity of the site.

To the west of the Palomar Observatory sits the 763-ha (1,886-ac) Palomar State Park. Locally, 3,440 ha (8,500 ac) of wilderness area has been deeded to the Pala and Pauma tribes of the Mission Indians.

Grazing is the primary agricultural land use within the immediate vicinity of the site. Mining operations are ongoing to the northeast and within 4.8 km (3 mi) of the Palomar Observatory.

As privately owned land, the Palomar Observatory is subject to the planning and jurisdictional control of San Diego County under the North Mountain Subregional Plan (Part XVIII of the San Diego County General Plan).



Source: SeaWest, Inc. 2004b

FIGURE 6-4. REGIONAL MAP OF PALOMAR MOUNTAIN, CALIFORNIA

As of 1994, the Observatory has operated under a Major Use Permit (MUP # P94-021) granted as part of the approval process for the Palomar Testbed Interferometer Project constructed by the Jet Propulsion Laboratory. The MUP also contains provisions for the operation and maintenance of the multiple observatories built prior to the permit issuance including the:

- 508-cm (200-in) Hale Telescope
- 102-cm (40-in) Oshcin Telescope
- 46-cm (18-in) Schmidt Telescope
- 152-cm (60-in) reflecting telescope.

Additionally, the MUP covers the operations of the various buildings, structures, and roads existing at the time of application:

- Twelve-room lodge/dormitory
- Thirteen employee cottages

- Maintenance facility, including machine shop, auto repair shop, and wood shop
- 190-kl (50,000-gal) high tower water tank
- 38-kl (10,000-gal) propane storage tank
- 7.6-kl (2,000-gal) gasoline storage tank
- 5.7-kl (1,500-gal) liquefied nitrogen tank
- 6.4 km (4 mi) of paved roads and 32 km (20 mi) of unpaved roads
- 3,785-kl (1,000,000-gal) water reservoir.

Existing Activities. The Palomar Mountain region has a number of hiking and recreation trails both on and around the 815-ha (2,013-ac) site, including Doane Valley Nature Trail, Weir Trail, French Valley Trail, Observatory Trail, and Boucher Hill. The Palomar Observatory is a destination for tourists and outdoor enthusiasts, and it hosts facility tours, museum displays, telescope viewing gallery, and gift shop.

6.4.2.2 Cultural Resources

Resource Definition. See Section 3.1.2.1 for cultural resource definitions.

Cultural Environment. A San Diego County staff archaeologist recently investigated the State-maintained archaeology database for the property parcels associated with the Palomar Observatory and concluded that no "archaeology surveys or archaeology sites have been recorded for these parcels. However, there have been archaeology surveys and archaeology sites found on nearby properties" (Stevenson 2004b). (The surveys on nearby properties were not done in connection with San Diego County-issued permits; therefore, the County does not have specific documentation on those particular surveys and sites.)

San Diego County does recognize the archaeological, historical, and cultural significance of Palomar Mountain and recommends in their current County General Plan: Part XVIII North Mountain Subregional Plan that "wherever an environmental analysis is required, archaeological surveys with these areas would aid in protection of the archaeological history" (San Diego County 2002).

6.4.2.3 Biological Resources and Threatened and Endangered Species

Biological Resources. Montane coniferous forest with areas of open grass dominates the landscape of the Palomar Observatory grounds. The forest and the species it supports are unique to southern California and qualify Palomar Mountain as a Resource Conservation Area. Evergreens that populate the forest on and around the site include tall Coulter pines, Jeffrey pines, big cone Douglas fir, white fir, incense cedar and giant Sequoia trees. The giant Sequoias planted by Observatory staff in the 1920s, are not native to the site. Bark-beetle infestation is a current threat primarily to the Coulter pines surrounding the site. Annually, the forest receives 71 to 91 cm (28 to 36 in) of rainfall. Mountain lions, bobcats, and reptiles including the California mountain king snake inhabit the Palomar Mountain region. The spotted owl prevalent throughout mountainous regions of western North America, has an estimated population that ranges from 42 to 60 in the Palomar region (as of 1994). Their habitat elevations range from 800 to 2,600 m (2,625 to 8,530 ft) and occur in forests of

mixed conifer canyon live oak, and big cone fir.

The Observatory property has various vegetative climates in addition to the montane coniferous forests: black oak woodlands, mixed evergreen forest, Sierran mixed coniferous forest, and bigcone spruce-canyon oak forest. Five main types of chaparral surround the observatory grounds: granitic northern mixed chaparral, scrub oak chaparral, montane scrub oak chaparral, montane chaparral, and most prevalent, red shank chaparral. Dry Montane Meadows span the areas between the cool upland slopes where the forests are located. The Dry Montane Meadows consist of grasses surrounded by bracken. Graminoid species in the area include Mexican rush, Toad rush, Kentucky bluegrass, and cluster field-sedge, dominated by bracken fern. The San Diego milk vetch *(Astragalus oocarpus*), a Category 2 species endemic to San Diego County, is found in chaparral at the edges of the dry montane meadows. A 1994 survey of the area identified a small population of this plant east of the Palomar Testbed Interferometer building site.

Horkelia clevelandii, the Cleveland horkelia, is also found in the meadows of Palomar Mountain. This plant is host to the Laguna Mountains Skipper butterfly. In 1997, both the Cleveland horkelia and the Laguna Mountains Skipper butterfly were Federally listed as endangered. Both occur on "meadow margins within northwestern points of the Palomar Observatory lands" (Osborne 2003). Cattle grazing in the Palomar Mountains have adversely affected the horkelia population. Studies have shown that the decline of the Laguna Mountain Skipper butterfly may be directly related to the declining population of the Cleveland horkelia. The Laguna Mountains Skipper will also use an additional host plant, *Potentilla glandulosa*, and also lives in small wooded glens and large open meadows, suggesting that the species may occur in many unstudied areas in the Cuyumaca, San Jacinto, Palomar, Laguna, San Gabriel, and the San Bernardino Mountains.

In a more current survey conducted by the FWS in 2002, Laguna Mountains Skipper was not detected on Observatory lands. However, survey conditions were extremely difficult because of grasshoppers that came into maturity. The grasshoppers flew within a few meters of the surveyor's approach preventing small butterflies such as the Laguna Mountains Skipper from being seen.

Threatened and Endangered Species. The Southern bald eagle (*Haliaeetus leucocephalus leucocephalus*) a Federally listed endangered species. Migrant birds of this species visit the area during the winter season. Roosting areas are located on Palomar Mountain, but no active nests have been identified (Planning Unit 1976).

6.4.2.4 Hydrology, Water Quality, and Wastewater

Regulatory Framework. The SWRCB and the RWQCB administer the CWA and State water regulations in California. The San Diego RWQCB is the local agency responsible for the Palomar Mountain area. The RWQCB manages the California NPDES permits process. State regulations have a waste discharge requirement (WDR) for permitting discharge. A report of waste discharge (RWD) is required for actions that would involve discharge of waste to surface and/or groundwater. The California Porter-Cologne Water Quality Act implements the NPDES program for the State (USAF 1998).

Surface Water. The variable nature of rainfall, rainfall cycles, and groundwater

infiltration-storage-release factors creates highly variable surface water quality. Surface water normally does not contain more than 1,000 mg/l of total dissolved solids (TDS), except near the ocean or estuaries. Imported Colorado River water occasionally exceeds 700 ppm TDS at the westerly portal of the San Jacinto Tunnel. The most significant potential source of degradation to existing water quality would be sedimentation from erosion after a large wildfire (Planning Unit 1976).

Groundwater in the Palomar Mountain Area. The Palomar Observatory is completely dependent on local groundwater for its water supply.

The North Mountain Subregion's water supply is generated from groundwater. Water companies with districts in this area include: (1) Palomar Mountain Mutual Water Company, (2) Bailey Mutual Water Company, and (3) Los Tules Mutual Water Company (San Diego County 2002).

There are no designated sole source aquifers at or near the proposed site. The closest sole source aquifer is the Campo/Cottonwood Creek Aquifer located near the San Diego/Mexico border. Observatory property is not located on a 100-year flood plain. There are no wild and scenic rivers at or near the Observatory.

Stormwater runoff from the Observatory goes into the Santa Margarita River to the north and the San Luis Rey River to the south. A portion of this runoff is collected in the Redec, Tule Creek, Pauma, and Warner sub-basins.

According to County documentation, groundwater recharge is conservatively estimated at 18,500 m^3 (15 acre-feet) per acre per year for the Palomar area.

The groundwater extraction rate is estimated at 620 m^3 (0.5 acre feet) per acre per year per household, assuming a three-member household and includes landscape and domestic water use. This estimate excludes water recycling to groundwater by septic disposal system(s), which would be taken into consideration at the Observatory.

Domestic Wastewater Collection, Treatment, and Disposal. The Observatory uses septic tanks with leach lines to process the effluent/wastewater. Comments from the Observatory Superintendent indicate that reported recent difficulties in obtaining a permit far a septic system upgrade were related to the selection of a wetland location as the installation site. Avoidance of these habitats would be necessary for any proposed projects at the Observatory.

