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 Hawaiʻi.

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 Hawaiʻi (UH). UH, in turn, has subleased parcels of the MKSR in the summit area to

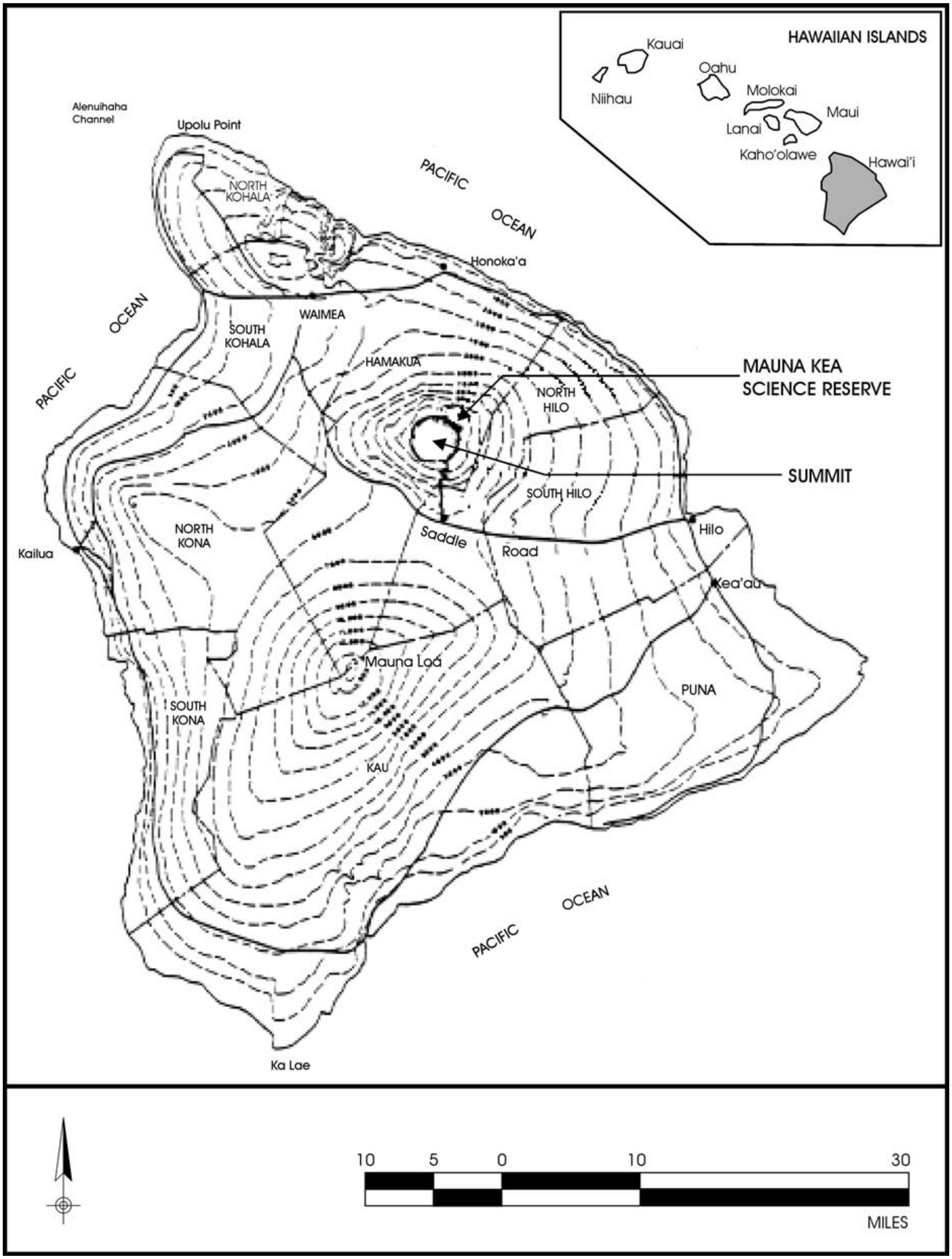
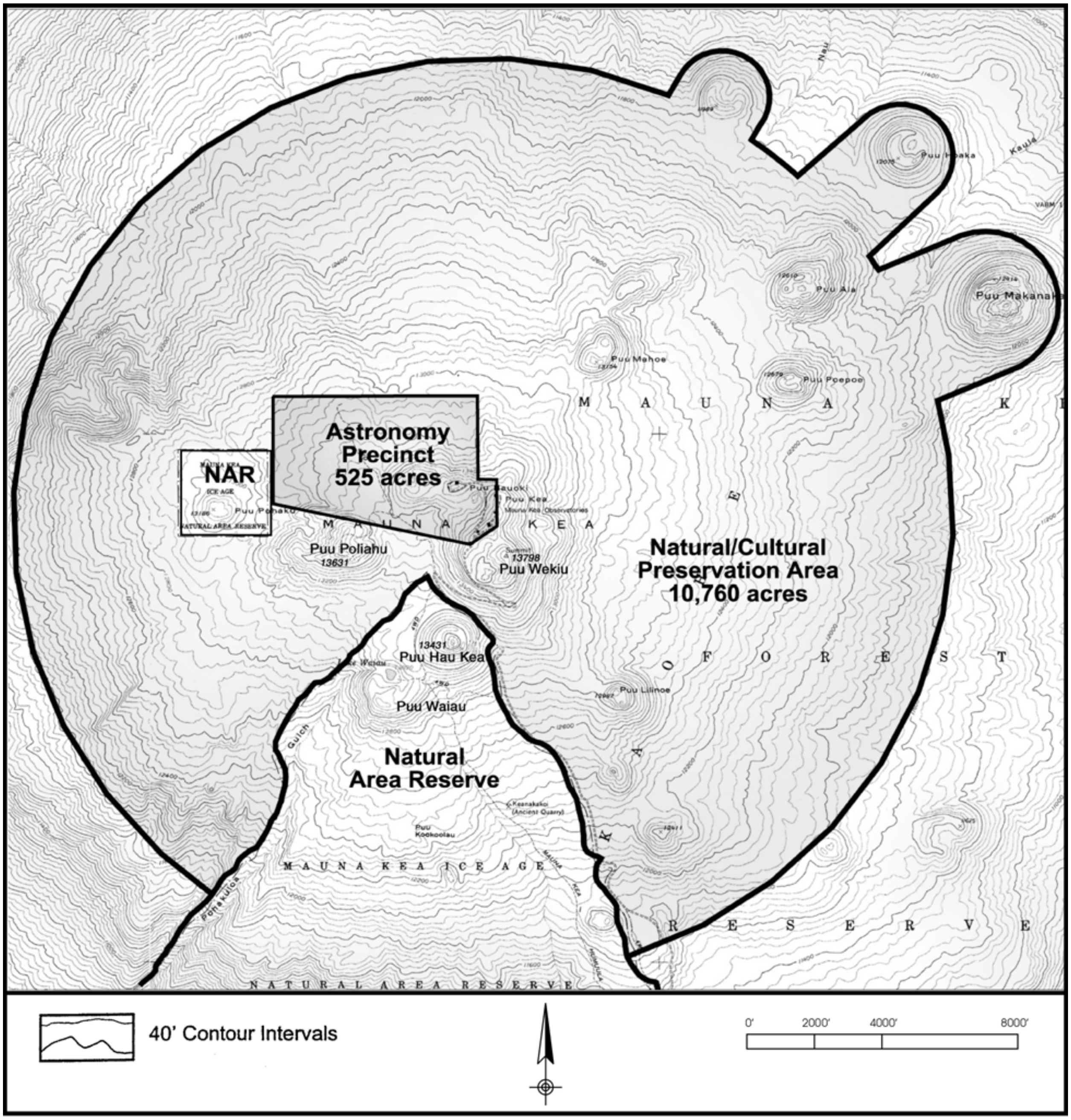
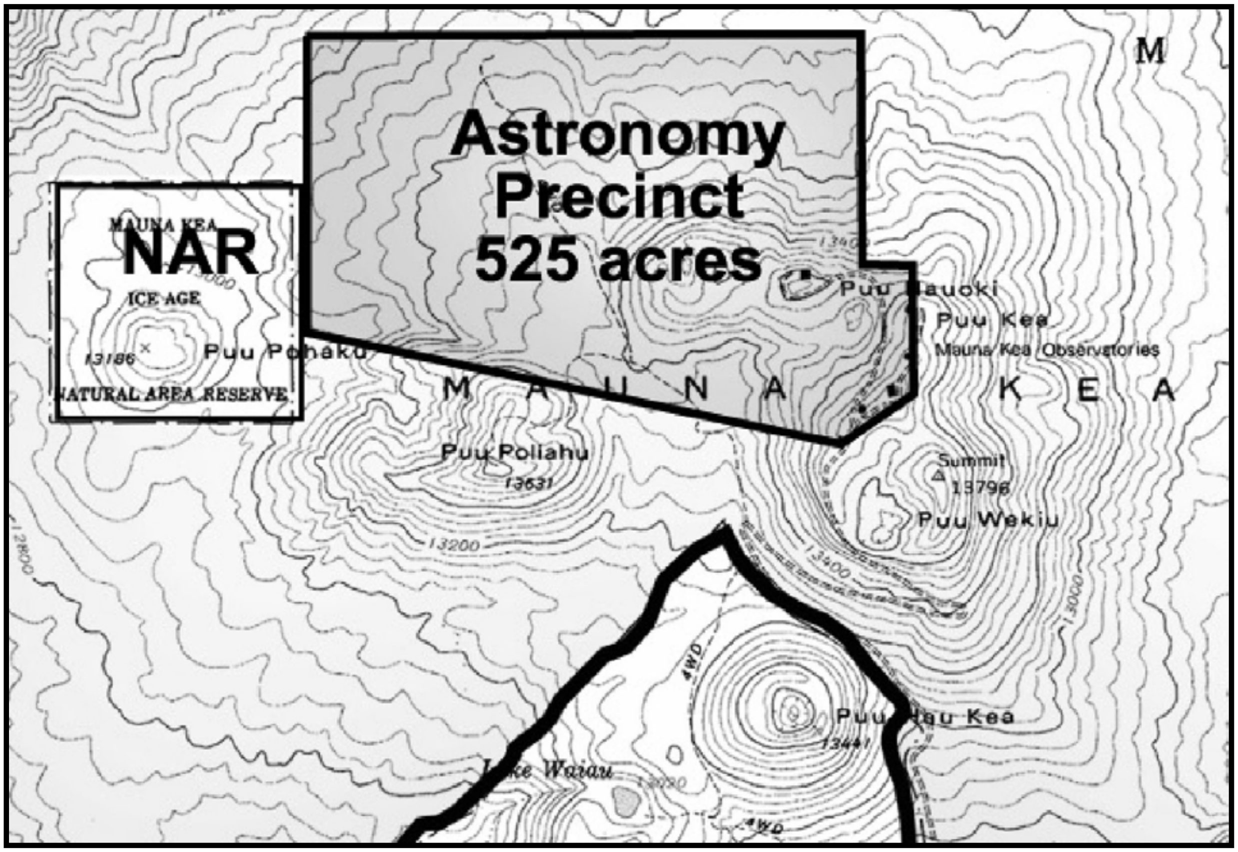


