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RADIO ASTRONOMY LABORATORY BERKELEY, CALIFORNIA 94720

June 24, 1976

25 Meter-Millimete Wave Telescope
Memo #45

Dr. David Heeschen, Director
National Radio Astronomy Observatory
Edgemont Road
Charlottesville, Virginia 22901

Dr. Mark Gordon, Associate Director
National Radio Astronomy Observatory
Suite 100, 2010 N. Forbes Boulevard
Tucson, Arizona 85705

Dear Dave and Mark,

As there is now a formal proposal for the 25-meter telescope for millimeter wavelengths, I want to make some further comments about White Mountain as a potential site for it. WM is an exceptional place for astronomical measurements which are limited by water vapor, and I enjoy doing astronomy there and encouraging others to bring facilities there. The University of California encourages such activity, and the National Radio Astronomy Observatory would be very welcome at WM.

Last winter we installed and began astronomical observations with a 62 inch telescope for sub-millimeter wavelengths. The precipitation was exceptionally low that winter, although we were not ready to operate during the most unusual months of good weather. The transmission of the atmosphere, the logistic problems due to weather, and the general operation were just about what were expected from previous water vapor measurements and the very extensive climate measurements. Our arguments for the qualities of WM for astronomical observations have been partially validated, making allowance for the milder than normal winter. The experience with the 62 inch telescope and its observations, coupled with the experience of 25 years of operation and climate measurement, cannot be denied. In particular there are more climate measurements with better analysis at WM than at any other high altitude site.

It is important to separate the fundamental climatic and physiological limitations of WM from those which can be dealt with by better management, modern technology, and more money. The management of the research station has deteriorated, so that recently some problems became overwhelming. Steps are being taken to improve the management, especially with a view to supporting astronomical operations. A recently acquired, modern tracked vehicle clearly shows that such vehicles can play a major role in operation of observatories, bypassing much of the need for snow removal. The University has started firm plans for replacing much of the unreliable power pole line with an underground line and adding an underground telephone cable. I just prepared a report on improving travel on WM, in accord with the NRAO needs for quick access for maintenance, and I am enclosing a copy of that. That report calculates (I believe realistically) travel time from Bishop to the 13,189 plateau to be 25 minutes one way 70% of the time, 90 minutes about 30% of the time, and impossible less than 1% of the time. Such travel uses a mixed stable of an STOL aircraft, a helicopter, and high quality wheeled vehicles and tracked vehicles on a currently unused road to be extended and improved.

There have been some comments in NRAO documents which are somewhat inaccurate or misinterpreted, and I would like them to be corrected. No matter what reasons you have for your decision for choice of site, other people who may be interested in high altitude sites will be influenced by your documents and decision. An excellent example of this is with Mauna Kea, where the NASA decision had been accepted as a significant evaluation, although by now at least the management arrangements there have become unsatisfactory. Perhaps some of the site evaluations there also have been based on overenthusiasm.

There was a meeting on millimeter wave astronomy at the NSF office on 1974 October 25, at which Bill Howard handed out a brief document comparing sites, stating that there was "no road" at White Mountain. It turned out that hostile anecdotes from someone who had worked there in 1962 and 1963 (when there was a road just as now) had been repeated as the source of Bill's statement. Also Bill's report had not made use of our carefully analyzed atmospheric data, but it had mis-interpretations of other data.

The 1975 September prospectus for the 25-meter telescope for millimeter wavelengths is much more careful in its evaluation of sites, but some errors have remained. Page V-10 appears to derive the amount of time during which observations may be lost from precipitation from the White Mountain Research Station Climatological data summary. This shows the number of days on which there is <u>any</u> discernible precip at <u>any</u> time during the 24 hours, and that is a third of the days in January through March. NRAO reported that observations could be lost to precip a third of the time, while the actual fraction is not known but is much less because few days have precip all day and some days have only a trace.