6.4.2.5 Waste and Hazardous Materials Management

Solid Waste. The Palomar Mountain area has three bin-transfer sites, the closest being the Palomar Mountain site. Solid waste is collected at this site and hauled to the nearest landfill in Ramona. However, San Diego County is considering a new, closer landfill area in Gregory Canyon. The Observatory itself has two 4.6 m^3 (6 yd^3) solid waste/trash dumpsters that are emptied weekly by a contractor.

Hazardous Waste. Palomar Observatory currently has on file with the County of San Diego, Department of Environmental Health (DEH), Establishment Permit Number 104071, inventory of hazardous materials (Table 6-11) and hazardous waste materials (Table 6-12) stored on site.

Palomar Observatory recoats telescope optics on site. The facility has the capacity to handle all mirrors up to 190 cm (75 in) in diameter, and with some modification, can

TABLE 6-11. PALOMAR OBSERVATORY HAZARDOUS MATERIALS DISCLOSURE

Chemical Name	1st Hazard Category	2nd Hazard Category
Acetylene	Fire	Acute
Argon	Pressure Release	
Carbon Dioxide	Pressure Release	
Diesel	Fire	Acute
Gasoline	Fire	Acute
Helium	Pressure Release	
Kerosene	Fire	Acute
Liquid Nitrogen	Pressure Release	
Mineral Spirits/Paint Thinner	Fire	Acute
Motor Oil & Hydraulic Fluid	Fire	Acute
Oxygen	Fire	Pressure Release
Paints	Fire	Acute
Propane	Fire	Pressure Release

Source: SeaWest, Inc. 2004b

TABLE 6-12. PALOMAR OBSERVATORY HAZARDOUS MATERIALS WASTE STREAM

Waste Category	Annual Quantity	Storage Method
Waste Oils	2,700 l (720 gal)	Metal Drum
Waste Latex Paint	1,800 l (470 gal)	Metal Drum
Waste Solvent	9.1 kg (20 lb)	Can
Absorbent Rags	125 lb (275 lb)	Metal Drum
Used Oil Filters	9.1 lb (20 lb)	Metal Drum

Source: SeaWest, Inc. 2004b

service the larger optics within the Observatory. The process involves the acid etch removal of old reflective coatings and re-application of a molecular aluminum coating in a vacuum chamber.

Fewer than 19 l (5 gal) of reflective mirror treatment solution (HCl) are stored on site. The excess waste is neutralized with either calcium carbonate or lime.

Palomar Observatory has and emergency action plan, and employees are responsible for understanding and following its procedures. In the event of a minor spill of a chemical, Observatory personnel alert people in the area of the spill; confine the spill; avoid breathing vapors from the spill; and, during clean-up, wear personal protective equipment, such as safety glasses, gloves, and a lab coat.

For emergency situations, the On-Call Supervisor is responsible for notifying the appropriate regulatory agencies and coordinating personnel evacuation, as

needed. Subsequent documentation is provided by the Superintendent and On-Call Supervisor.

6.4.2.6 Geology, Soils, and Slope Stability

Palomar Mountain is located in the central portion of the Peninsular Range batholith. This range extends from the Santa Ana Mountains to the north into Baja California to the south, with rock types consisting of metavolcanics, metasedimentary, and igneous crystalline bedrock. A majority of the mountain consists of granite interlaced with some metamorphic rock.

In this region, the primary geomorphic processes are mass wasting and fluvial erosion. The summit areas of Palomar Mountain are overlain by decomposing granitic soils (mafic plutonics to diorites), ranging from fine sandy loams to loamy coarse sand. These soils vary in depth from exposed bedrock down to several tens of feet, with depth variations a function of both elevation and slope, (typically thinning on the steeper slopes and at higher elevations).

Figure 6-5 shows the Palomar Observatory site, indicating the terrain in excess of 25 percent slope (Stevenson 2004h).

There are no designated floodplains within the Palomar Observatory.

6.4.2.7 Transportation

Palomar Mountain is located within San Diego County. Access to Palomar Mountain is via I-15 to I-76 eastbound and then to County Road S-6, which ends at the Observatory gates. The nearest cities are Escondido and Temecula, approximately 48 km (30 mi) from the Observatory. Approximate travel time from Pasadena to the Observatory is 2 hours. County Road S-6 is a paved and maintained mountain road, the only road maintained by the San Diego County; all others are private and maintained by the Observatory (SeaWest, Inc. 2004a).

The ADT for traffic on the major traffic arteries that connect the Palomar Mountain community and observatory to the rest of southern California are as follows:

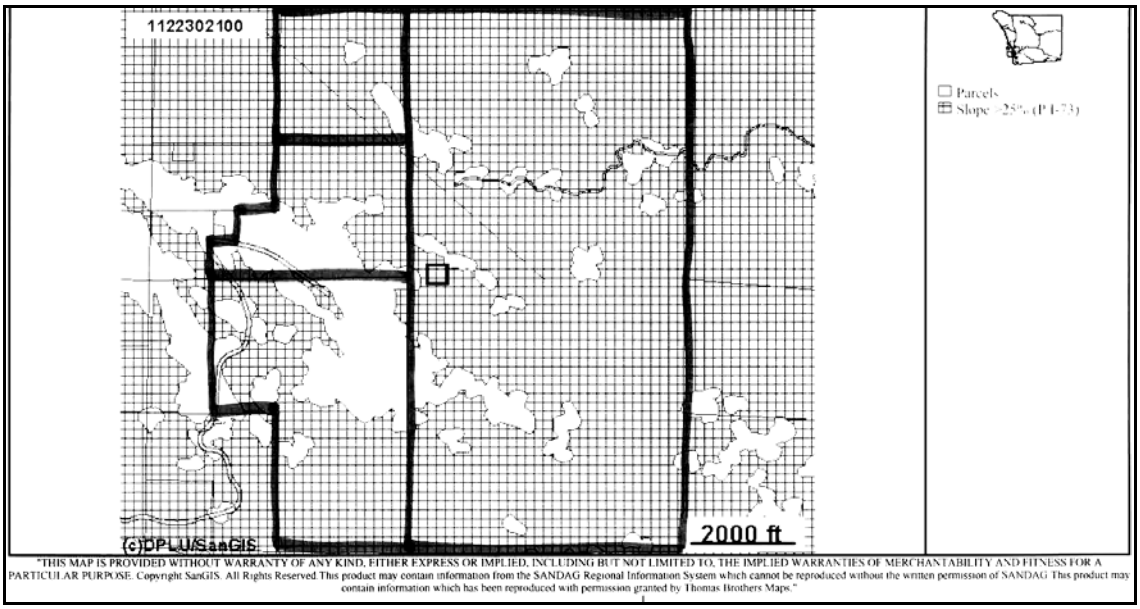
- At the Interstate 15 and California CA-76 junction, the 2002 ADT was 117,000 vehicles.
- The 2002 ADT on CA-76 at Palomar Mountain Road (the estimated closest monitored site to the CA-76/South Grade Road intersection) was 3,600 vehicles. However, recent California Highway Patrol estimates bring the ADT closer to 10,000 vehicles.

6.4.2.8 Utilities and Services

Water Supply. The Observatory has its own wells for water supply. Two wells and five springs are located on site. The Observatory supports a 3,785-kl (1,000,000-gal) water storage tank on site (SeaWest, Inc. 2004a).

Palomar Observatory currently utilizes a 26,497-kl (1,000,000-gal) reservoir and a 190-kl (50,000-gal)-high tower pressure tank, licensed small water system. The average weekly water consumption at the Observatory is approximately 265 kl (70,000 gal). The majority of use occurs during the summer months, likely due to the public restrooms (estimated 100,000+ visitors per year) and irrigation systems for lawns within the Observatory. The Palomar Observatory is completely dependent on the limited local groundwater resource for its water supply (SeaWest, Inc. 2004b).

Electrical Power and Communications. San Diego Gas & Electric providing 12 kW



Source: Stevenson 2004h

FIGURE 6-5. PALOMAR OBSERVATORY SITE INDICATING THE TERRAIN IN EXCESS OF A 25 PERCENT SLOPE

at 480 volts of electricity to the Palomar Observatory. The Observatory infrastructure includes an underground power grid and backup generator. The generator is nearing capacity, with about 50 kVA available.

The Observatory's telecommunication infrastructure consists of an underground fiber optic backbone supported by two T1 lines (serviced by Cox Communications), regular telephone service (provided by SBC), and an Ethernet radio link equivalent to a T3 line. Also, Caltech is currently funding the construction of a new microwave antennae communication, projected to be completed by year's end (SeaWest, Inc. 2004b).

Emergency Services and Fire Suppression.

Emergency Services. An updated Emergency services plan is available for Palmer Observatory.

As a result of the isolated work location of the Palomar Observatory, many miles from the nearest professional EMS, the employees at each observatory facility are the primary source of first aid assistance. There are no emergency medical facilities on Palomar Mountain. 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 available equipment. In addition, the plan recommends that some staff members undergo EMT training and that each facility establish regular first aid drills and test emergency and safety equipment.