FIGURE 2-1. MAUNA KEA SCIENCE RESERVE ON THE ISLAND OF HAWAIʻI



Source: UH 2000b

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



Source: UH 2000b

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

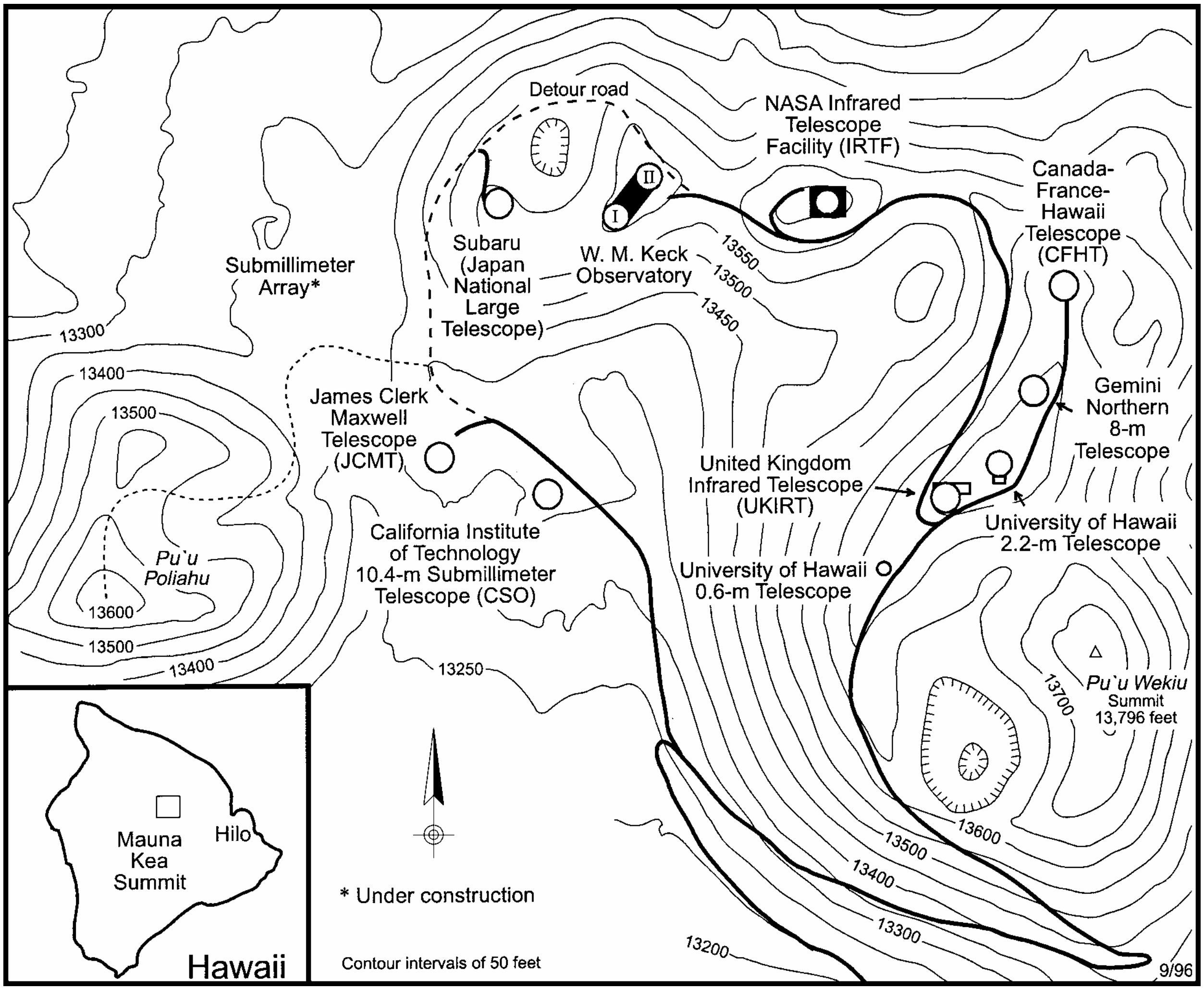


FIGURE 2-4. EXISTING OBSERVATORIES IN THE SUMMIT AREA OF THE MAUNA KEA SCIENCE RESERVE

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).

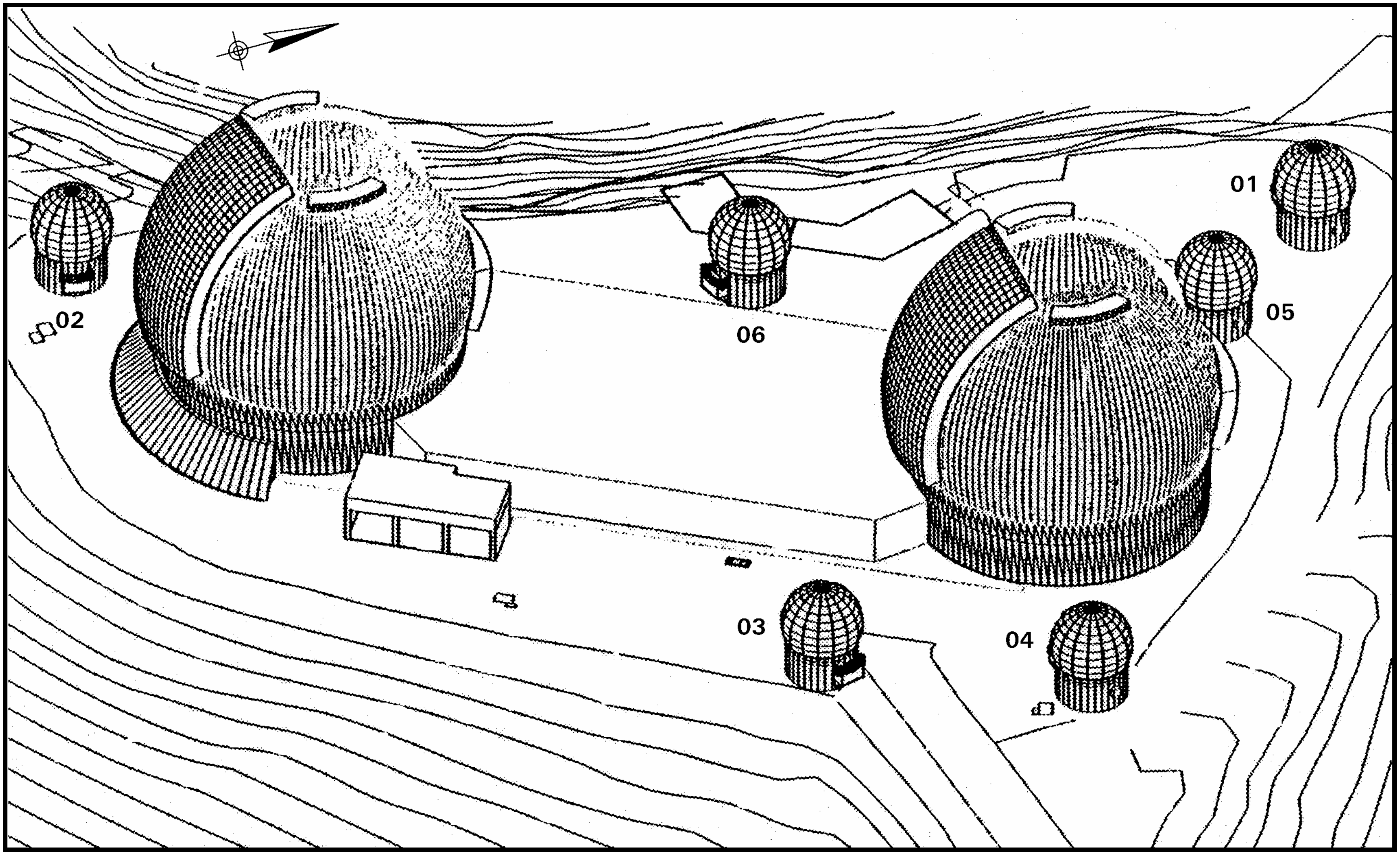
Permission to reprint photo obtained from CARA.