In the same paragraph of your report it is stated that winds can be higher than at other sites, exceeding 100 mph on occasion. Actually we have never had an anemometer which read that high, but I told NRAO people that speed probably occurred. On page V-6 you state, "Winds are usually 10 to 15 miles per hour, although they are sometimes much higher." for Mauna Kea, as if that were a reasonable comparison with the guessed maximum winds at WM. My carefully determined distribution of wind speed at the most exposed point of the summit of WM was never quoted, although it gives a median of < 10 knots in summer and < 25 knots the rest of the year. I do not know of maximum winds being reported at Mauna Kea, nor do I know that terrible weather at White Mountain is necessarily worse than at Mauna Kea. I have been very honest with NRAO people about how bad White Mountain weather can be, and we have 25 years of experience and measurement to describe that. Perhaps such description has not been provided for Mauna Kea, Mt. Lemmon, or other high altitude sites, and I think it is unscientific to bias your report in the above way.

This shows the continuing problem of the excellent climate data at White Mountain being misused and often being compared with unrealistically enthusiastic anecdotal data from other mountains.

On the other hand, page V-1 of your report gives a number of clear days at WM which is too high. On page 34 of my report, An infrared observatory for White Mountain, California, the number of mornings with less than 10% cloud cover at 8 AM is about 180 per year, and the number with less than 50% cloud cover is about 270. I have not looked up the reference cited in your report, but it is important to know whether it refers to mountain top or to average nearby conditions.

Finally the NRAO report and Bill Howard's document focus attention for travel on an expensive tramway, without giving any thought to other means of improving travel. That is simply a straw man. Although a tramway could be a pleasure to have, the road and STOL aircraft we are suggesting would do very well for an order of magnitude less cost.

If you have any information showing that such development is impossible, I would appreciate having a concise report on it. Our experience has some value in comparison with engineering reports you might have based upon brief visits.

I consistently try to give an accurate view of the sometimes severe problems at WM, and I tend to suspect supporters of other sites who do not mention their problems. High mountains can be tough and dangerous places, and I have no reason to believe that any mountain is exempt. WM may or may not prove to have worse weather than some, because of its latitude, but that proof cannot come from partisan anecdotes. If proved, that still would be compensated by lower water vapor and by the amazing flat land at high altitude.

If the NRAO 25 meter telescope is to push to shortest possible wavelengths, including incoherent measurements at sub-millimeter wavelengths, and if there is any interest in at times using the telescope as part of an interferometer, the advantages of White Mountain may very well offset the disadvantages.

If those advantages high on the mountain are not worth the trouble, the 10,000 foot site I discuss in the report on improving travel may be of interest for telescopes. That site is probably comparable with the Cerro Gordo site at the same altitude suggested by Eugene Epstein, except that there are probably fewer clouds at Cerro Gordo because of lack of a cloud-forming higher peak. Both of those sites have much less water vapor in summer than has Mt. Lemmon, and because of higher latitude I expect they have less in winter.

I apologize for the length of the documents I am sending you, but I feel it is important to state my case clearly.

With best personal wishes,

David D. Cudaback
Associate Director for Astronomy
White Mountain Research Station

cc: Dr. Peter Boyce
National Science Foundation

DDC/vg

Improvement of Travel on White Mountain, California

D. D. Cudaback, Associate Director for Astronomy
White Mountain Research Station, University of California

1976 June 16

Introduction

More and more organizations are considering use of White Mountain for astronomical research, and travel up and on the mountain is a major factor in whether such work can be done. Any mountain with the altitude of White Mountain will have greater travel problems than at lower places, but White Mountain may well have fewer problems than most mountains of the same altitude. White Mountain has better weather than most and has more room for airstrips than almost any others. A base station at the Bishop Airport is 18 air miles from telescope sites, and there is the good possibility of people working on the mountain going to and from home in the Owens Valley every day.

The plan suggested in this report is based on support of a ten million dollar facility, where it is important to minimize time lost because of equipment problems, requiring quick access by maintenance engineers. For an annual operating cost of 20% of the capital cost, $5.5k/day is lost by down time. A reasonable approach to travel can be devised which would lose less than three days per year or less than $16k/year because of travel problems.

The plan suggested here can support at least twice the size of research facility discussed, with only modest increase in the operating costs shown. The biggest cost in the plan is for road improvement, and there can be a large increase of road users for the same fixed cost.