The closest hospital facility is Palomar Medical Center in Escondido. Police

protection and ambulance services are provided by the County Sheriff, Rural Law Enforcement Division, which serves 6,734 km^2 (2,600 mi^2) – from the Riverside County line to the Mexican border –and is staffed by 19 resident deputies, each serving 389 km^2 (150 mi^2), and by the California Highway Patrol. Two Sheriff substations are located in Julian and Valley Center, and two offices, in Ranchita and Warner Springs. In September 2003, the CHP opened a satellite office in Pauma Valley to handle the increased traffic on CA-76 and on Valley Center Road. Sheriff's deputies and volunteer fire department personnel, who all have EMT training, also handle medical emergencies.

Fire Suppression. The fire suppression equipment at the Palomar Observatory consists of widely available handheld fire extinguishers, which consist of halon and dry chemical (A-B-C) types. Breathing apparatuses are also available. A 3,785-kl (1,000,000-gal) water storage tanks feeds the water system that is attached to the hydrants.

Fire protection is provided by the USFS during the fire season and by the local Palomar Mountain Volunteer Fire Department (CSA1100) all year, the fire department is located at S-7 and Crestline Road, approximately 9.7 km (6 mi) from the Observatory.

6.4.2.9 Socioeconomics

The total population of San Diego County as of 2003 was 2,951,600 and is forecasted to increase by an average of 1.5 percent per year to approximately 3,885,500 by the year 2020. San Diego County is the fourth most populated county in the nation, with a median household income of $49,649 and 2003 unemployment rate of 4.5 percent.

The closest metropolitan community to Palomar Observatory is Escondido, about 32 km (20 mi) to the southwest. Escondido's total 2003 population was 138,015, with approximately 45,800 housing units (single-family homes, multifamily units (apartments) and mobile homes) with a median household annual income of $45,165.

The current population of the North Mountain Subregion is 2,619, with the County estimating future population growth up to 5,281 by the year 2020. The existing population for Palomar Mountain, based on 2000 census data, is 245.

6.4.2.10 Climate/Meteorology/Air Quality

Climate/Meteorology. Mean annual precipitation for the Palomar Observatory area is 71 cm (28.07 in). Snowfall accounts for additional 91 cm (36 in) per year, on average. The Palomar climate does not hold snow pack, and the largest average snow depth (occurring in January) is 5 cm (2 in). The mean freeze-free period for the Palomar Mountain region is about 200 to 250 days, and the mean annual temperature for the Observatory area is 13.3° C (55.9° F). Predominant wind direction for San Diego County is from the northwest.

Air Quality

Regulations. See Section 3.1.11.2 for a discussion of Federal regulations. Air quality for the Palomar Mountain area is also regulated under the California Code of Regulations (CCR), Title 17.

The San Diego County Air Pollution Control District (SDCAPCD) also regulates Palomar Mountain, incorporating the Federal regulation for Operating Permits under Title 40 CFR Part 70.

Air Quality Monitoring. Air quality in California is assessed on a county and regional basis. Both the U.S. Environmental Protection Agency (EPA) and California Air Resources Board have designated the SDAB as being in attainment of the NAAQS for SO_X, NO_X, and CO. San Diego County has been designated by the EPA to be unclassified with the Federal PM_{10} standard but has been designated by California Air Resources Board to be in nonattainment with the more stringent California standard for PM_{10}. The EPA has classified San Diego County as being in serious non-attainment for the Federal ozone standard.

> The Palomar Observatory site is within Zone A, an area designated by San Diego County Ordinance No. 6900 as "*…the circular area, fifteen (15) miles in radius centered on the center of Palomar Observatory…*" (SD Ordinance 2000b). Palomar Mountain is essentially free of the smog that is characteristic of southern California. In addition, air quality for Palomar Mountain is generally good to excellent.

6.4.2.11 Noise

According to statements in the USFS Environmental Statement for the Palomar Mountain Planning Unit (1976), "there is no identifiable sound disturbance associated with the lands within or adjacent to the unit….Affected areas can best be described as point source sounds originating from any one of the roads described…. and areas of concentrated use…" The USDA Palomar Mountain Planning Unit encompasses the Palomar Observatory, which has never been named as a source of noise within Federal, County, or State publications.

San Diego County publication, Code of Regulatory Ordinances, February 2000, mandates that for the Palomar Observatory, the maximum noise sources may not exceed the following standards:

- 50 dBA (7:00 a.m. to 10:00 p.m.)
- 45 dBA (10:00 p.m. to 7:00 a.m.) (see Table 6-13).

There are currently no on-site sources that exceed these standards.

The North Mountain Subregional Plan, part XVIII of the SDC General Plan, dated April 2002 …" that noise generated in rural areas can travel greater distances and is much more noticeable therefore potentially more irritating to residents…."

The Birch Hill and Palomar Mountain Sub-Divisions located south-southeast of the Palomar Observatory are the residential communities nearest to the site. Both communities are documented as approximately 4.8 km (3 mi) from the Observatory site, placing each development approximately 3.2 km (2 mi) from the southern observatory boundary line. There are also sparsely distributed private residences located near Bull Pasture and around the Crestline group, both of which lie within 3.2 to 4.8 km (2 to 3 mi) of the Observatory grounds.

6.4.2.12 Visual/Aesthetics

Palomar Observatory sits at an elevation of 1,676 m (5,500 ft) above sea level surrounded by elements of the Cleveland National Forest. Above the 5,000-foot elevation the visual aspects of this terrain are described as follows:

> *…plateaus with mixed conifer stands and oak woodlands… large meandering meadowlands… found in protected valleys and occasionally on coastal facing slopes. Weathered rock*

TABLE 6-13. SAN DIEGO COUNTY NOISE ORDINANCE EXTERIOR NOISE STANDARDS

Zoning	Noise Metric	Noise Level Not to be Exceeded	
		7 A.M. to 10 P.M. (Daytime)	10 P.M. to 7 A.M. (Nighttime)
R-S, R-D, R-R, R-MH, A-70, A-72, S-80, S-81, S-87, S-88, S-90, S-92, R-V, and R-U Use regulations with a density of less than 11 dwelling units or less per acre.	L_{eq} (1-hour)	50 dBA	45 dBA
R-RO, R-C, R-M, C-30, S-86, R-V, and R-U Use regulations with a density of 11 or more dwelling units per acre.	L_{eq} (1-hour)	55 dBA	50 dBA
S-90 and all other commercial zones	L_{eq} (1-hour)	60 dBA	55 dBA
M-50, M-52, M-54	Anytime	70 dBA	70 dBA
S-82, M-58, and all other industrial zones	Anytime	75 dBA	75 dBA

Source: San Diego County Code, Section 36.404

a. Zoning Designations:
R-C, R-D, R-M, R-MH, R-R, R-RO, R-S, R-U, R-V = residential zones
A-70, A-72 = agriculture zones
M-50, M-52, M-54, M-58 = manufacturing/industrial zones
C-30 = commercial zone
S-80, S-81, S-82, S-86, S-87, S-90, S-92 = special purpose use zones

b. The noise limit shall be raised to the measures ambient noise level, if the ambient noise level is higher. The ambient noise level shall be measured when the alleged noise violation source is not operating.

c. The noise limit on the boundary between two zoning districts shall be the arithmetic mean of the respective noise limits, provided however, that the one-hour average sound level limit applicable to extractive industries (including but not limited to borrow pits and mines), shall be 75 dBA at the property line regardless of the zone where the extractive industry is actually located.

> *outcroppings are frequently found in these meadowlands and timber stands, but contrast little with the land due to their low relief.*
>
> USFS-R5 1976

California State Highway 76 and Canfield Road to the south of the Observatory are designated as Eligible State Scenic Highways. Therefore, these local routes fall under the San Diego County General Plan Scenic Highway Element's goals and objectives, including protecting and enhancing scenic resources within both rural and urban scenic highway corridors by establishing and applying design standards to regulate visual quality of development within scenic highway corridors.

San Diego County also addresses their concerns over retaining and enhancing the rural character of the Palomar Mountain community in the North Mountain Subregional Plan (Part XVIII), which

preserves existing natural landscape features. *"Natural landscape features include, but are not limited to: drainage courses, streams and other wetlands, ridgelines, rock outcroppings, native and old-growth vegetation and steep slopes greater than 25 percent"* (San Diego County 2002).

6.4.3 Potential Environmental Impacts of the Palomar Mountain Reduced Site Option

6.4.3.1 Land Use and Existing Activities

ROI for Land Use and Existing Activities. The ROI for assessing land use and existing activities includes areas near the Palomar Observatory, the Cleveland National Forest, and the travel routes used by construction and operation vehicles.

Land Use**.** *On-Site Construction and Installation Impacts.* The construction and installation of the Outrigger Telescopes at the Palomar Observatory would be subject to the review and approval processes of the San Diego County Department of Planning.

It is expected that the Outrigger Telescopes would fit within the basic guidelines for future projects at Palomar and would not result in any impact on designated land use at the Observatory.