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

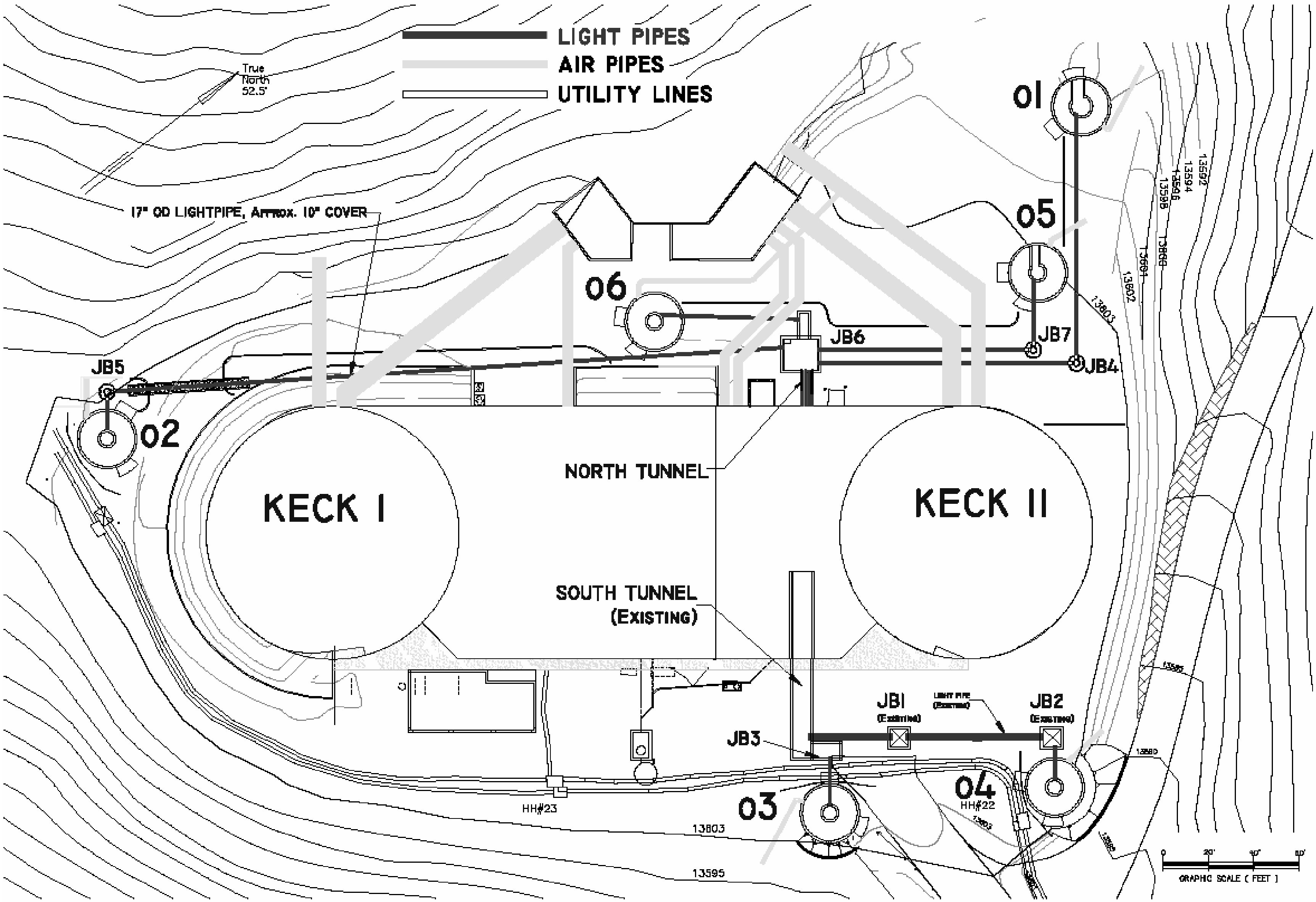


FIGURE 2-7. PROPOSED OUTRIGGER TELESCOPES ON THE WMKO SITE

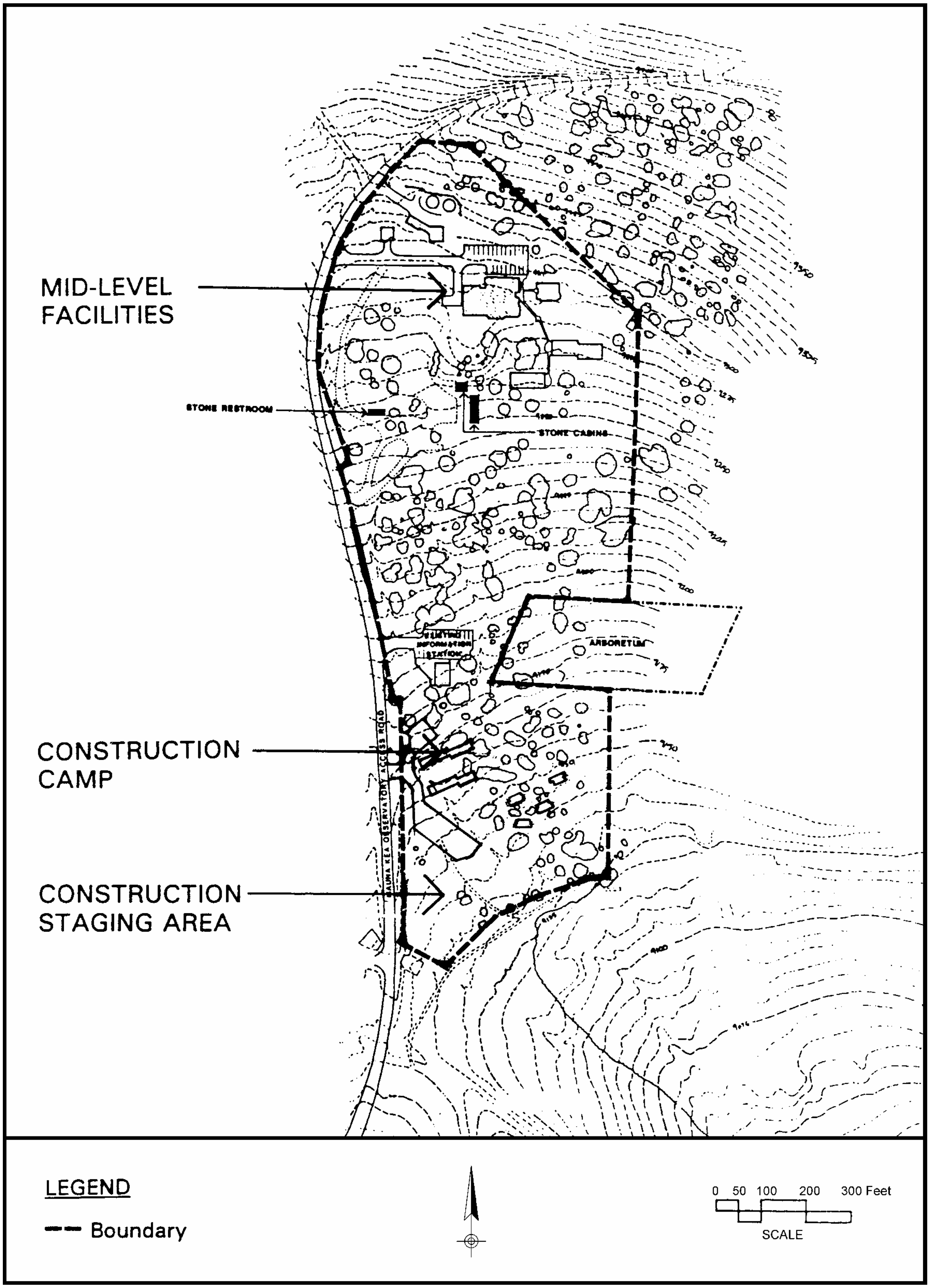


FIGURE 2-8. HALE PŌHAKU

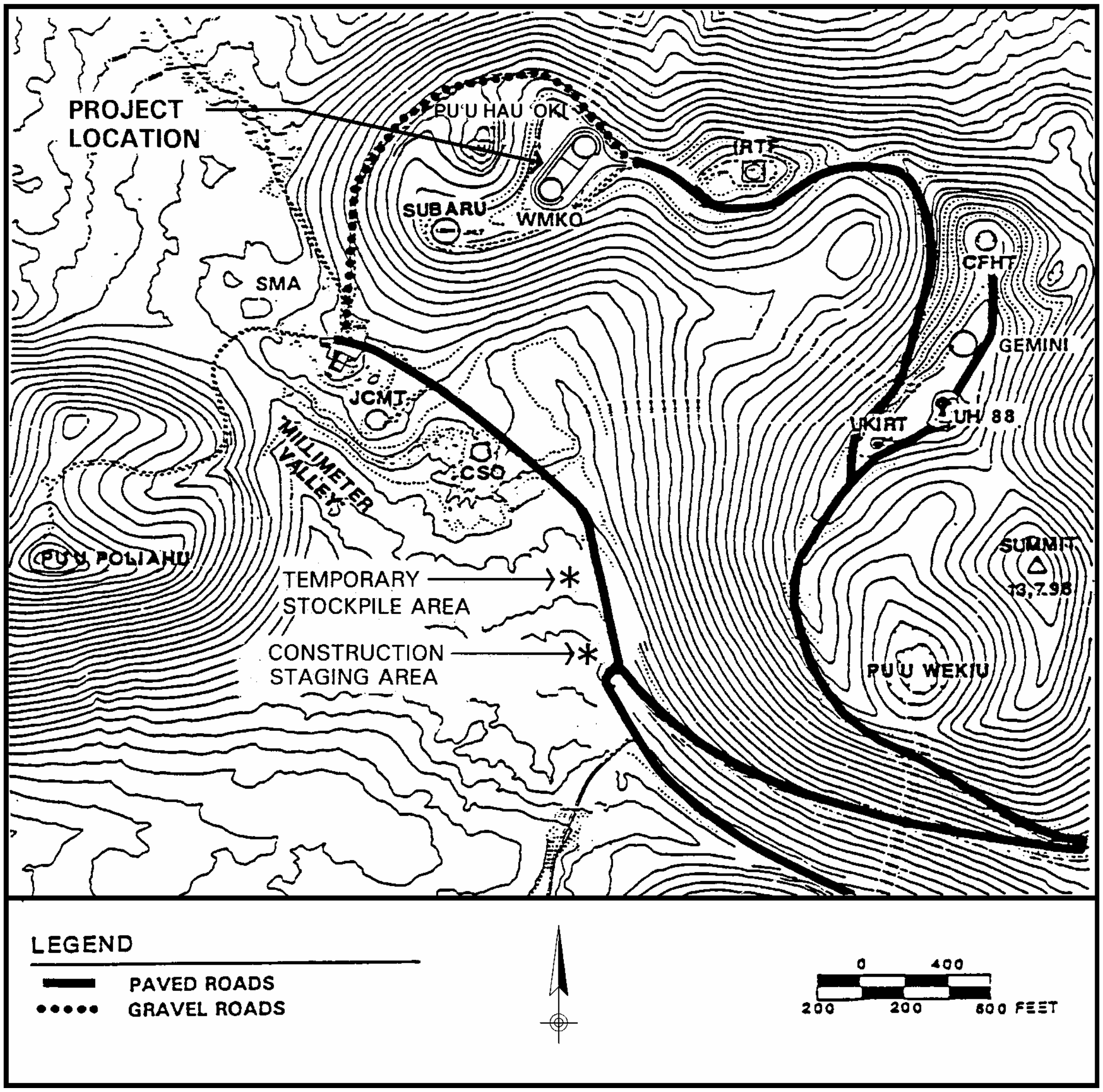


FIGURE 2-9. LOCATION OF THE TEMPORARY STOCKPILE AND CONSTRUCTION STAGING AREA

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.