Travel times from Bishop to the 13,189 foot plateau beyond the Barcroft Laboratory are calculated to be 25 minutes by air one way 70% of the time, 90 minutes by ground one way about 30% of the time, and impossible less than 1% of the time. A new road is recommended to enable the 90 minute travel time, and a new living base is suggested at about the 10,000 foot level along this road. That base would be one hour from Bishop by ground travel and half an hour from the plateau by ground in winter.

There are several possibilities for improving travel on White Mountain. The National Radio Astronomy Observatory suggestion for a cable car is appealing, but it has some problems in addition to its expense. Most cable systems have a maximum wind speed under which they can operate, such a device puts all the travel investment into one system which must be shut down completely for small malfunctions, and the proposed site may be in conflict with a proposed wilderness area.

Other travel arrangements can be much more flexible, and a varied stable of such arrangements is best. Each system has its limitations, but the limitations do not all occur at the same time. Under the worst weather conditions the telescopes will not be able to operate, so the normally required travel time of 1.5 hours may not be necessary during these conditions.

Air travel

Air travel is certainly the quickest when the weather allows. Helicopter use is quick and flexible, but is the most expensive and the most dangerous technique. Nevertheless, we have thoroughly demonstrated its usefulness, and it should continue to be a part of the stable. The budget below allows 180 hours of helicopter use provided by a commercial operator, as the White

Mountain Research Station is now using. The $235/hour budgeted for that allows use of a modern turboprop helicopter, carrying three passengers and making a round trip in 25 minutes.

Short takeoff and landing (STOL) aircraft appear to be the most useful vehicles when there is sufficient traffic to one point to justify an airstrip. There is space for STOL airstrips close to telescope sites and the US Forest Service can approve of them. A well equipped single engine aircraft carrying five passengers such as the Helio Courier costs about $120k new and operation would cost around $55k/year, having two pilots on full time payroll. That operational cost includes picking up people at Los Angeles or San Francisco airports twice per week and delivering them to the telescope on White Mountain in 1.5 to 2 hours. For people living in Bishop or Mammoth, travel time from the Bishop or Mammoth airports to the telescope airstrip would be 12 to 15 minutes going up and much less going down. Such aircraft are commonly equipped with combined wheels and skis to enable operation both at airports and on top of the snow on the mountain. Takeoff roll is claimed by the manufacturer to be much less than 700 feet at 13,000 ft altitude, so a 1500-2000 ft airstrip would be suitable. Many sites are available for such airstrips adjacent to telescope sites.

Airstrips on the mountain would not be paved, but would have wind indicators and lights for night operation. The vehicles described below would connect the airstrips with the telescopes with a maximum of 10 minutes for ground arrangements.

The weather allows helicopter and STOL operation about 70% of the time, as calculated from the product of the cumulative relative frequencies of wind speed at the most exposed point of the summit of the mountain and of cloud cover at the Barcroft Laboratory. The wind speed at the summit is below

40 knots 81% of the time, on the basis of one year's measurements of a random sample of conditions, and the cloud cover is less than 50% for 85% of the time, on the basis of 20 years' measurement.

One estimate of operation cost can be made by budgeting a flight from Bishop to the mountain three times a day at the times of shift changes. At one half hour of flight time per round trip this requires 548 hours per year. Two trips per week to Los Angeles or San Francisco airports at four hours per trip take 416 hours per year, giving a total of about 1000 hours.

Since there is excellent airline service from Los Angeles to Bishop, the use of the STOL aircraft for that trip may well be much less than estimated. More than 1000 hours per year can be flown by the two pilots, so the marginal cost for hours beyond 1000 will be at $25/hour. Much of the routine maintenance will be done by the pilot/aircraft mechanic shown in the budget, so the hourly operating cost may be less than budgeted.

Surface travel

Surface travel on White Mountain has several options shown on the accompanying maps, of which the provision of an all-weather road for all vehicles and all drivers is unnecessarily expensive. The existing road, although paved for most of the distance, is very impractical because it requires traveling south from Bishop for 15 miles before starting up the mountain. Furthermore that route requires traveling long distances above snow line.