Operation Impacts. The operation of the Outrigger Telescopes would be consistent with the current designated land use. There would be no impact associated with this phase of the Outrigger Telescopes Project.

Existing Activities. *On-site Construction and Installation Impacts.* Activities associated with the on-site construction and installation of the Outrigger Telescopes Project would occasionally delay traffic along State Route 76 and South Grade Road and temporarily increase noise levels. See sections related to transportation (Section 6.4.3.7) and noise (Section 6.4.3.12) impacts for additional information. The current viewscape of the proposed site and construction staging areas at the Palomar Observatory would be impacted temporarily by the presence of large construction equipment, materials, and telescope components. See Section 6.4.3.13 for more information regarding visual impacts.

Although some transportation, noise, and visual impacts would occur, it is anticipated that the Outrigger Telescopes Project would not result in a long-term conflict with or have a substantial impact on existing activities in the ROI. The ability to use the land within the ROI for astronomical and other scientific research, and a variety of recreational activities would remain consistent with the current use. In conclusion, all construction and installation activities on Palomar Mountain would be conducted in a manner that would allow the surrounding area to remain accessible for all existing activities.

Operation Impacts. It is anticipated that the Outrigger Telescopes would be both locally and remotely operated. The primary on-site activities would require a staff of trained individuals, likely to include mechanical engineer, electrical engineer, optic specialist, software specialist, two technicians and a supervisor. The resident science team would be two or three individuals depending on the activity and programs underway. Based on current plans, the average daily workforce would be six people.

All telescope and facility operations associated with the Outrigger Telescopes Project would be conducted in a manner that would preserve access to the surrounding area for all existing activities. The only continuing impact of the

Outrigger Telescopes operations on existing activities would be the visual presence of the telescope enclosures. Thus, the impacts associated with this project phase would be insignificant.

Mitigation Measures. Refer to the following sections of this chapter for mitigation measures associated with transportation (Section 6.4.3.7), noise (Section 6.4.3.12), and visual (Section 6.4.3.13) impacts.

6.4.3.2 Cultural Resources

ROI for Cultural Resources. The ROI for the Outrigger Telescopes Project would be Palomar Mountain and access roads/trails and construction staging areas required for on-site construction and installation.

On-Site Construction and Installation Impacts. As stated in Section 6.3.2.2, no archaeological surveys have been conducted for either of the proposed Outrigger Telescopes locations. While there are currently no recorded sites for these land areas should the Outrigger Telescopes Project be implemented at Palomar Observatory, a cultural resources survey may be conducted.

It is anticipated that no culturally or historically significant sites would be found during construction. Therefore, on-site construction and installation would have no impact on cultural resources.

Operation Impacts. Operations of the Outrigger Telescopes would have minimal impact on cultural resources.

Mitigation Measures. In the absence of more detailed information indicating otherwise, an archaeological and cultural survey should be conducted prior to excavation according to a plan prepared detailing the steps to protect a discovery. If cultural or archaeological resources were to be found either prior to or during construction, appropriate protective measures and mitigation plans would be developed in accordance with applicable Federal and State regulation, and enforced.

6.4.3.3 Biological Resources

ROI for Biological Resources. The ROI for the Outrigger Telescopes Project consists of Palomar Mountain, any access roads/trails, and construction staging areas required for on-site construction and installation.

On-Site Construction and Installation Impacts. The Outrigger Telescopes Project would require the removal of trees in the immediate vicinity of the dome enclosures and combiner facility and along the access trail to the site.

Before any on-site construction, any and all critical habitat in the vicinity of project activities would be identified to ensure protection from disturbance. Signage, fencing, and field crew information sessions would be used to prevent disturbance and/or potential damage to the environment surrounding the project site access roads, and construction staging areas. Periodic inspection by qualified biologists and environmental scientists would ensure that construction site awareness and protection practices are enforced and maintained.

Operation Impacts. No biological impacts would occur as a result of operating the Outrigger Telescopes in the proposed project area.

Mitigation Measures. Within sensitive habitat areas, the removal of trees is often accompanied by a requirement for a one-for-one or two-for-one replacement with like species. If such a project requirement were imposed, the new trees would be planted at a reasonable distance from the

facility and other potential project areas. Due to the ongoing efforts to reduce combustible fuels in and around structures, such as those being conducted by the San Diego Forest Area Safety Task Force, it is anticipated that the removal of trees at the Long Canyon Ridge (or Weather Tower Ridge) site for the construction of the Outrigger Telescopes facility probably would not require tree replacement within the immediate vicinity of the Palomar Observatory infrastructure or science facilities.

6.4.3.4 Hydrology, Water Quality, and Wastewater

ROI for Hydrology, Water Quality, and Wastewater. The ROI for hydrology, water quality, and wastewater is defined as the Mount Wilson summit and any areas where construction laydown activities would occur.

Water Use and Wastewater Treatment and Disposal for Construction Workers. Separate work crews would be required to prepare the Palomar Mountain site for installation, erection, and testing of the Outrigger Telescopes and related components. The workforce would vary in size from 25 and 35 workers and short-term peaks of 50 to 60 individuals. The overall construction term would likely be approximately 20 to 24 months, and it is assumed all workers would commute to the site daily. Water supply and wastewater collection and disposal for construction workers would be handled by completely self-contained portable facilities. and serviced on a routine basis. They would create no hydrologic or water quality impacts.

The requirement to wash down trucks, tools, forms, and equipment during concrete placement, however, could account for 38 to 76 kl (10,000 to 20,000 gal) of water during the construction period. If workers must mix concrete on site, the amount of water would increase substantially. Wash-down basins/containers would be used to contain the wash water, which would be allowed to evaporate. The remaining solid residues would be disposed of off site.

Surface Runoff from the Palomar Observatory. Surface runoff from the construction site and laydown areas would be controlled through appropriate erosion and drainage controls as specified in applicable environmental permits and regulations. Impacts would be expected to be small lasting only for the 20–24 month construction period.

Subsurface Disposal of Domestic Wastewater. To evaluate wastewater impacts of Outrigger Telescopes operation, it is assumed that the volume of water currently trucked to Palomar Observatory approximates the volume of domestic wastewater generated. Based on available information, the Palomar Observatory uses about 1,060 kl (280,000 gal) per month (SeaWest, Inc. 2004a). It is estimated that operation of the Outrigger Telescopes Project would add about 9.5 kl per month (2,500 gal per month), a 1 percent increase to existing wastewater volumes. It is assumed the current septic system could handle this without modification, resulting in no significant impact.

Mitigation Measures. As noted appropriate runoff and erosion controls would be implemented during on-site construction and installation. No mitigation measures would be needed for operation.

6.4.3.5 Solid Waste and Hazardous Materials Management

<u>Solid Waste.</u>

On-Site Construction and Installation Impacts. On-site construction activity would generate debris consisting of wood, scrap insulation, packaging material, excess concrete, and other construction-related wastes. This debris would be disposed of in large roll-off containers sized to accommodate debris generated over several days of construction. No other construction waste process would be disposed of in these containers. It is assumed that all construction debris would be removed from the site by the construction contractor and taken to an authorized disposal facility at least weekly during the construction period in accordance with best construction management practices. Occasional high winds could potentially blow construction debris from the containers and disperse the material about the site and onto the surrounding area. Unsecured building materials and equipment could also be susceptible to wind dispersal.

Operation Impacts. Operation of the Outrigger Telescopes would not generate substantially greater solid waste (trash) than that currently generated by the Palomar Observatory.

As an approximation, it is assumed that the amount of trash generated in operating the Outrigger Telescopes would increase proportionately to the current average number of workers and visitors to the Palomar Observatory. It is anticipated that operation of the Outrigger Telescopes will require an additional four staff per day on average, representing an increase of about 1 percent over the current 24 staff and 278 visitors per day. This small increase would likely have little to no impact on the existing solid waste management system in place at the Palomar Observatory.

Because the Outrigger Telescopes do not have habitable spaces, they would not require trash containment systems. The existing infrastructure at the Palomar Observatory would be used to collect trash stemming from operation of the Outrigger Telescopes.

Mitigation Measures. It is assumed that the Outrigger Telescopes on-site construction and installation contract(s) would contain provisions regarding the management of solid wastes. Those provisions would be enforced.

<u>Hazardous Materials Management.</u>

On-Site Construction and Installation Impacts. The bulk of hazardous materials brought on site during construction of the Outrigger Telescopes likely would be diesel fuel and motor oil(s) for construction equipment. No mercury would be used for the Outrigger Telescopes (CARA 2001d). The earthwork phase it is anticipated that up to several hundred gallons of fuel for excavation equipment may be stored for short periods of time within skid-mounted or truck-mounted transfer tanks. Following adopted best management practices guidelines, all such fuels and oil would display MSDS information and warning labels. The storage of all hazardous liquids would be restricted to protected locations within the project site. Spill containment facilities would be provided for all such storage areas to avoid potential contamination of soils in or around the construction zones (typically, such containment systems provide a capacity of 150 percent of all stored liquids). A program of regular inspections of containers and reviews of handling procedures would ensure compliance. A program of spill containment and reporting would be submitted to the site authority before the delivery or offloading of any hazardous materials (SeaWest, Inc. 2004b). The handling guidelines and reporting procedures for other construction-related hazardous materials such as paints,

solvents, and lubricants, would also follow best management practices. Hazardous materials management activities during on-site construction and installation would be expected to have no environmental impact.