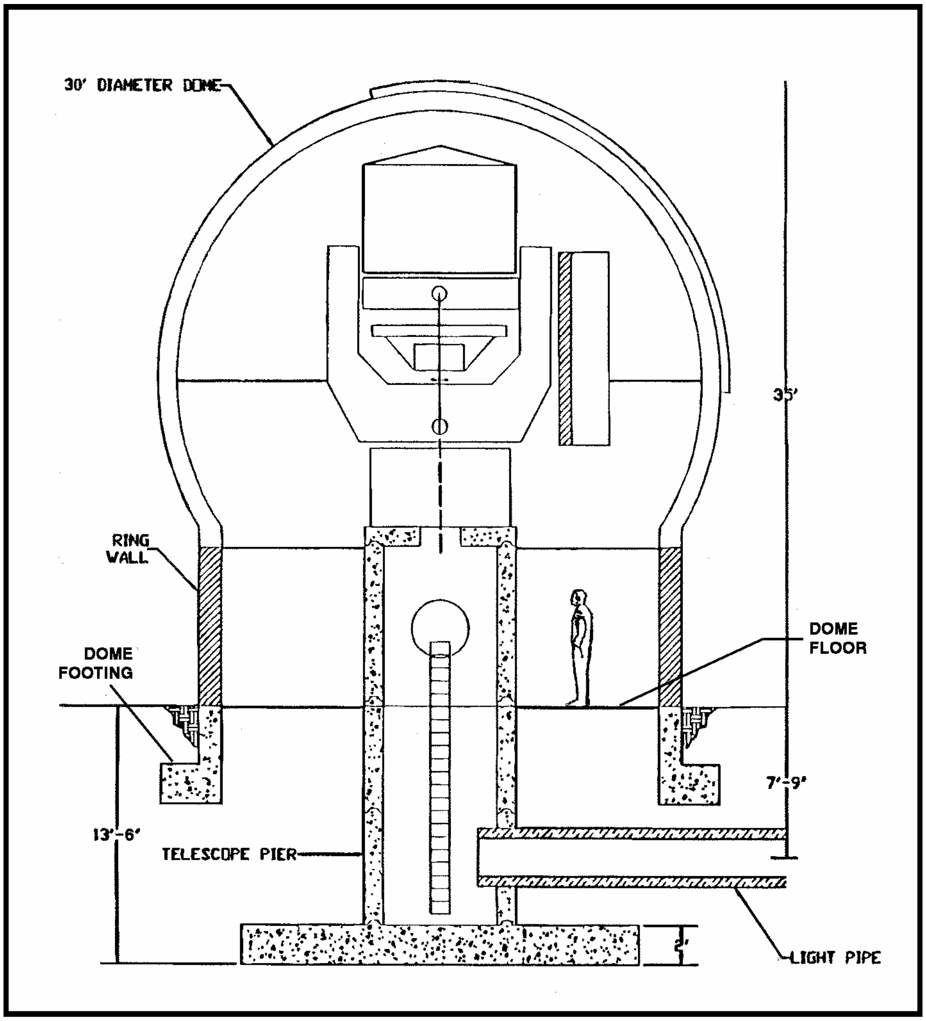
The existing 2.4-m (8-ft) wide by 2.1-m (7-ft) high by 20-m (67-ft) long (interior dimensions) underground tunnel on the south side of the facility and a proposed new junction box (JB-3) would provide a path for the starlight beams from Outrigger Telescopes 3 and 4 and personnel access to JB-3.

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.

