NASA TECHNICAL MEMORANDUM

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SYSTEMS STUDY OF AN AUTOMATED FIRE WEATHER DATA SYSTEM

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FOREWORD

This study was conducted to aid the California Division of Forestry in its long-range planning in applications of advanced aerospace technology and to help NASA derive a better understanding of the problems faced by the user of aerospace technology. The information derived from this study will help NASA develop guidelines for future space systems which will fulfill such needs. All statistical data on fires used in this study were supplied by the California Division of Forestry in the form of Annual Fire Statistics Reports, unpublished data and from discussions with Division personnel. California Division of Forestry fire data were used primarily because of their availability and accessibility of personnel for detailed discussions. Results of this study are therefore applicable directly to the California Division of Forestry protected land areas. But, in addition, these results are also applicable, in general, to U.S. Forest Service protected lands in California. U.S. Forest Service protected lands are, by and large, more inaccessible than those lands protected by California Division of Forestry and thus the economic benefits derived from an automated fire weather data system should be greater.

Cost data used in this study were the best generally available at the time. Unfortunately cost data, especially for high technology areas, are a highly perishable commodity. Thus in the case of the satellite-data relay system, the costs dropped from \$1700[a] to possibly \$500[b] per voice channel per month just as this report went into typing. Therefore, the costs shown in the study for the use of satellite data relay are

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(a) "First Coast-to-Coast Commercial Satellite is Initiated by RCA," Wall Street Journal, January 9, 1974.

(b) Telecommunications, Volume 40, No. 20, Pages 14-16; May 20, 1974.

higher than they will be if the system were to be instituted today. Also the concept of sharing the data relay channel that is leased, accessing the satellite with multiple data collection platforms and having private receiving stations has yet to be studied and approved by the Federal Communication Commission.

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SUMMARY

A study of a conceptual automated fire weather data system for use by the California Division of Forestry has been completed. The results of the study indicate clearly that such an automated system would be desirable because of its economic and intrinsic advantage over the current manual system.

This was a preliminary systems analysis of a conceptual automated fire weather data system, investigating the feasibility of the concept based on technological and economic criteria. In order to accomplish this, the current fire weather data system and fire data[1] were examined to obtain base comparison data. The basic automated fire weather data system was then synthesized and the major system components identified, i.e. the automated meteorological station, data relay equipment, data receiving and processing facility, and the data dissemination and display equipment. Tradeoff analysis of competing component systems for data relay by satellite, telephone lines or microwave network were performed to identify the most desirable system. The analysis shows that the overall system is technically feasible without any new major technological development. Gross costs for each of the major system components were estimated to obtain system costs based on a network of 150 automated fire weather stations.

The overall non-recurring costs ranged from \$462,000 to \$618,000 while recurring costs per year ranged from a minimum of \$35,000 to a maximum of \$93,500. In both the recurring and non-recurring costs the minimum-maximum range (comparing satellite, microwave, and telephone data relay technology costs) was spanned by the satellite system. The large

(1) Numbers in parenthesis refer to references listed at the end of the report

cost range results from whether or not cost sharing of the data relay network by other users can be effected. In comparison, the current manual fire weather system has a capital value of $105,000 and recurring costs of $127,000 per year. Cost breakeven for the automated system (assuming equal effectiveness) should occur within 6 to 21 years, again depending on the cost assumption.

But the automated system with its greater capability is expected to yield additional benefits by helping reduce fire losses, an additional benefit. Average wildland fire losses per year experienced by the State of California (excluding federally and privately protected lands) are approximately $15 million. The automated system can be expected to reduce this loss by about 1 to 5 percent. Including this benefit it reduces the system breakeven period to less than one year to not more than four years for the minimum and maximum cost cases, respectively. These results indicate that the automated fire weather data system is economically viable and its use will be advantageous.

The future potential of expanded roles for the automated fire weather data system (with proper modification) appear very good. They could, for example, provide weather data from remote uninhabited sites on land or sea to provide weather forecasters with valuable information (heretofore unavailable). Other application areas in pollution (water/air) monitoring watershed, stream condition, etc., are all possibilities.

A more detailed analysis of the automated fire weather data system will be useful in refining the cost estimates, resolving certain policy issues and in identifying any technology areas requiring research and development.

INTRODUCTION

Ames Research Center was asked by the State of California to provide technical expertise in developing a sensor system applicable to an automated weather station by the California Division of Forestry. A successful prototype unit was constructed and installed at Sunol, California. It is currently providing automated fire weather data which correlates excellently with the manual readings. With the successful development of a prototype unit, both Ames Research Center and California Division of Forestry agreed on the desirability of a system study for an automated fire weather data system for California. Because Ames Research Center has the expertise to conduct such studies, it agreed to conduct the study with California Division of Forestry providing necessary fire related data.