The minimum travel above snow line would be with an existing rough mine road to the Moulas Mine, which leaves US Highway 6 about 13 miles north of Bishop at Piute Creek. The existing road ends about three miles short of the main road on the crest of the White Mountains ridge, and the intervening route appears to be straightforward to develop. The total trip from the highway to the 13,189 plateau climbs 9000 feet in about 21 miles, with the steepest part climbing 7400 feet in about 16 miles. The steepest grades are around 12%, as determined by inspection of the map. This route is never in shaded canyons above the snow level, being on a southwest facing ridge most of the way. The steepest slopes may have snow rarely, with long lasting snow being only at the altitudes where the slopes are flattening out toward the summit ridge.

A practical approach to winter use of this road would be to remove snow only up to the altitude where the snow is continuous enough for a tracked vehicle to operate on top of the snow. We have very successfully used a modern tracked vehicle during this last winter, and it easily travels at 20 mph on a normal snow surface. The route described above may utilize 30 to 45 minutes of tracked vehicle travel.

The problem with such a vehicle is its greatly reduced speed when there is little snow and it must travel on bare ground. The worst condition is too much snow for wheeled vehicles and too little for tracked vehicles, and that is the limiting problem for surface travel at White Mountain. That has indeed been serious during this last winter of low snowfall.

Complete snow removal to enable operation only with wheeled vehicles is possible because the average snow depth is 24 inches at the Barcroft Laboratory in March, the month of greatest average snow depth. The problem of snow removal is in handling wind drifted snow and not in handling its original precipitation, and snow fences can reduce this problem.

A schedule for travel between Bishop and the 13,189 plateau is shown in Table 1. The highway section is almost completely straight except for two turns, so it can be traveled at the speed limit. The three mile section after leaving the highway goes almost straight up an alluvial fan, where the road surface is easy to improve, and the average speed probably can be higher than tabulated. The maximum rate of climb is on this section, where engine power is at a maximum because of the lowest altitude. The tabulated speed and rate of climb for that section are easy to maintain on steeper grades and more twisting roads.

The tabulated rates of climb decrease almost monotonically above the alluvial fan, fitting the decrease of engine power with altitude. The mountain slope is a maximum in the section following the alluvial fan and decreases monotonically going up, in accord with the generally convex outward nature of the slope. The estimated speed of 15 mph for the sections between the alluvial fan and the Barcroft Laboratory gives a very reasonable rate of climb, so only the turn radii and road surface will limit the speed. The lowest of these sections has most of the turns in the entire trip, and inspection of the existing road suggests that straightforward modification will allow the necessary speed.

The route shown on the map and estimated in the budget gives gentle grades and turns, at possibly too great an expense in cost and land use. Keeping closer to the existing Moulas Mine road gives an estimate of three miles less road between Piute Creek and the 10,000 foot station, steeper grades, lower speed, same travel time, less land use, and lower cost. A more detailed survey is necessary to select between these choices.

The section of completely new road above the proposed new living base at 10,000 feet altitude needs no switchbacks and so the tabulated speed is probably too low. The sections along the existing crest road are well known in current operation of the White Mountain Research Station, they have almost no turns except for a half mile section above the Barcroft Laboratory, and speed on them is now limited entirely by road surface.

Decreased visibility in blowing snow will increase ground travel times, to the point where people will decide to stay at one place rather than fight the visibility. We approximate this by specifying no increase of ground travel time most of the days and no travel at all on three days out of the year. That is the most uncertain estimate in this report.

In general the road surface is the critical item in enabling the schedule to be kept. Paving the road is unnecessarily expensive, since the average total annual rainfall at the Barcroft Laboratory is 2.5 inches. The average total annual snow water content there is 17 inches and much of that sublimes away without ever being liquid. A well drained gravel surfaced road is recommended for such conditions, being easy to maintain and especially free of frost heaving problems.

Another possibility is the improvement of the Silver Canyon road, which climbs quickly to 10,000 feet altitude but then requires over 10 miles of travel to reach the junction with the Moulas Mine route at 11,600 feet. Much of the road in Silver Canyon is in deep shade, and much is close to the stream and would require bridge and culvert work. Tracked vehicle usage would be about 60 minutes, and the total travel time from Bishop probably would be greater than with the Moulas Mine route because of 8 miles of highway travel being replaced by high altitude travel.