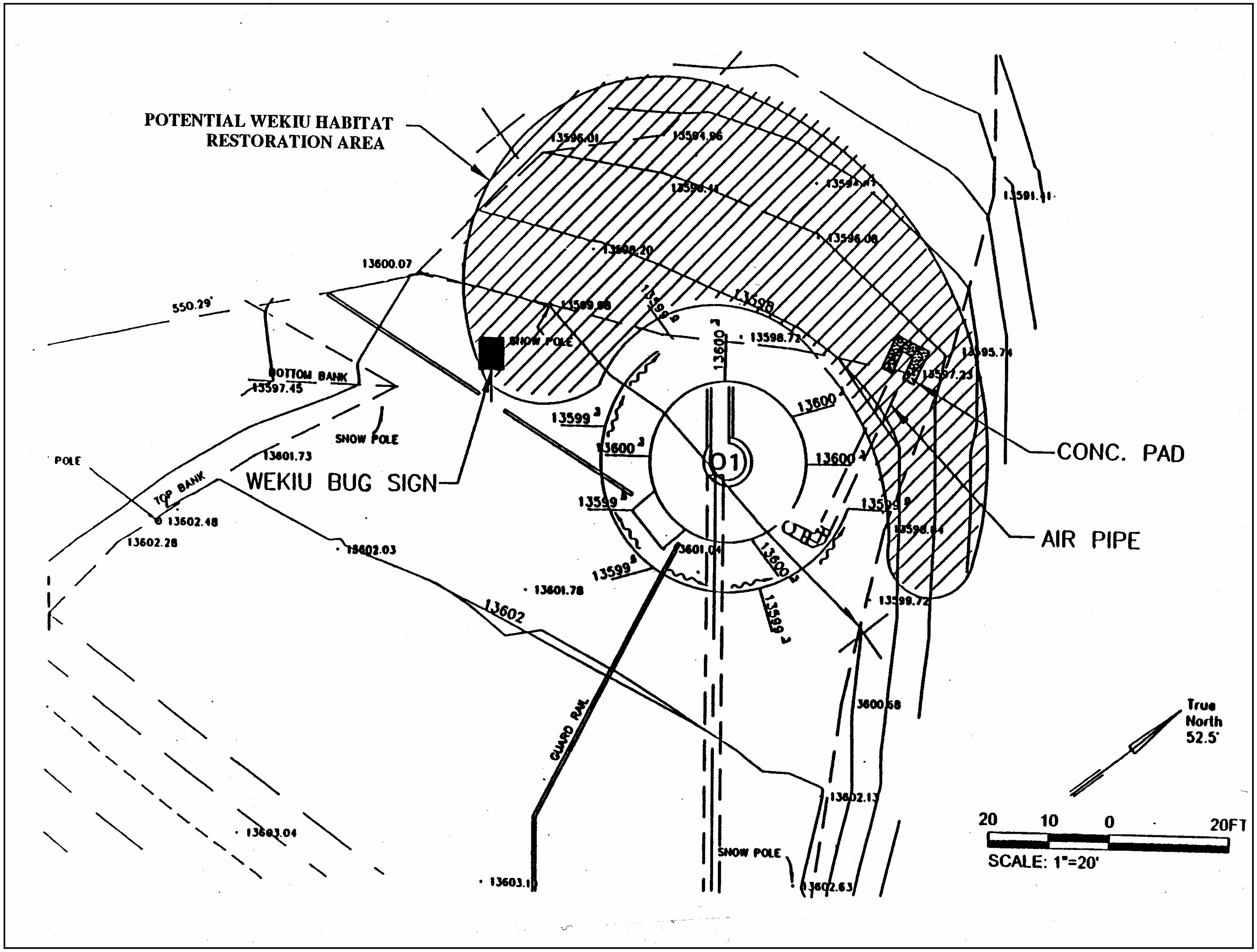
2.1.3.3 Grading Plans for Outrigger Telescope Domes and Junction Boxes

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.

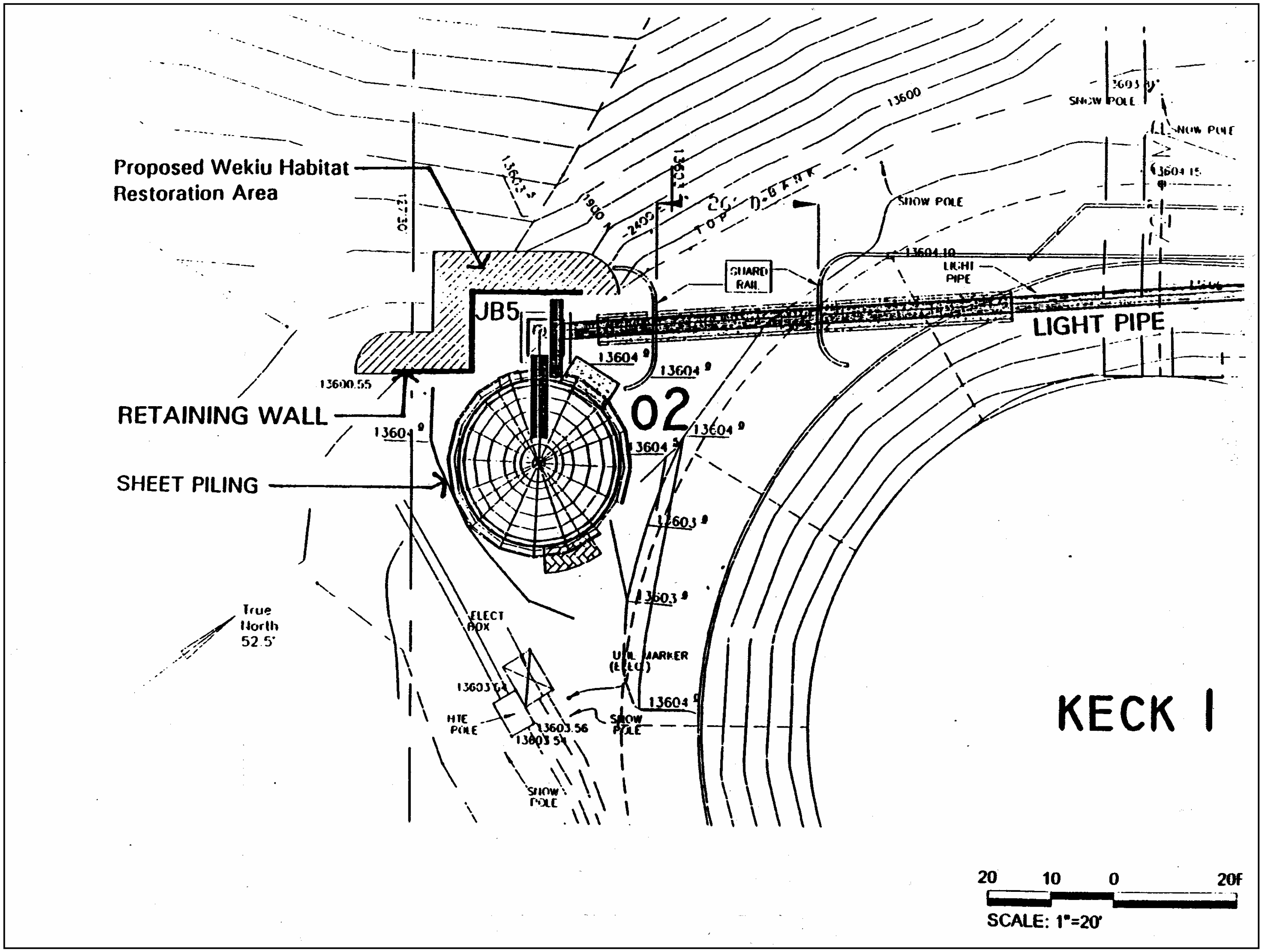
Outrigger Telescope 3. The proposed location for Outrigger Telescope 3 is on the existing graded area near the entrance to the W. M. Keck Observatory site. This area is slightly elevated so that surface water would flow away from the dome. A cinder-colored concrete masonry block retaining wall would 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.