The need for new equipment and methods to aid in the surveillance and protection of our wildlands from fires is highly desirable. The methods and equipment in use today have evolved through the years and have fulfilled the need adequately, but in recent years, especially in states such as California, the combination of rapidly increasing population and unprecedented increases in the standard of living has resulted in severe demands on the wildlands for recreational purposes. New gadgets such as campers and trailers have made possible the use of the wildlands in almost home-like comfort, and trail bikes (motorcycles) have opened remote areas to weekenders whereas they were previously accessible only to hikers with enough time to make the trip.

This unprecedented increase in wildland use has resulted in increased numbers of fires as documented in the California Division of Forestry's Fire Statistics(1). Thus closing of wildland areas to the public during extreme fire danger may be desirable for both conservation of wildlands and the safety of the using public. But closing of recreational areas during periods of peak usage, which unfortunately coincides with periods of high fire danger (summer), is undesirable. Such closing should only occur when there is undeniable evidence to justify such an action. Unfortunately the data provided by the current fire weather data gathering system is inadequate and thus of little help in making such decisions. The automated fire weather station will be capable of taking continuous data readings, if necessary, of areas where closings are being contemplated. Therefore the fire danger can be monitored and decisions on closing of areas can be made on up-to-the-minute trends in the fire danger index.

This study has conceptually designed the overall automated fire weather system from the automated data gathering to the dissemination of the collected and processed data to users in the field. The automated system proposed in this study is intended to be fully integrated and automated without manual interaction anywhere in the system except at the user terminal. Data will be automatically obtained and transmitted, automatically relayed, received, processed, stored and disseminated. Elements of the automated system are now available separately. For example, the automated weather station, satellite data relay and data receiving elements of the system have been designed and verified by the Ames Research Center/California Division of Forestry joint development effort. Automated data processing and data dissemination equipment have been developed in the U.S. Forest Service. The computer programs necessary for data processing, data storage and retrieval (called FIRDAT* and AFFIRMS*) are now available and are operational. Data dissemination is via remote computer terminals. If the efforts by the Ames Research Center and U.S. Forest Service were tied

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* FIRDAT - Fire Data

AFFIRMS - Administrative and Forest Fire Information Management and Retrieval System together with proper modifications a working "Automated Fire Weather Data System" would be available.

Other examples of the automated data gathering weather station portion of the system are also available. The U.S. Forest Service is experimenting with an automated weather station[2] using a VHF radio or, where available, a telephone link. The California Department of Water Resources* has over 40 automated data stations for gathering hydrologic and meteorologic data which employ a telemetry system composed on VHF radio repeaters and the State's microwave network to link with the water resources central interrogation station in Sacramento. This latter is a different application area, but the concept of automated data sensing and gathering is the same as for fire weather applications.

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* Details on this system are available through George W. Barnes, Jr. of the California State Department of Water Resources

LOSSES AND COSTS OF WILDLAND FIRES

Introduction

The true loss from fires occurring in the wildlands is difficult to evaluate. Elements making up the loss are many and vary considerably with the location where fires occur. Typically the loss can be divided into five primary areas: (1) value of physically burned material (timber, structure, etc.); (2) fire suppression cost; (3) rehabilitation cost for burned areas; (4) loss of use of lands (recreation, watershed, etc.); and (5) other (floods, mudslides, etc.) aftermath of fire. Quantitative losses are available in each of the first three areas and are presented below. The data available in the fourth area is spotty and is very dependent on the particular area in which the fire occurs. Quantitative values can be estimated from studies,[3,4] but because of low confidence in the quantitative results, they have not been included here. Losses associated with the fifth area are even more difficult to quantify. Therefore, only quantitative data from the first three areas will be considered, although all five areas are discussed below. Values of loss shown have not been corrected for inflation, unless so indicated.

Table 1 shows a summary of the quantifiable losses for the first three categories mentioned above. The values shown in the table represent average values based on ten years of actual data (1962-1971), with the exception of rehabilitation cost which is based on U.S. Forest Service data[5]. Actual values as well as values corrected for inflation are shown. Inflation has been corrected to base year 1973.