Operation Impacts. Operation of the Outrigger Telescopes would require periodic maintenance parallel to that associated with the Palomar Observatory telescopes.

The quantities and use frequency of hazardous materials during the operation of the Outrigger Telescopes would be limited. MSDS information, and warning and handling data sheets would be on file at the Observatory, and storage would be in compliance with Caltech and San Diego County Department of Environmental Health policy. No internal combustion engines or turbines would be associated with the operation of the interferometer and therefore the need for fuels and motor oils would be limited, primarily for to staff use of the personal automobiles. It is anticipated that the Palomar Observatory maintenance equipment and vehicles already on hand would be able to service this site. There are no airborne pollutants associated with the operation of an optical interferometer.

The optics surfaces for the telescopes and light beam paths are most often comprised of a molecular aluminum coating that degrades over time. Based on historical evidence, mirror-recoating operations for the Outrigger Telescopes probably would be necessary on a 1- or 2-year cycle at this facility. This would probably be performed at the Palomar Observatory facility. The quantity of etching solution HCl used to clean the mirror substrate, is limited (several gallons, diluted) and is delivered to the site on an as-needed basis for scheduled cleaning/coating operations. Waste HCl is neutralized using a calcium carbonate powder. The Palomar Observatory has conducted optics coating operations on site and has both the cleaning facilities and vacuum chambers to accomplish these tasks. A small quantity, (typically less than 5 gallons) of HCl is stored at the Observatory machine shop.

Chapter 4 describes typical maintenance and operations activities for the Outrigger Telescopes. Table 6-14 compares current hazardous materials use at the Palomar Observatory with the anticipated requirements of the Outrigger Telescopes.

The Outrigger Telescopes facility would develop and maintain hazardous materials management and spill plans as required by applicable Federal and State regulations and permits. Personnel would be trained in the implementation of these plans.

Mitigation Measures. It is assumed that all on-site construction and installation contract(s) would contain provisions regarding hazardous material management similar to those identified in Appendix F of this EIS.

6.4.3.6 Geology, Soils, and Slope Stability

ROI for Geology, Soils, and Slope Stability. The ROI for accessing the potential impacts of implementing the Outrigger Telescopes Project on geology, soils, and slope stability would be Palomar Mountain and areas where construction staging and laydown activities would occur.

On-Site Construction and Installation Impacts. As stated in Section 4.1.2, under the current design configuration, the Outrigger Telescopes would consist of a set of four (4) 1.8-m (6-ft) telescopes and enclosures arranged around a central combiner facility. The final collective footprints of the four telescope enclosures, light beam foundations, and the combiner

TABLE 6-14. EFFECT OF OUTRIGGER TELESCOPES ON HAZARDOUS MATERIALS USE AT THE PALOMAR OBSERVATORY

Material Class	Current Use at Palomar Observatory	Anticipated Requirements of Outrigger Telescopes
Cooling	378 l (100 gal) Polyethylene glycol	No glycol used
Fuel	Gasoline (7.6 kl) (2,000 gal), Propane (38 kl 10,000 gal), Diesel, Kerosene	No fuel required; emergency power provided by existing infrastructure
Hydraulic Fluid	In use (189 l ;50 gal)	No hydraulic fluid used
Lubricants	Motor oil, in use	Gear oil (66 l 917 gal) per Outrigger Telescope) and grease used; no additional lubricants stored on site
Mercury	No mercury used	No mercury used
Mirror De-coating & Re-coating	Done on site; less than 20 l (5 gal) acid solution stored on site	(Up to six) Mirrors de-coated with hydrochloric acid every two years; no additional chemical stored on site
Motor Oil	In use and storage (946 l, (250 gal) total)	
Other Compressed Gases	Acetylene, Argon, Carbon dioxide, Helium, Nitrogen (5.7 kl (1500 gal), Oxygen	Carbon dioxide used for snow cleaning monthly; 8.6-kl (205 ft^3) bottle stored in each Outrigger Telescope
Paints & Related Solvents	Paints (570 l (150 gal)); solvent (946 l, (250 gal) total)	Used as needed; no additional paint and solvents stored on site

Source: SeaWest, Inc. 2004b

building would be approximately 1,301 m^2 (14,000 ft^2). The access trail (suitable for light vehicular traffic) would involve a terrain disturbance of approximately an additional 1,115 to 1,394 m^2 (12,000 to 15,000 ft^2) from the point of connection with the existing Observatory Access Road to the Outrigger Telescopes site. The soil and rock types found within the boundary of the Palomar Observatory are mostly friable and would require the use of only conventional earthwork and grading equipment for removal. Rubber-mounted backhoes, articulated loaders, track-mounted excavators, and drill rigs would likely remove and move the earth in this type and scale of project. During the earthwork, transport vehicles, including 26,000 GVW bobtail trucks and 25-ton capacity truck and trailer combination rigs, would transport, handle, dispose of and deliver soil and aggregate, as required.

Disturbed and excavated soils would be stockpiled as required on site(s) selected to minimize the impact on surrounding terrain and potential erosion during inclement weather. All disturbed slopes and construction excavations would be protected from erosion and degradation following accepted best management practices in accordance with applicable permits and regulations. Areas of the site where soils would be compacted by construction activities would be restored during final contouring of the site. It is anticipated that impacts to geology, soils, and slope stability would be small and not significant.

Operation Impacts. There would no geology, soils, or slope stability impacts associated with the operation of the Outrigger Telescopes on Palomar Mountain.

Mitigation Measures. It is anticipated that when the construction activities related to the Outrigger Telescopes Project are completed, areas disturbed by the project including slopes and drainage channels would be restored to a natural condition.

6.4.3.7 Transportation

ROI for Transportation. Transportation refers to the movement of vehicles along roads. The ROI for assessing transportation impacts includes the Palomar Observatory and other areas affected by on-site construction, installation, and operations including the Cleveland National Forest and vehicle travel routes.

On-Site Construction and Installation Impacts. The daily workforce anticipated for the construction and installation phases of the Outrigger Telescopes Project varies between an average of 25 to 35 workers and a peak of 60 workers (SeaWest, Inc. 2004b). During construction of the Outrigger Telescopes, it is anticipated that daily construction related vehicular trips, ADT, would vary from 50 to 75 depending on the size of the workforce and the amount of equipment and material delivered. At peak periods of activity the ADT might exceed 100 vehicles per day. This traffic volume would be much lighter than the 730 ADT for Palomar Mountain Road intersection with CA Highway 76 (the estimated closest monitored site to the CA-76/South Grade Road intersection) at 3,000 vehicles. However, recent estimates bring the ADT closer to 10,000 vehicles (SeaWest, Inc. 2004b). The closest regional arterial to the Palomar Observatory is Interstate 15. The 2002 ADT-volume for the I-15 at the point on intersection with CA-76 was 117,000 vehicles (SeaWest, Inc. 2004b). It is anticipated that the paved sections along the state routes provide sufficient durability to handle traffic associated with such a construction project at this time.

The access trail needed to enter the site for construction activities would remain in use for the life of the Outrigger Telescopes Project. As such, it would be designed to handle the traffic and loads anticipated as a part of the operations and maintenance of this facility over an extended period of time. The access trail would follow the ridgeline from the existing observatory corridor to the array site, a distance of 37 m (120 ft). Based upon the current design configurations, it is estimated that between 230 and 382 m^3 (300 and 500 yd^3) of material would be involved in the excavation and earthwork operations for this access way.

Vehicular traffic associated with construction and installation activities would occasionally delay traffic along State Route 76 and South Grade Road. The greatest traffic delays would occur when the telescopes and domes are trucked up the mountain. This would only occur intermittently and thus should not regularly interfere with normal traffic flow. While construction vehicles are slow and difficult to maneuver, they would not have any long-term adverse impact on the overall traffic flow.

Construction traffic within the ROI would create minor short-term increases in dust and emissions and temporarily increase noise levels. See Section 6.4.3.11 for impacts associated with air quality and Section 6.4.3.12 for information on noise impacts.

It is also anticipated that the current viewscape of the proposed site and construction staging areas at Palomar Mountain would be temporarily impacted by the presence of large construction vehicles. See Section 6.4.13 for more information regarding visual impacts. Overall, impacts would be expected to be short-term and minor during this phase of the Outrigger Telescopes Project.

Transportation of minimal quantities of hazardous materials (e.g., diesel fuel, motor oil(s), paints, and solvents) and wastes would be expected throughout the course of constructing, installing, and operating the Outrigger Telescopes on Palomar Mountain. Handling of these materials would be guided by best management practices. No impact is anticipated.