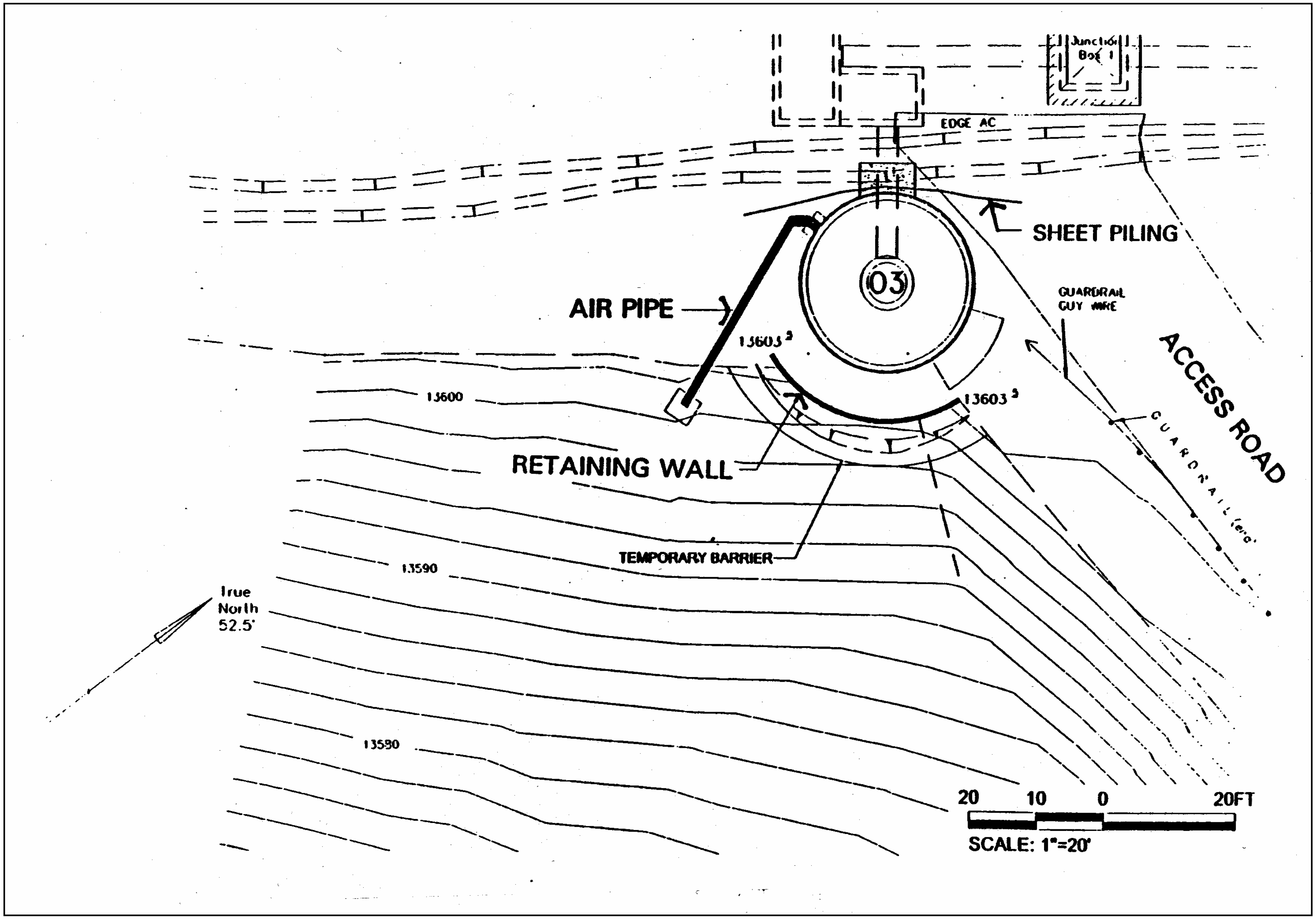
A retaining wall would be built as a barrier to keep the fill from spilling onto the nearby access road. The retaining wall would be constructed of cinder-colored masonry blocks. The wall would be about 13.7-m (45-ft) long and 1.2-m (4-ft) high. A 56-m (185-ft) long retaining wall is already in place 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).