Table 1

SUMMARY OF TOTAL LOSS TO
WILDLAND FIRES

Loss Item	Average Loss $ Per Acre: Actual Loss	Inflation Corrected Loss
Value of Material Burned by Fire	$ 38.45	$ 48.00
Fire Suppression*	78.05	103.00
Rehabilitation of Burned Areas (Reseeding)	1.50	1.50
Loss of Use of Lands (Recreation, Watershed, etc.)	———	———
Other Losses (Floods, Mudlsides, etc.)	———	———
Total Loss Per Acre	$118.00+	$152.50+

*

* Cost here includes the actual suppression and applicable pre-suppression activity costs

Value of Physically Burned Material

These data are readily available in the Fire Statistics issued anually by the California Division of Forestry. The summary data format was changed in 1972 and therefore the data from that year has not been used. A summary of the annual losses divided into six categories, for ten years from 1962 through 1971, is shown in Table 2. The descriptive headings are as used in the Fire Statistics Summary and are self explanatory with the possible exceptions of "Improvements" and "other". "Improvements" cover the losses due to burning of houses and other structures such as storage sheds, picnic tables and bridges. "Others" is the catch-all group for those items that cannot be categorized under any of the other five headings. Examples of items that could be listed under this heading are automobiles caught in fires and tourist-camper related losses such as camping gear, etc.

As seen in Table 2 the totals and individual yearly entries for each category vary widely from year to year. No definite pattern can be seen except for an overall trend toward increasing losses. The highest loss category varies from year to year. But on an overall basis, the losses under the "Improvements" category far exceed the losses under all the other categories. In fact, the 10-year totals show that the losses under "Improvements" exceed almost 4 to 1 the combined losses in the other five categories.

Fire Suppression Costs

The California Division of Forestry budgets about $35 million per annum for fire control. Thus the cost of fire suppression* can, as a first approximation, be said to be this amount. This amount includes the actual dollars spent in fighting fires, the facilities and equipment (e.g. Fire Stations

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* Cost data shown are approximate numbers obtained from CDF for FY 1972. For FY 1975 about $60 million has been budgeted.

Table 2

10-YEAR SUMMARY FIRE DAMAGE BY MATERIAL CLASS

Year	Merch. Timber	Immature Timber	Hay & Grain	Forage Value	Improvement	Other	Total	Total Acres
	Dollar Value							
1962	133,544	219,278	43,662	83,882	813,688	53,010	1,347,064	91,935
1963	5,481	32,096	78,859	74,127	346,904	33,500	570,967	32,250
1964	2,065,661	319,611	13,727	187,127	3,723,872	162,421	6,472,419	204,936
1965	24,570	166,695	102,530	438,759	4,189,314	261,181	5,183,049	245,482
1966	382,389	348,480	90,066	101,297	418,739	81,834	1,422,805	92,333
1967	69,334	6,475	62,329	201,481	3,464,783	22,781	3,827,183	163,378
1968	57,273	67,178	100,185	211,338	1,927,367	173,989	2,537,330	121,733
1969	32,462	44,275	42,678	131,701	1,196,767	106,554	1,554,437	79,422
1970	880,934	1,869,184	45,746	875,845	17,296,270	64,498	21,032,477	208,479
1971	286,064	18,048	19,949	77,956	4,858,369	175,494	5,435,880	45,008
10-Yr Total	3,937,712	3,091,320	599,731	2,383,513	38,236,073	1,135,262	49,383,611	1,284,956

and Firetrucks), air attack programs, and all pre-suppression activities. Pre-suppression activities cover such activities as clearing road sites, removal of forest litter, clearing brush and constructing fuel breaks. Of the $35 million, about $10 million dollars is used directly for fighting fires and includes manpower, equipment, aircraft and chemicals.

A summary of the CDF manhours spent in actually suppressing fires is summarized, along with suppression cost and fire damage loss, in Table 3. The ten-year totals for suppression cost and fire damage losses are within 11% of each other.

Rehabilitation Costs for Burned Areas

Rehabilitiation has been largely confined to emergency reseeding of watershed lands. This program started in 1956 in the State of California with legislative enactment. The primary purpose is to provide a protective cover of vegetation quickly over denuded lands which are prone to solid losses, flooding and mudslides. Table 4 summarizes the number of acres that have been part of the emergency revegetation projects through the years. By comparing the total acres burned per year with the total acres reseeded for specific years in Tables 3 and 4, respectively, it is seen that the percent of acres reseeded of burned lands are substantial, i.e. about 34%.

The cost of emergency reseeding is tied primarily to aircraft and seed costs (80%). The remaining 20% cover project mapping, labor for handling and transporting seeds, and aircraft ground operations and crew. Overall cost was found to be approximately $1.52 per acre[5].