Operation Impacts. Operation of the Outrigger Telescopes at the Palomar Observatory would be expected to add 6 to 12 vehicular trips per day along State Route 76 and South Grade Road (SeaWest, Inc. 2004b). This slight increase in traffic associated with this project phase would create a very small impact on transportation.

Mitigation Measures. During the construction and installation phase of the Outrigger Telescopes Project, heavy truck trips would be scheduled during off-peak hours to avoid interfering with normal traffic flow along State Route 76 and South Grade Road.

All road cuts and fills will be designed to minimize the potential for erosion and concentrated runoff.

6.4.3.8 Utilities and Services

ROI for Utilities and Services. The ROI for assessing utilities and services impacts of the Outrigger Telescopes Project includes the Palomar Observatory, the Cleveland National Forest, and travel routes used by construction and operation vehicles. This section analyzes potential impacts on water supply, electrical supply and communications, and emergency services and fire suppression.

Water Supply. *On-Site Construction and Installation Impacts.* The Outrigger Telescopes Project would result in an increase in the demand for potable water due to the increased number of workers at the site and the implementation of dust controls. The construction contractor(s) would transport this additional water to the summit area. Therefore, there would be no impact on the existing water supply at the Palomar Observatory.

Operation Impacts. Current water consumption at the Palomar Observatory is approximately 265 kl (70,000 gal) per week (SeaWest, Inc. 2004b). The additional water demand associated with operating the Outrigger Telescopes would not be expected to substantially impact the existing water supply. However, consumption during drought periods may be a significant operations consideration.

Electrical Power and Communications. *On-Site Construction and Installation Impacts.* On-site generators provided by the construction contractor would provide power needs. Only a minor increase in demand for electrical power on the current distribution system would occur during this period. This increase would have no impact on the existing electrical supply system.

Operation Impacts. The electrical power requirements of each Outrigger Telescope are estimated to be 30 kW (UH IfA 2001a). If the Outrigger Telescopes were placed here, the current electrical supply would be insufficient. Additional power could be

made available with the installation of another transformer (SeaWest, Inc. 2004b).

The existing communications system for the Palomar Observatory would support the needs of the Outrigger Telescopes Project. In addition, Caltech is currently funding the construction of a new microwave antennae communication network, projected to be completed by the end of 2004 (SeaWest, Inc. 2004b).

Emergency Services and Fire Suppression. *On-Site Construction and Installation Impacts*. The need for emergency services is related to the number of personnel at the summit and the types of work or activities they perform. As described in Section 6.4.1.2, the workforce anticipated for this project varies from between 25 to 35 workers and a peak of 60 workers.

The construction contractor would have the primary responsibility for ensuring worker safety. In the event of an injury or accident, the existing emergency plan that applies to the Palomar Observatory would be adequate to provide on-site treatment or evacuation off the summit. No additional equipment, personnel, or modification of emergency procedures is anticipated to be required during on-site construction. There would be no impact associated with this phase of the Outrigger Telescopes Project.

Operation Impacts. As described in Section 6.4.1.3, the average daily workforce would be six people. Existing emergency services would be adequate to accommodate this small increase in personnel.

The Outrigger Telescopes would include fire alarm systems and suppression equipment. Operations personnel would be trained in fire emergency procedures.

6.4.3.9 Socioeconomics

ROI for Socioeconomics. The ROI for assessing the potential socioeconomic impacts from implementing the Outrigger Telescopes Project would be Palomar Mountain and at any areas where construction staging and laydown activities would occur.

On-Site Construction and Installation Impacts.

On-site construction and installation would generate about 25 to 35 construction jobs over the 20–24 month construction period, possibly peaking at 60 jobs. A number of these workers may come from nearby local communities which would have a moderate but beneficial impact on construction jobs in those areas for the 20–24 month construction period. Some highly specialized workers needed to perform highly skilled activities during commissioning of the Outrigger Telescopes may originate from locations far removed from Mount Wilson. The local communities would be likely to benefit temporarily from even these jobs through worker expenditures for lodging and subsistence in those communities.

Operation Impacts. It is anticipated that the level of activity at the Palomar Observatory would not be substantially impacted as a result of the construction of the Outrigger Telescopes. Some of the 8 jobs created by operation may be filled locally. Some operation workers may also move into the local area purchasing or renting homes establishing themselves and their immediate families in the local communities resulting long-term impacts to local/regional socioeconomics would be minimal.

Mitigation Measures. Given the relatively limited workforces involved in construction

and operation, no socioeconomic mitigation measures would be necessary.

6.4.3.10 Air Quality

ROI for Air Quality. The ROI for accessing the potential impacts on air quality would be Palomar Mountain and any areas where construction staging and laydown activities would occur.

On-Site Construction and Installation Impacts. During construction of the Outrigger Telescopes Project, fugitive dust from terrain modification and construction activities would be minimized by approved grading, excavation, and vehicular traffic dust abatement programs, typically by adding moisture to project excavations and traffic corridors. The addition of crushed rock material to the temporary haul roads and staging areas along with dust suppression measures employed by the construction contractor would also minimize dust generated by construction activities. No significant impact to ambient air quality would be expected.

Operation Impacts. Air quality at Palomar Mountain would return to virtually existing conditions once the Outrigger Telescopes are installed. Scientists traveling to the project site would cause slight increase in vehicular traffic and emissions. Overall, air quality at Palomar Mountain is good. The Outrigger Telescopes operation would have no impact on air quality.

Mitigation Measures. The construction contractor(s) would be required to employ appropriate dust control measures, maintain motorized vehicles in good repair, and abide by applicable vehicular emissions standards.

6.4.3.11 Noise

ROI for Noise. The ROI for assessing noise impacts from the Outrigger Telescopes Project includes the Palomar Observatory and other areas affected by on-site construction, installation, and operations including the Cleveland National Forest and vehicle travel routes.

On-Site Construction and Installation Impacts. Noise would result from excavation, trenching, grading, installation of sheet piling for utility protection, installation of junction boxes, construction of light and air pipes, the construction of telescope dome foundations, and the installation of telescopes and domes.

Actual noise levels would be dependent upon the mix and duration of construction equipment usage and the construction methods employed. The vibrating hammer, which would be used to install the sheet piling required for utility protection, would most likely be the loudest piece of equipment used during construction (approximately 95 A-weighted decibels (dBA) at 15 m (50 ft)). It is anticipated that the use of this equipment would be short-term, lasting one or two days in duration. There would be no blasting during the construction process.

Transport of materials and equipment and daily construction traffic would also create noise. Increased noise levels would occur intermittently along routes used by construction and operation equipment. Most heavy construction equipment would be stored on site during the construction period. See Section 6.4.3.7 for additional transportation information.

This intermittent and short-term noise could result in minor disturbances to scientists, staff, recreational users, and other visitors within the ROI. However, any noise disturbances or interruptions

would end once on-site construction and installation is completed. Therefore, moderate noise impacts would be associated with this project phase.

Operation Impacts. Operation of the Outrigger Telescopes would result in a negligible increase in noise and a minor increase in vehicular traffic noise along State Route 76 and South Grade Road. See Section 6.4.3.7 for additional vehicular traffic information. In conclusion, there would be no impact associated with this phase of the Outrigger Telescopes Project.

Mitigation Measures. Any noise impacts on construction workers would be mitigated by adherence to appropriate Occupational Safety and Health Administration (OSHA) standards.

6.4.3.12 Visual/Aesthetics Resources

ROI for Visuals/Aesthetic Resources. The ROI for visual impacts consists of the Palomar Observatory area and nearby areas from which the Outrigger Telescopes would be visible.

On-Site Construction and Installation Impacts. Visual impacts during construction could be significant to some viewers. These impacts would be largely temporary however, persisting for only the 20–24 month construction period.

Operation Impacts. San Diego County also addresses its concerns over retaining and enhancing the rural character of the Palomar Mountain community in their North Mountain Subregional Plan (Part XVIII) by preserving existing natural landscape features. *"Natural landscape features include, but are not limited to: drainage courses, streams and other wetlands, ridgelines, rock outcroppings, native and old-growth vegetation and steep slopes greater than 25 percent"* (San Diego County 2002).

The Outrigger Telescopes, if constructed on either the Weather Tower Ridge Site or the Long Canyon Ridge site, would not be visible from Canfield Road or State Hwy 76.

As a function of its 41 m (135-ft) height and 42 m (137-ft) diameter, the Hale Telescope dome is visible from several regional vantage points at substantial distances from the Observatory. If the Weather Tower Ridge site is selected, potential off-site view planes, (similar to those impacted by the Hale Telescope enclosure), would be examined. It is reasonable to assume that due to both overall reduced height and substantially smaller diameters, the Outrigger Telescope enclosures would not be as prominent visually as the Hale facility.

Should the Long Canyon Ridge site be selected for the Outrigger Telescopes, the potential view plane would include lower elevations to the northwest and to the north, including portions of the communities of Temecula and Aguanga in Riverside County (approximately 32 km and 10 km (20 mi and 6 mi) from the site respectively).