Regardless of whether the Piute Creek or Silver Canyon roads are improved, it may be necessary to do heavy hauling during construction along the existing road via Big Pine, because the grades are much lower there. Speed on the 20 mile unpaved portion of this road is currently limited by the rough surface rather than by grades and turns. Improvement of this unpaved surface will enable travel five or six months of the year in 2.5 hours from Bishop to the Barcroft Laboratory, and such improvement can be done for $75k from the end of the paved road to the gate. The decision as to whether these lower grades and surface improvement are indeed necessary will depend upon the detailed survey of the new route, so this item does not appear in the budget.

New living base

A new living base can be developed at 10,000 feet altitude, which is the optimum altitude for comfortable sleeping without acclimation while simultaneously forcing acclimation to enable work at higher altitude. At about 10,000 feet along the Moulas Mine road there is a marked change of slope of the terrain, gentler slopes being above that level. The road alignment changes there from repeated switchbacks to a direct route to the gate on the main road. There is an intermittant stream and a spring shown on the map, so probably a water supply can be developed. It may be possible to remove snow from the road below that level most of the time, with the change to tracked vehicles taking place there. Electricity can be delivered three miles down from the gate area, or alternatively the proposed underground power line can come up the mountain along the new route. That alternate may require four miles of new pole line from Highway 6 to the 8000 foot level, followed by four miles of underground line to the gate.

Because there are no switchbacks on the road above this base, except for a short stretch above the Barcroft Laboratory, travel between it and telescope sites can be made quick, easy, and safe even in moderately bad weather and at night. Reflective markers along the road will be important for safety. The steepest grades on the road, the most switchbacks, and the steepest slopes traversed are mostly below 8000 feet altitude, where there is seldom snow. The total safety of mountain operations would be greatly improved with this new road and living station, and personnel readily can be taught the operation of the specialized vehicles and the bad weather operations.

Budget

As shown in the budget, STOL travel has less fixed cost than improved ground travel and because of its short travel time it will be used the most. Perhaps only 30% of the personnel travel would be on the ground, when neither STOL nor helicopter travel is possible.

This leads to a budget where much of the fixed travel cost is spent on a small fraction of the travel, although most of the operating cost would be for most of the travel. Alternatively, the travel budget could be arranged to spend less fixed cost on ground travel with the acceptance of more times when travel is not possible.

A preliminary plan and budget for road improvement was prepared by Mr. Torleif Myhrer, a site development engineer at the Lawrence Berkeley Laboratory. Estimates were based on a one day site visit, ground inspection of some parts of the road and helicopter inspection of other parts, and later map inspection. Cost estimates are based on normal contractor rates in the area, but there may be sizable savings if the California Ecology Corps does much of the work. It is within their mandate to do such work, and negotiations are under way for them to do other major jobs at the White Mountain Research Station.

The earth moving cost estimate is based upon 15,000 yards between Piute Creek and the top of the steepest slopes, with an average side slope of 17 degrees, and a three square yard cross section of cut and fill; and 8400 yards between the slope change and the gate, with an average side slope of 7 degrees, and a one square yard cross section of cut and fill. Total cut and fill is 53,400 cubic yards, and standard rate for this is about $3 per cubic yard. Much less earth moving is possible, at the expense of steeper grades.

The surface improvement cost estimate is based upon 18 miles from Piute Creek to the 13,189 plateau, using three cubic yards of gravel per yard of road distance. Standard rate for delivery and application of gravel is around $3 per cubic yard, depending upon the location of the quarry. Probably considerably less gravel would still give a suitable road.

In order to compare this budget with that proposed three years ago in the prospectus for an infrared observatory submitted to the National Aeronautics and Space Administration, account must be taken of different principles of operation. That earlier prospectus was based on university operation of a modest facility. This report is based on national laboratory operation of a bigger facility, serving more visitors, and with a very high standard of quick access time for unexpected maintenance. In addition this report has provided for staff normally to travel daily to and from homes in the Owens Valley, with a large increase in travel expense.

Land use

All of the new route except for the first two miles beyond Highway 6 is in Inyo National Forest. There has not been time to discuss this plan with the US Forest Service, as some astronomical groups are close to making decisions on site selection. Any use of National Forest land requires extensive studies of environmental impact and a considerable review process. The University of California is currently negotiating such study and review with the Forest Service for use of the land higher on the mountain. Those negotiations have already described the potential use of White Mountain for large astronomical installations, so that further review of the new road and living base can be added to the existing negotiations. The land use plan under study specifies that the University of California coordinates and transmits to the Forest Service land use requests in the Scientific Research Area north of the gate, and the Forest Service has informally agreed to such coordination now.