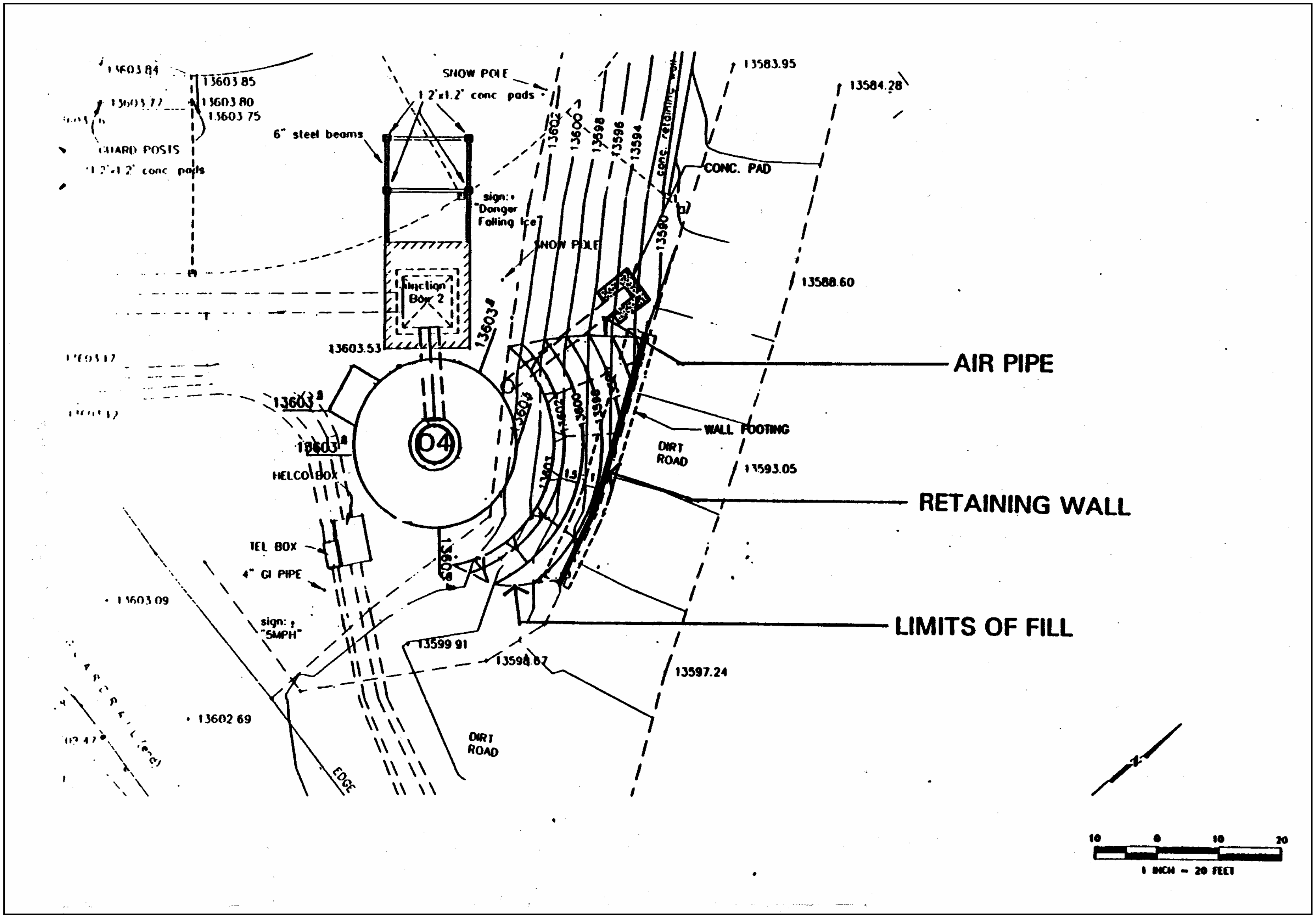
Source: UH IfA 2001a

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



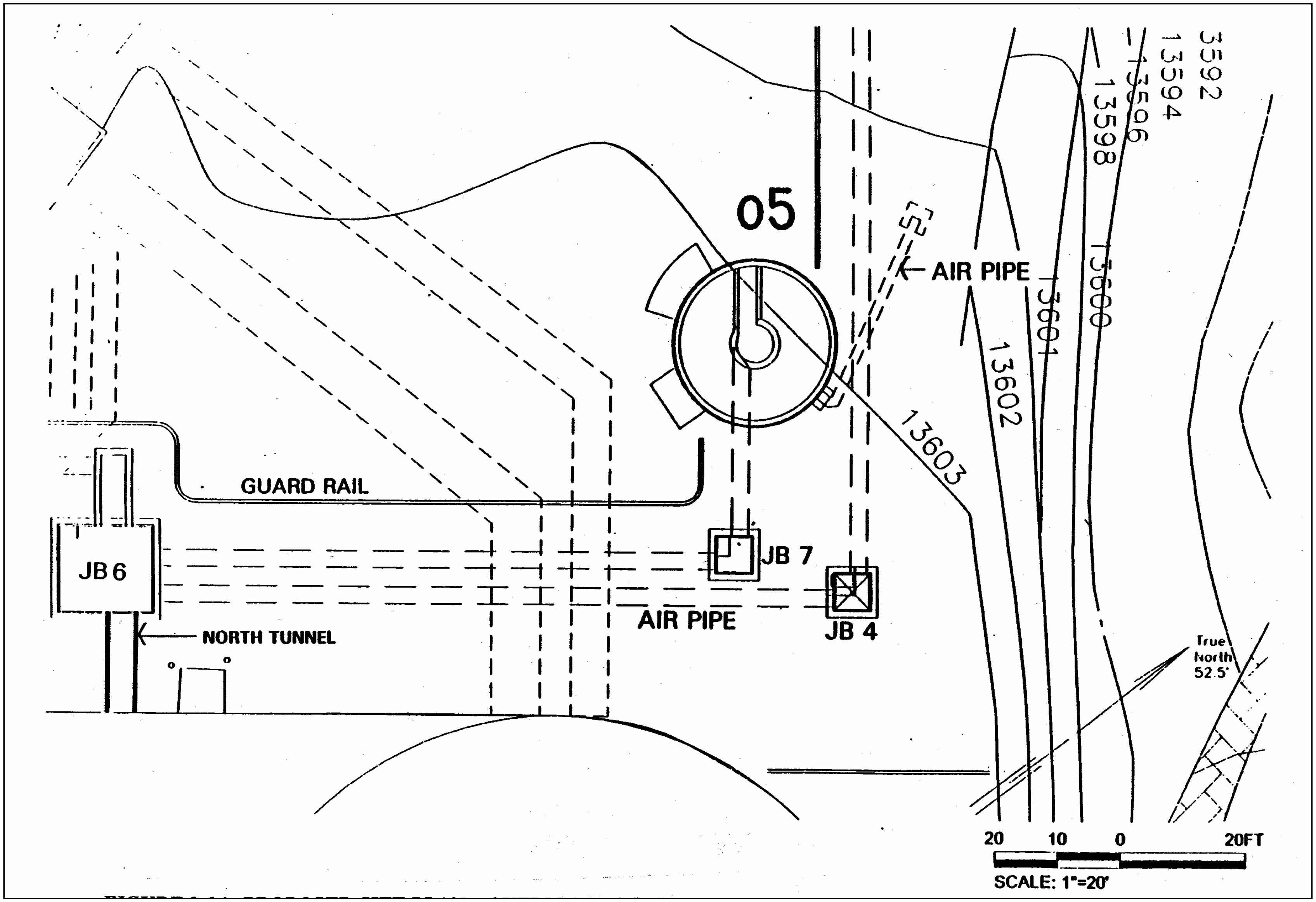
Source: UH IfA 2001a

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

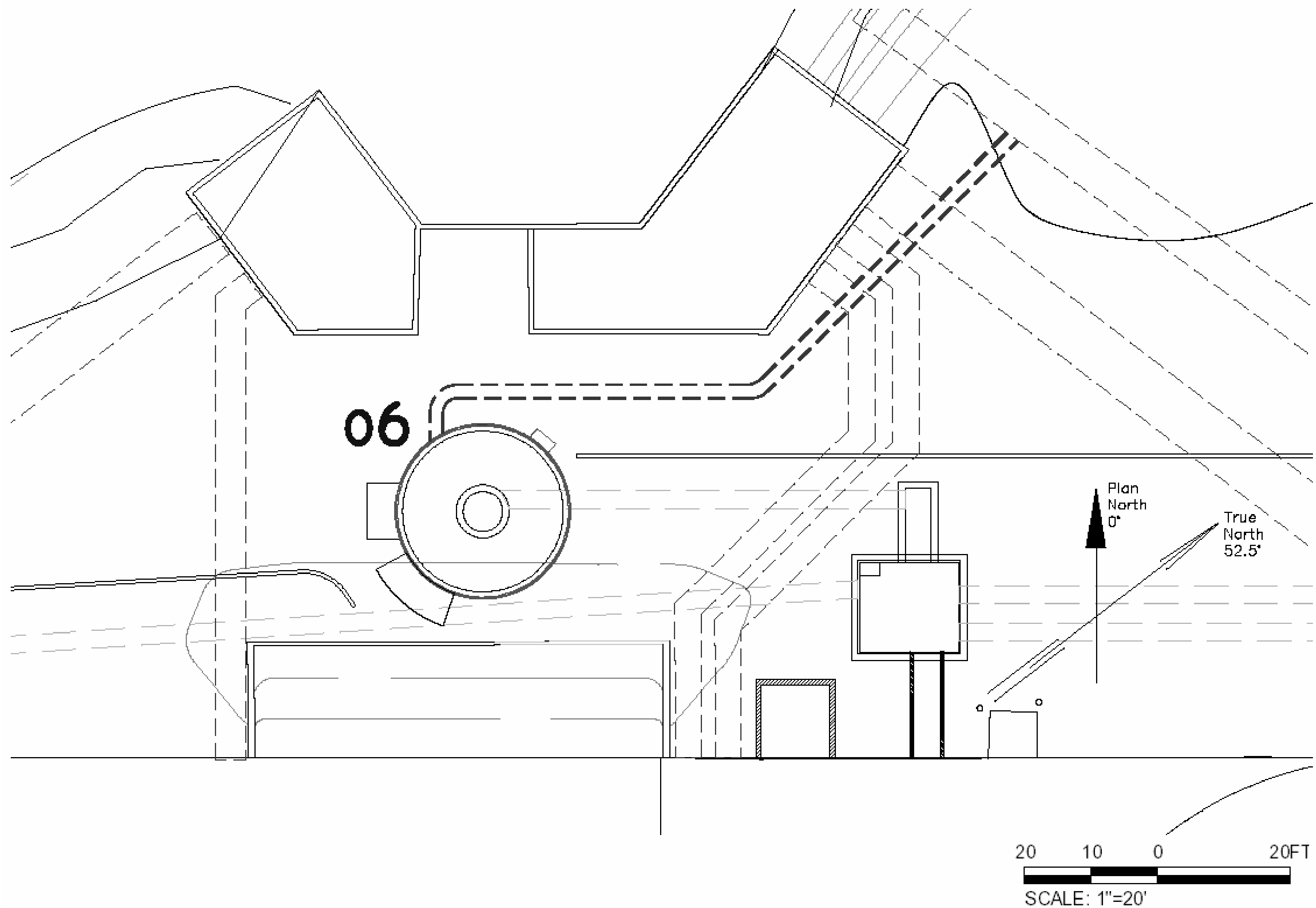


FIGURE 2-16. PROPOSED SITE PLAN—OUTRIGGER TELESCOPE 6

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.

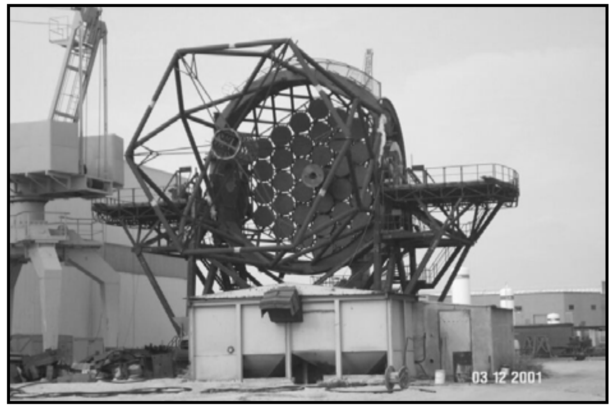


FIGURE 2-21. THE GRAN TELESCOPIO CANARIAS UNDER CONSTRUCTION AT LA PALMA

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

Screening Criteria Evaluation

<u>Tier 1 Criteria</u>. 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.

<u>Tier 2 Criteria</u>. 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).

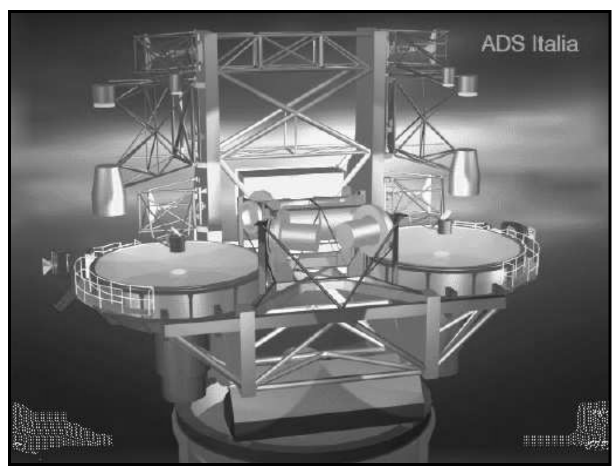


FIGURE 2-22. ARTIST'S RENDERING OF THE LBT SHOWING THE TWO PRIMARY MIRRORS AND THE TELESCOPE MOUNT

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.