6.4.3.13 Environmental Justice

Onsite construction, installation, and operation of the Outrigger Telescopes at either of the Palomar Observatory sites would not result in disproportionately adverse impacts on minority or low-income populations.

6.4.3.14 Cumulative Impacts

Past and Present Activities. The origins of the Palomar Observatory date to the 1920s, when the astronomical observations from the 100-in Hooker telescope at Mount Wilson demonstrated the need for a larger instrument. After numerous locations were tested for atmospheric quality, Palomar

Mountain was selected as the official site in 1934. During that same year, Caltech, the recipient of a grant from the International Education Board (a Rockefeller Foundation), began purchasing property on Palomar Mountain for the Observatory.

Construction for the 508-m (200-in) telescope began in the mid-1930s, but was delayed by World War II. The 508-m (200-in) Hale Telescope was not completed until 1948. Other telescopes have been added to the Observatory and include the 122-m (48-in) Oschin Telescope, the 46-m (18-in) Schmidt Telescope, and the 152-m (60-in) reflecting telescope.

Table 6-15 summarizes the history of Palomar Mountain.

Reasonably Foreseeable Future Activities. A proposed landfill site located approximately 29 km (18 mi) to the west may have a future effect on the air quality at the Observatory. As former Associate Director of the Caltech site commented:

> "San Diego County has announced plans to open a new solid waste landfill in the north county area—with six candidate sites located within 32 km (20 mi) of the observatory. Dust from grading at the landfill (which will be required daily) and pollution from vehicles hauling trash (130 trucks a day, each carrying about 50,000 lbs (25 tons) of material) threaten to increase the amount of airborne particles in the atmosphere over the observatory."
> (SeaWest, Inc. 2004b)

Summary of Cumulative Impacts. There are no known plans for construction and operation of any additional telescopes at the Palomar Observatory site for the foreseeable future.

On-site construction, installation, and operation of the Outrigger Telescopes at the Palomar Observatory site would have little incremental impact on the whole. Construction would, even at the estimated 20–24 months, have little adverse impact on the observatory site. Visitors and staff on the mountain would experience minor inconveniences at various times during construction. From an environmental impact perspective, construction of the Outrigger Telescopes would not combine with past and present sources of environmental impact sufficient to result in exceedances of existing environmental standards, either Federal or State.

Operation of the Outrigger Telescopes may incrementally impact the existing potable water supply system at the Palomar Observatory. These potential advance impacts, if verified during more detailed planning and design of the Outrigger Telescopes Project, can be avoided by upgrading or supplementing the exiting systems.

6.4.4 Adverse Environmental Impacts That Cannot Be Avoided for Palomar Observatory

Adverse impacts are divided into short- and long-term effects. Short-term effects are generally associated with construction, and prevail only for the duration of the construction period. Long-term effects generally follow completion of the improvements, and are permanent. Effects that can be considered both adverse and unavoidable are described below for both short- and long-term effects:

6.4.4.1 Unavoidable Adverse Short-Term Effects

- Operation of construction equipment, trucks and worker vehicles would temporarily impede traffic along the

TABLE 6-15. HISTORY OF PALOMAR OBSERVATORY

Year	Event
1908	Under the supervision of George Hazle, and through grants from the Carnegie Institution of Washington, the Mount Wilson 60-in telescopes is completed and see first light.
1917	Despite challenges, the 100-in telescope is completed in 1917.
1928	Six million dollars was secured for construction of an observatory including the 508-cm (200-in) telescope.
1929	Bernard Schmidt designs a photographic survey telescope.
1930-34	With increasing light pollution at Mount Wilson, Hale selects Palomar Mountain for the home of the 508-cm (200-in) telescope.
1934-36	Combining with Corning Glass Works, a design was made possible for the 508-cm (200-in) mirror using a new glass blend called Pyrex.
1934-36	Overcoming design and engineering concepts, the design of the mirror now includes an oil bearing system, and a mirror support cell.
1936	The construction on the 508-cm (200-in) dome begins; the mirror blank is shipped from New York to Pasadena where it is grinded and polished at Caltech.
1936-47	The 18-inch (Schmidt) telescope is in operation.
1937	The 508-cm (200-in) telescope parts are assembled at various sites and are shipped to the Mountain for assembly.
1938	Work on the 48-inch Schmidt is started.
1941	Telescope production halts due to World War II.
1947-49	The 508-cm (200-in) mirror is transported from Pasadena to Palomar.
1948	The 508-cm (200-in) telescope is dedicated on June 3rd and named in honor of George Ellery Hale.
1948	First light is achieved on the 48 inch Schmidt telescope.
1949	Edwin Hubble takes the first photographic exposure with the 508-cm (200-in) telescope; in October the telescope is made available to astronomers.

roads serving Palomar Mountain during the construction period. This minor impact would be intermittent and temporary and would cease once construction is completed. The transport of large machinery and large Outrigger Telescope components could temporarily impede traffic flow and result in temporary traffic delays on State Route 76 and South Grade Road. These impacts would be limited to a brief period of time at the beginning and end of construction.

- Increased vehicular traffic and internal combustion engines on heavy equipment would result in the generation of air emissions. These emissions would be localized and would not impact the overall air quality on Palomar Mountain. Emissions from road construction-related vehicles and equipment would cease once construction is completed.
- Heavy construction equipment operations on site would lead to the temporary generation of small dust particles. Although daily mitigation measures would be taken to significantly reduce these impacts, some soil would occasionally be subject to erosion during periods of high winds.
- Heavy construction equipment operations on site and the transport of large machinery along the roads serving Palomar Mountain would lead to intermittent and temporary increases in noise levels. The transport of large machinery would be limited to a brief period of time at the beginning and end of construction.
- Construction equipment, related materials, and temporary structures, located on site during the construction phase of the project would affect the visual quality of the area for some viewers. Because all equipment and excess materials would be removed at completion of construction any changes to the visual quality of the area would be temporary.

6.4.4.2 Unavoidable Adverse Long-Term Effects

- The presence of the Outrigger Telescopes would affect the visual quality of the area for some viewers using the area around the Observatory. To minimize this visual impact, the Outrigger Telescopes would be painted to blend into the natural surroundings to the extent possible.
- Workforce traffic associated with the Outrigger Telescopes would result in minor increases in noise levels along the roads serving Palomar Mountain, including State Route 76 and South Grade Road.

6.4.5 Incomplete or Unavailable Information

Sufficient information exists at this stage in development of the Reduced Science Option at the Palomar Observatory to determine whether or not the potential exists for significant environmental impacts would occur as a result of implementation of the Outrigger Telescopes Project.

Assuming the Reduced Science Option were to move forward at the Palomar Observatory three areas would require particular attention in facility design and planning: (1) a culture resources survey of the project sites may be needed and a suitable protection and mitigation plan developed prior to start of construction; (2) determinations of the capability of the existing Palomar Observatory potable water

supply system to meet the needs of an operational Outrigger Telescopes Project; and (3) a pre-construction site survey for threatened or endangered species and critical habitat may be needed and if appropriate, development of protective and mitigation measures to be implemented during construction and/or operation.

6.4.6 Relationship Between Short-Term Uses of the Human Environment and the Maintenance and Enhancement of Long-Term Productivity

The Outrigger Telescopes Project would be an important addition to California's research and development industry, which can provide broadened employment opportunities for State residents. The productivity of Palomar Mountain, however, cannot be measured in purely traditional economic ways. Palomar Mountain is a natural and scientific resource that belongs to all State residents and future generations. The use of the mountain as an astronomical observatory need not be incompatible with its use by recreational users and tourists.

Any assessment of the comparative productivity of Palomar Mountain's role as an astronomical observatory, as compared to its role as a natural laboratory for other scientists or an aesthetic and recreational resource, should take into consideration that astronomy and other activities on Palomar Mountain are not mutually exclusive. Upon removal, long-term productivity would not be affected.

6.4.7 Irreversible and Irretrievable Commitment of Resources

The Outrigger Telescopes Project would require a commitment of natural, physical, and human resources. In all of these categories, an irreversible and irretrievable commitment of resources would occur. A commitment of resources is irreversible when primary or secondary impacts limit the future options for a resource. An irretrievable commitment refers to the use or consumption of resources neither renewable nor recoverable for future use. Construction of the Outrigger Telescopes would consume energy and building materials. In general, natural and propane gas and diesel fuel would be used directly by construction equipment and also to generate electrical power and heat. The electrical power requirements of each Outrigger Telescope are estimated to be 30 kW (UH IfA 2001a). The additional electrical demand would be supplied by the electrical utility supplying the observatories largely through fossil-fuel power generation. Petroleum products would continue to be consumed during operation; however, quantities would be significantly less than during construction. Construction material such as steel, cement, and aggregate would also be expended. These physical resources are generally in sufficient supply, and their commitment to the project would not have an adverse effect on their availability. In some instances, at least some material resources such as structural steel and copper wiring could be reclaimed, recycled, and reused.

In terms of human resources, trade and non-skilled laborers would be used during the development, construction, and operation of the Outrigger Telescopes. Labor is generally not considered to be a resource in short supply, and commitment to the project would not have an adverse effect on the continued availability of these resources.