Recommendation

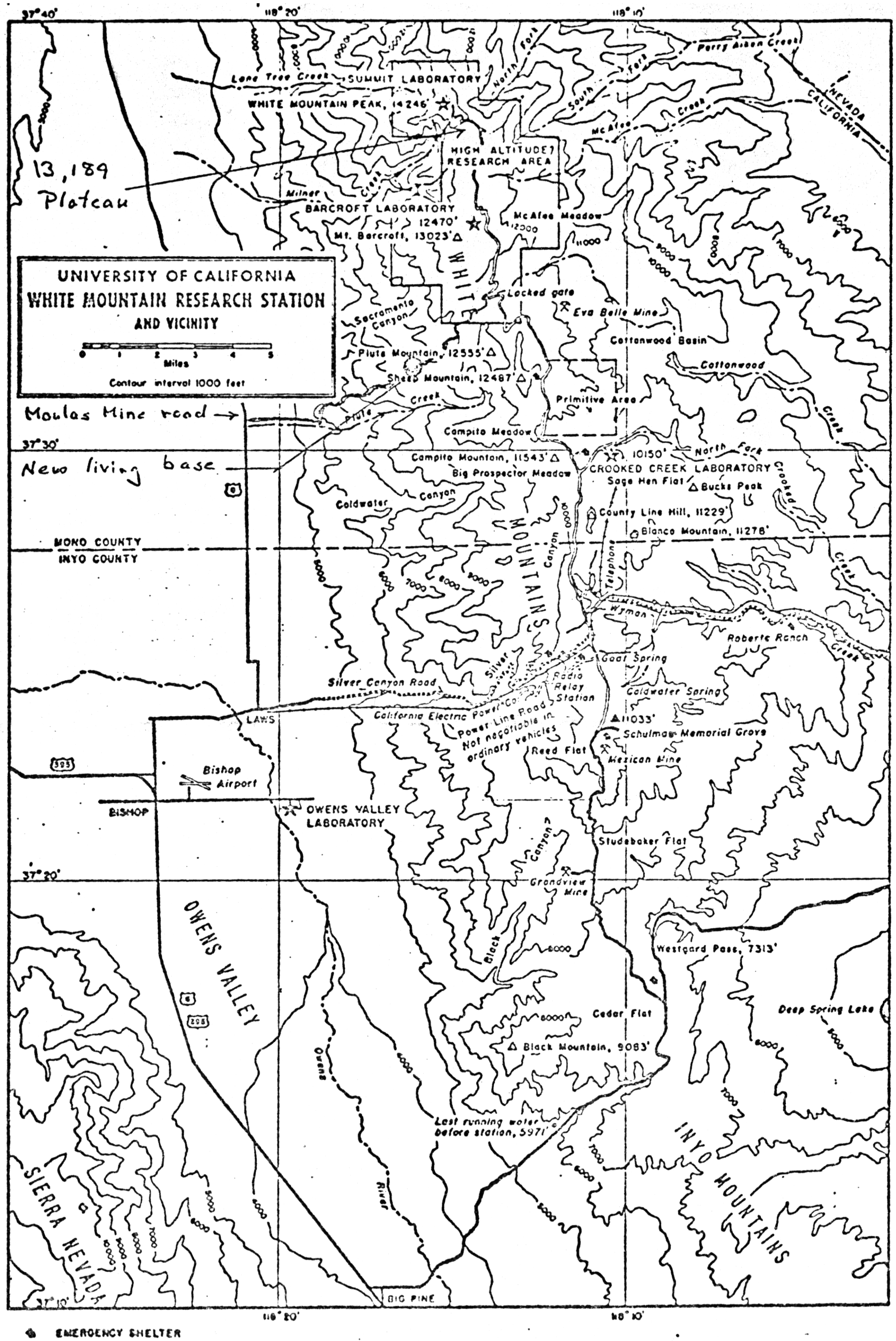
A cost estimate should be solicited immediately for preliminary surveying and engineering of the road and living base plans suggested here. Among other organizations the Lawrence Berkeley Laboratory could be solicited for such an estimate and Mr. Torleif Myhrer there has visited White Mountain, prepared the enclosed cost estimate, and is interested in developing further plans.