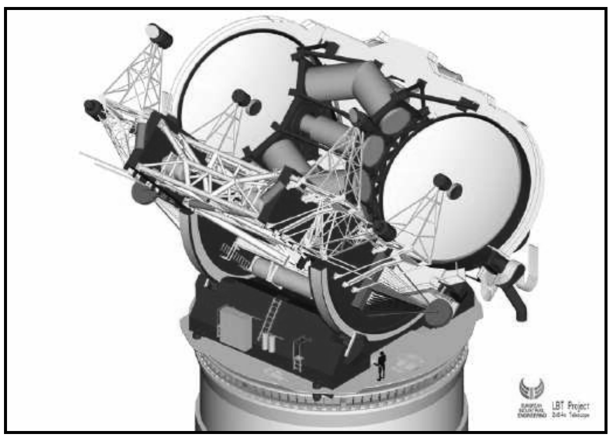


FIGURE 2-23. THIS IMAGE SHOWS THE LBT PRIMARY MIRRORS AS WELL AS THE THREE INSTRUMENT STATIONS (TUBE SHAPED TUNNELS) BETWEEN THE MIRRORS

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.

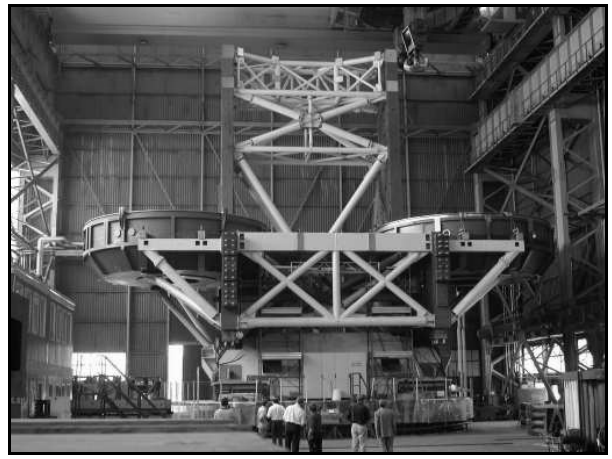


FIGURE 2-24. PHOTOGRAPH OF THE LBT MOUNT STRUCTURE INSIDE THE TELESCOPE ENCLOSURE

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.

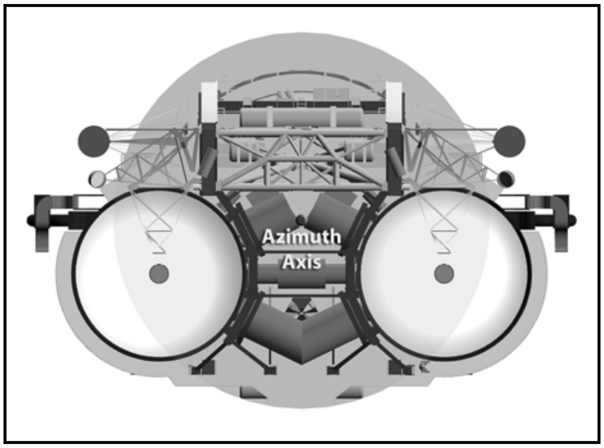


FIGURE 2-25. VIEW LOOKING DOWN THE LINE OF SIGHT OF THE TELESCOPE

Note: The azimuth axis of the mount is indicated.

Image courtesy of the LBT Project.

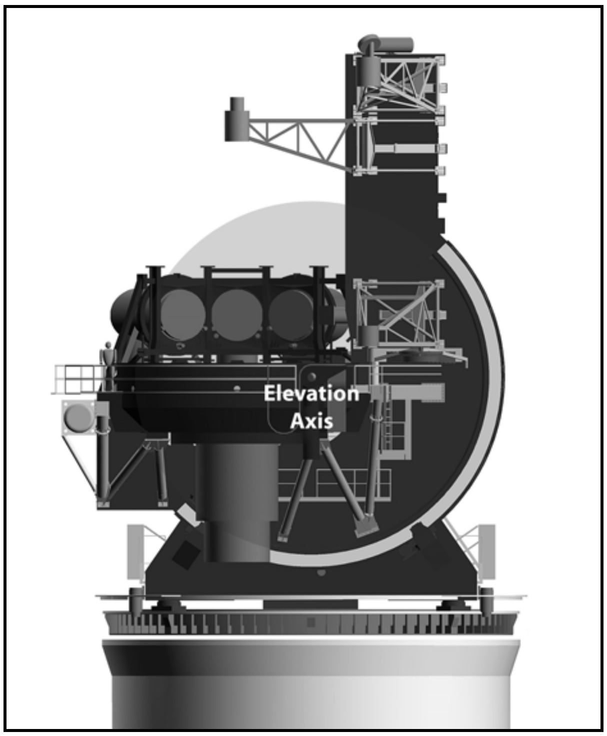


FIGURE 2-26. VIEW LOOKING HORIZONTALLY AT THE TELESCOPE

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.

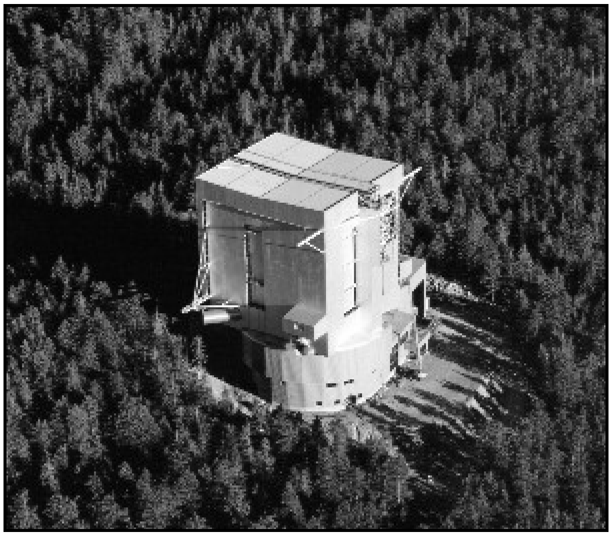


FIGURE 2-27. AERIAL VIEW OF THE LBT ENCLOSURE

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

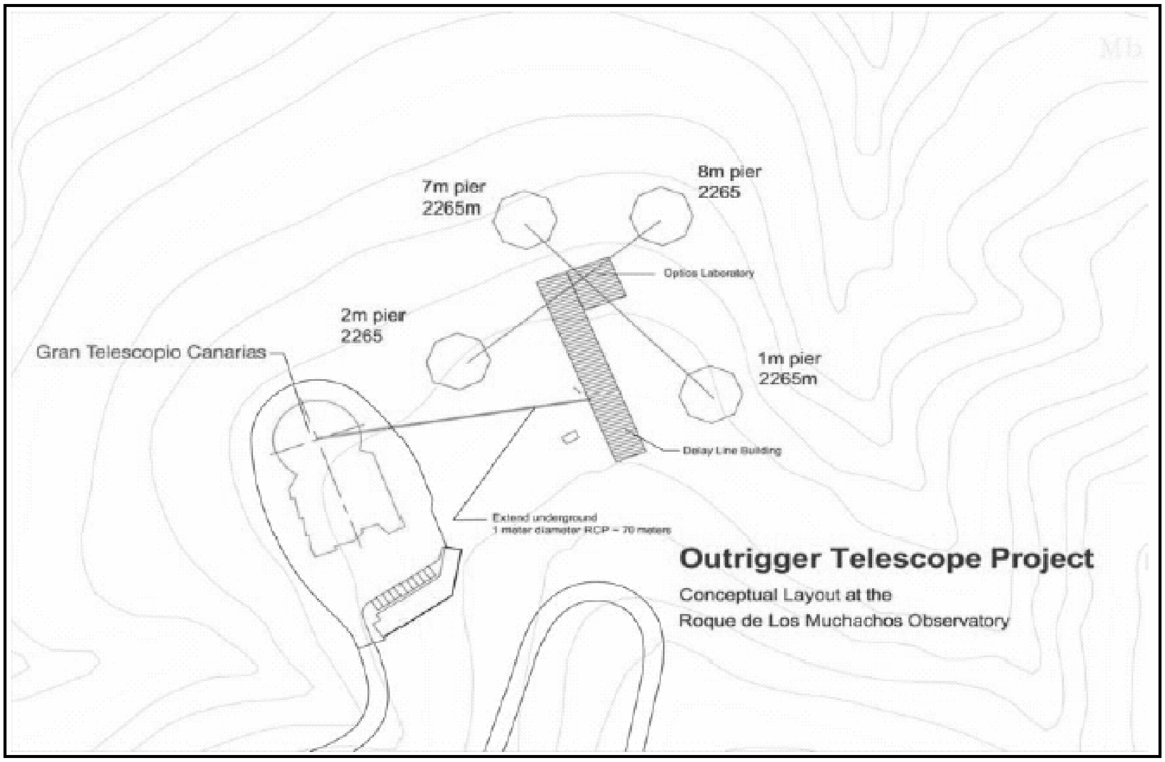
Construction activities at the 2,400-m (7,900-ft) elevation on the island of La Palma are possible on a year round basis, although during the winter months – principally the months of December through March – intermittent periods of inclement weather would be anticipated. Snowfall at the observatory 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 Hawaiʻi 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.