6.5 COMPARISON OF REDUCED SCIENCE OPTIONS

Table 6-16 provides a summary comparison of the Reduced Science Options.

TABLE 6-16. SUMMARY OF MOUNT WILSON OBSERVATORY AND THE PALOMAR OBSERVATORY REDUCED SCIENCE OPTIONS

Impact Area	Mount Wilson Observatory	Palomar Observatory
Cultural Resources	On-site construction, and installation—Not likely to impact any cultural or archaeological resources. Operation—Would not impact cultural or historic resources within the project area.	On-site construction, and installation—Not likely to impact any cultural or archaeological resources. Operation—Would not impact cultural or historic resources within the project area.
Biological Resources	On-site construction and installation—Would require the removal of trees in the immediate vicinity of the dome enclosures. Operation—No substantial impact would occur.	On-site construction and installation—Would require the removal of trees in the immediate vicinity of the dome enclosures. Operation—No substantial impact would occur.
Hydrology, Water Quality, and Wastewater	On-site construction and installation—No water quality impacts anticipated. Operation—Potentially adverse impact on wastewater operations.	On-site construction and installation—Small hydrologic and water quality impact anticipated. Operation— No substantial impact would occur.
Solid Waste and Hazardous Materials Management	On-site construction and installation—No impacts despite temporary increases in solid waste generation and hazardous material use. Operation— Little, if any, impact since increases in solid waste generation and hazardous materials use anticipated to be minor.	On-site construction and installation—No impacts despite temporary increases in solid waste generation and hazardous material use. Operation—Little, if any, impact since increases in solid waste generation and hazardous materials use anticipated to be minor.
Geology, Soils, and Slope Stability	On-site construction and installation—No substantial impact on geology or slopes at the site. Operation—No impact.	On-site construction and installation—Small impact anticipated. Operation—No impact.
Land Use and Existing Activities	On-site construction and installation—<u>Land Use:</u> Expected to be consistent with designated use. <u>Existing Activities:</u> No long-term conflict or substantial impact. Operation—<u>Land use</u>: Consistent with the current designated land use. <u>Existing Activities</u>: The incremental impact would be small.	On-site construction and installation—<u>Land Use:</u> Expected to be consistent with designated use. <u>Existing Activities:</u> No long-term conflict or substantial impact. Operation—<u>Land use</u>: Consistent with the current designated land use. <u>Existing Activities</u>: The incremental impact would be small.
Transportation	On-site construction and installation—Small increases in traffic along the Angeles Crest Highway (SR-2) and Mount Wilson Road would be expected. Short-term minor impacts. Operation—Slight increase in traffic would create a small impact.	On-site construction and installation—Small increases in traffic along State Route 76 and South Grade Road would be expected. Short-term minor impacts. Operation— Slight increase in traffic would create a small impact.

TABLE 6-16. SUMMARY OF MOUNT WILSON OBSERVATORY AND THE PALOMAR OBSERVATORY REDUCED SCIENCE OPTIONS (CONTINUED)

Impact Area	Mount Wilson Observatory	Palomar Observatory
Utilities and Services	On-site construction and installation—Small increases would be accommodated by existing utilities and services. Operation—Because of the limited amount of water on site, a new well and storage tanks may be required. In addition, the project could have a substantial impact on the electrical and communications supply systems.	On-site construction and installation—Small increases would be accommodated by existing utilities and services. Operation—Except for electrical utilities, increases would be minimal and would be accommodated by existing facilities. Additional power could be made available with upgrades. Water supply could be limited during drought periods.
Socioeconomics	On-site construction and installation—Moderate beneficial impact to the local community. Operation—Mimimal long-term positive impact on local/regional socioeconomics.	On-site construction and installation—Moderate beneficial impact to the local community. Operation— Mimimal long-term positive impact on local/regional socioeconomics.
Air Quality	On-site construction and installation—Small impact on ambient air quality. Operation—No impact.	On-site construction and installation—Small impact on ambient air quality. Operation—No impact.
Noise	On-site construction and installation—Intermittent short-term noise increases would create a moderate impact. Operation—No impact.	On-site construction and installation—Intermittent short-term noise increases would create a moderate impact. Operation—No impact.
Visual/Aesthetics	On-site construction and installation—Temporary visual intrusion to the cultural landscape. Operation—Outrigger Telescopes would not be visible off-mountain, visual impacts would be small.	On-site construction and installation—Visual impacts during construction could be significant to some viewers. Operation—Long-term visual intrusion depending on vantage point.

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8.1 AGENCIES AND ORGANIZATIONS CONSULTED FOR THE FEDERAL ENVIRONMENTAL IMPACT STATEMENT

The following agencies, organizations, or individuals were consulted during the Federal NEPA process.

FEDERAL AGENCIES

Advisory Council on Historic Preservation
National Interagency Coordination Center
National Park Service
- National Register of Historic Places

U.S. Bureau of Labor Statistics
U.S. Census Bureau American Community Survey Office
U.S. Department of Agriculture
- Forest Service
- Natural Resources Conservation Service
  - National Water & Climate Center

U.S. Department of the Interior
- Office of Environmental Policy and Compliance
- Bureau of Indian Affairs, Southern California Agency

U.S. Environmental Protection Agency, (CMD-2), Region 9
U.S. Fish and Wildlife Service, Pacific Islands Manager

STATE OF HAWAI‘I AGENCIES

Department of Business, Economic Development & Tourism
Department of Hawaiian Home Lands
Department of Health
- Office of Environmental Quality Control

Department of Land and Natural Resources
- Board of Land and Natural Resources
- Historic Preservation Division

Legislative Reference Bureau
Office of Hawaiian Affairs
University of Hawai‘i at Hilo
- Department of Astronomy
- Office of Mauna Kea Management
  - Kahu Ku Mauna
  - Mauna Kea Management Board

University of Hawai‘i at Manoa
- Environmental Center
- Institute for Astronomy
  - Mauna Kea Support Services

COUNTY OF HAWAI‘I

Mayor, the Honorable Harry Kim
County of Hawai‘i, Council Chairman
Department of Planning, Director

STATE OF CALIFORNIA AGENCIES

California Department of Conservation
California Department of Forestry and Fire Protection
California Department of Transportation
California State Clearinghouse
University of California

CALIFORNIA COUNTY AND CITY AGENCIES

City of Pasadena, Mayor’s Office
County of San Diego
- Air Pollution Control District
- Department of Planning and Land Use
- Department of Public Works
- Department of Environmental Health
- Forest Area Safety Taskforce
- Office of Emergency Services
- Planning Commission
- Solid Waste Local Enforcement Agency

Los Angeles County
- Department of Regional Planning
- Sheriff's Department, Crescenta Valley Station

Pala Band of Mission Indians
San Diego Air Pollution Control District
San Diego Historical Society

South Coast Air Quality Management District
Southern California Edison
Southern California Tribal Chairman's Association
University of San Diego, Indian Reservations in San Diego County

STATE OF ARIZONA AGENCIES

Department of Environmental Quality

ARIZONA COUNTY AND CITY AGENCIES

City of Flagstaff, Mayor's Office

CANARY ISLANDS AGENCIES

Organismo Autónomo Parques Nacionales (National Parks Agency)

FLORIDA COUNTY AND CITY AGENCIES

University of Florida

OBSERVATORIES

Caltech Submillimeter Observatory
Canada-France-Hawai‘i Telescope
Gemini North
Gran Telescopio Canarias
Instituto de Astrofísica de Canarias
James Clerk Maxwell Telescope
Lowell Observatory, Flagstaff, Arizona
Mount Palomar Observatory
Mount Wilson Observatory
Roque de Los Muchachos Observatory
Smithsonian Submillimeter Array
Subaru Telescope
United Kingdom Infrared Telescope
Very Large Baseline Array
W.M. Keck Observatory

ORGANIZATIONS

Ahahui Ku Mauna
Ahahui Malama I Ka Lokahi
Aha Kahuna Nui, Hilo
Association of Hawaiian Civic Clubs, Hilo
Automobile Club of Southern California
Bishop Science Museum
California Association for Research in Astronomy
Conservation Council for Hawai‘i
Edith Kanaka‘ole Foundation, Hilo
Hāmākua Hawaiian Civic Club, Honoka‘a
Hawai‘i Island Burial Council
Hui Mālama I Nā Kūpuna O Hawai‘i Nei
Ilo‘ulaokalani Coalition
KAHEA
Ka Lahui Hawai‘i, Honolulu
Kawaihae Homestead Association, Kawaihae
Kingdom of Hawai‘i
Kohala Hawaiian Civic Club, Hawi
Kona Hawaiian Civic Club, Holualoa
Kona Hawaiian Civic Club, Holualoa
Life of the Land
Malama O Puna
Mauna Kea Anaina Hou
Moku O Hawai‘i
Protect Kohanaiki Ohana, Kailua-Kona
Royal Order of Kamehameha I
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Approximately 250 virtually identical e-mails were received from individuals entitled "Prevent Further Degradation of Mauna Kea."

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