Every attempt should be made to raise funds for this surveying and engineering, so that a 25% accuracy cost estimate for construction could be made within a few weeks. That estimate will be of major importance to the organizations considering use of White Mountain.

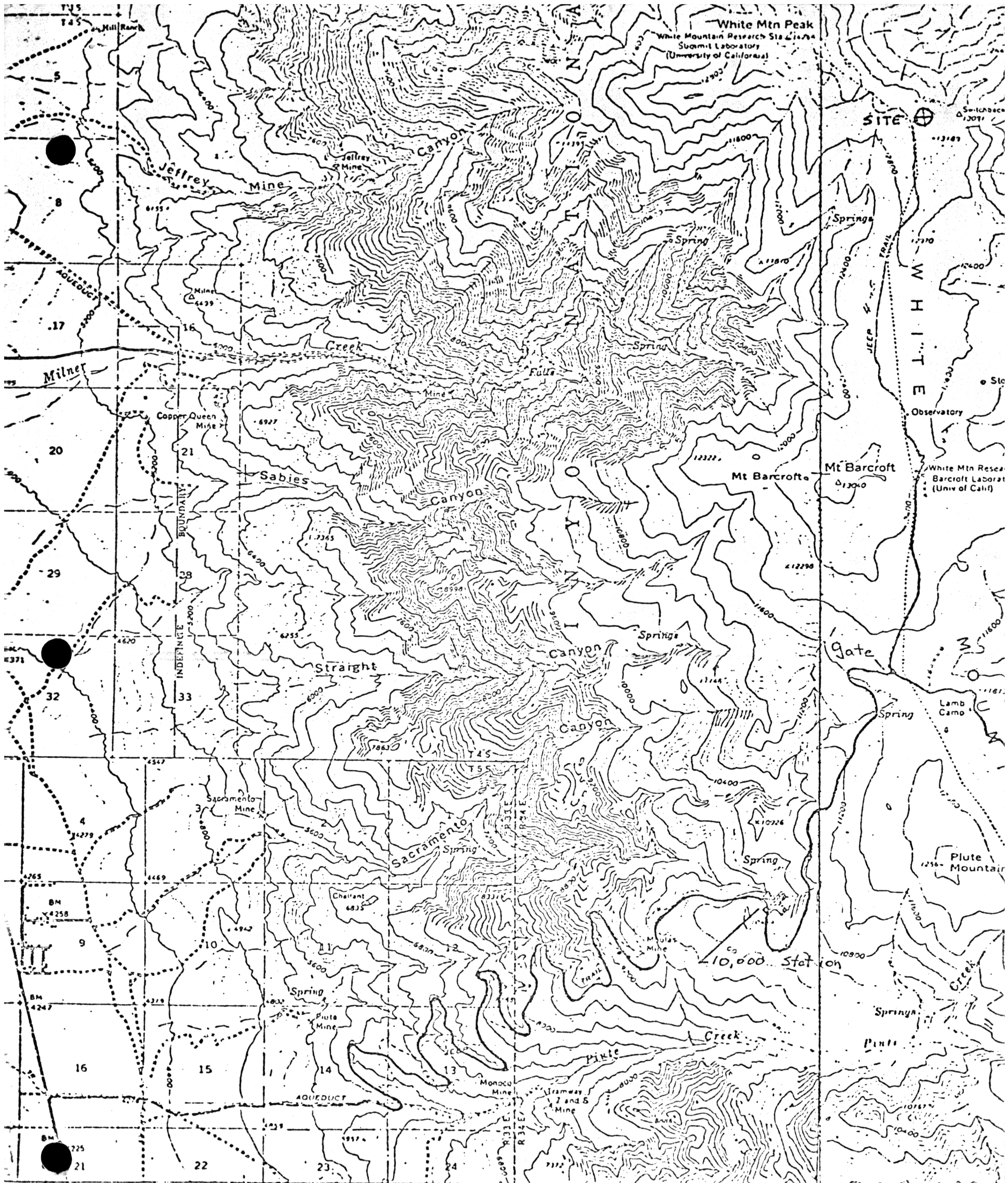
At the same time land use discussions must be started, before preliminary surveying is done. Although actual decisions on land use take a considerable time, authorization to consider the items here probably can be made quickly.

Schedule for ground travel from Bishop to 13,189 plateau

Location	Elevation (feet)	Elevation difference (feet)	Distance (miles)	Total distance from Bishop (miles)	Est. speed (mph)	Time (minutes)	Total time from Bishop (minutes)	Total time from 10,000 (minutes)	Rate of climb (ft/min)	Average grade (%)
Bishop	4,100									
		100	13		55	15			7	.15
Lv Hgy 6	4,200			13			15			
		1,400	3		30	6			230	9
Lv Piute Ck	5,600			16			21			
		4,400	10		15	40			110	9
10,000 Station	10,000			26			61			
		1,600	3		15	12			130	10
Gate	11,600			29			73	12		
		800	2		15	8			100	8
Barcroft Lab	12,400			31			81	20		
		800	3		20	9			90	5
13,189 Plateau	13,200			34			90	29		



UNIVERSITY OF CALIFORNIA
WHITE MOUNTAIN RESEARCH STATION
AND VICINITY
Miles
Contour interval 1000 feet
13,189 Plateau
Moulas Mine road
New living base
SUMMIT LABORATORY
WHITE MOUNTAIN PEAK, 14246'
HIGH ALTITUDE? RESEARCH AREA
BARCROFT LABORATORY 12470'
Mt. Barcroft, 13023'
McAfee Meadow
Locked gate
Eva Belle Mine
Cottonwood Basin
Piute Mountain, 12555'
Sheep Mountain, 12487'
Primitive Area
Campito Meadow
Campito Mountain, 11543'
Big Prospector Meadow
CROOKED CREEK LABORATORY 10150'
Sage Hen Flat
Bucks Peak
County Line Hill, 11229'
Blanco Mountain, 11278'
MONO COUNTY
INYO COUNTY
WHITE MOUNTAINS
Wyman Creek
Roberts Ranch
Goat Spring
Coldwater Spring
Radio Relay Station
Silver Canyon Road
California Electric Power Co. Power Line Road Not negotiable in ordinary vehicles
Schulman Memorial Grove
Reed Flat
Mexican Mine
LAWS
Bishop Airport
BISHOP
OWENS VALLEY LABORATORY
Studebaker Flat
Grandview Mine
Westgard Pass, 7313'
Cedar Flat
Deep Spring Lake
Black Mountain, 9083'
Last running water before station, 5971'
OWENS VALLEY
INYO MOUNTAINS
SIERRA NEVADA
BIG PINE
NEVADA
CALIFORNIA
EMERGENCY SHELTER



Scale 1: 62500

4 MILES

12000 15000 18000 21000 FEET

3 4 5 KILOMETERS

FEET

Proposed route of new White Mtn. road, Calif.

ROAD CLASSIFICATION

Medium-duty — Light duty

Unimproved dirt

...apped, edited, and published b...
...ontrol by USGS, USC&GS, and US...
...opography by photogrammetric me...
...hotographs taken 1954 Field ch...
Polyconic projection 1927 North...

Budget for improvement of travel on White Mountain, California

Fixed costs

	$k	
Helio-Courier, STOL airplane	120	
3 wheeled vehicles	45	
2 tracked vehicles	50	
Road and airstrip maintenance vehicle	15	
Total vehicles	230	230
Moulas Mine road completion and realignment, earth moving	162	
Moulas Mine road surface improvement, Piute Ck to plateau	285	
Road signs, culverts, reflective markers, etc.	25	
STOL airstrip construction and lights	40	
Total construction	512	512
Total fixed costs		742

Annual operating costs

Pilot	15	
Pilot/aircraft mechanic	15	
3 Drivers/road maintenance men	36	
Total salaries	66	66
STOL operation, 1000 hours, $25/hr	25	
Helicopter charter, 100 hours, $235/hr	24	
Surface vehicle maintenance, fuel, misc.	20	
Total operations	69	69
Total annual operating costs		135

Engineering, overhead, employee benefits, contingency not included.