Loss of Use of Lands

The wildlands have definite utility to both man and nature. In its natural or nearly natural state the wildland is home to wild animals and

Table 3

10-Year Summary of

Fire Suppression and Damage Cost and Other Data

Year	Totals Per Year				
	No. of Fires	Acres Burned	Damage Costs, $	Suppression Times, Hr	Suppression Costs*, $
1962	2,875	91,935	1,347,065	784,330	5,490,310
1963	2,545	32,250	570,967	394,768	2,763,376
1964	3,665	204,936	6,472,419	1,124,669	7,872,683
1965	3,256	245,482	5,183,049	682,829	4,779,803
1966	4,203	92,333	1,422,805	978,152	6,847,064
1967	3,469	163,378	3,827,183	678,875	4,752,125
1968	4,387	121,733	2,537,330	1,053,229	7,372,603
1969	4,397	79,422	1,554,437	748,998	5,242,986
1970	5,170	208,479	21,032,477	979,531	6,856,717
1971	6,001	45,008	5,435,880	474,879	3,324,152
Totals	39,968	1,284,956	49,383,611	7,900,260	55,301,820

* Estimated Suppression Cost is $7 Per Manhour Based on CDF Records

Table 4

SUMMARY OF NUMBER OF EMERGENCY REVEGETATION PROJECTS AND ACREAGE SEEDED, 1956-1971[5]

Year	Number of Projects	Acreage of Private and State Lands Seeded
1956	3	36,716
1957	7	7,818
1958	8	26,733
1959	7	3,421
1960	12	16,530
1961	9	35,565
1962	9	9,892
1963	1	1,632
1964	9	62,724
1965	4	13,120
1966	3	3,589
1967	11	92,951
1968	8	7,493
1969	5	19,087
1970	25	218,614
1971	1	8,740
Totals	122	564,624

has a definite aesthetic and/or historic value and appeal to man as recreational areas and use as watersheds.

When a fire occurs, it destroys the use of the land for the above purposes temporarily or in extreme cases permanently. The quantitative evaluation of the above use for the lands is difficult and is not usually made when a fire occurs. That there is a quantitative loss can be easily seen but measuring that loss is difficult. Specific studies[3] have analyzed the value of public recreation areas. Many parameters are involved, including accessibility, distance from populated areas, cost of entering the recreation area and available recreation facilities (hiking trails, fishing, etc.). With the loss of the land to recreational use, an additional loss to the local economy occurs because of the interruption in the flow of tourist dollars into the area.

Destruction of a historical wildland item such as a California Redwood grove by a forest fire goes far beyond the commercial value of the timber. It is almost irreplaceable as an object of wonder and awe by sightseers and yet the true loss is not quantifiable; only the commercial value as timber is quantifiable.

Loss of wildlife habitat could result in a reduction in the population of game animals thus reducing an important source of recreation. Also in order to rebuild this recreational resource the Department of Fish and Game would have to expend time and money. Even loss of non-game animals would be a loss but of a nature more difficult to evalute.

Other Losses

Unfortunately, the losses from fires can continue far beyond the immediate losses of timber, grazing areas, recreation, etc. Depending on location, time of year and weather conditions, soil losses (washouts), floodings and mudslides can result from the fire denuded lands.

For example, the Molera Fire in Monterey County in August 1972, burned approximately 4,300 acres and the dollar loss was estimated at $200,000. (The fire suppression cost for the fire was approximately $1,150,000). During the subsequent winter the area had well above average rainfall. The above average rainfall falling on the denuded hills is suspected to have been the cause of floods and mudslides resulting in roads (including California State Highway Number 1), homes, businesses, trailer homes, automobiles, etc., being washed away or buried by mudflows. The resulting economic losses were severe.

The above examples are intended to show that estimating losses from fires can be very complex; but that if all these losses are attributed to fires, the total economic consequences can be much greater than the first order damage losses or suppression costs would indicate.

CURRENT FIRE WEATHER DATA SYSTEM

System Description

The basic data obtained from a fire weather data station consists of wind speed and direction, temperature, humidity and fuel moisture. There are currently about 137 stations* scattered throughout the windlands under California Division of Forestry's protection. This section first presents a description of this system, including the flow of data, followed by the cost of the system.

Currently the fire weather data readings are taken manually and thus the weather stations are located near ranger unit headquarters, fire lookout towers and fire stations. The method used to obtain the readings are summarized in Table 5.

Table 5

Fire Weather Data and Method Used to Obtain Them

Data	Source	Observation Method
Wind Direction	Wind Vane	Visual
Wind Speed	Anemometer	Visual
Temperature	Thermometer	Visual
Humidity	Psychrometer	Visual
Fuel Moisture	Fuel Sticks	Weighed-Visual

The data readings from all weather stations are reported to their respective jurisdictional Ranger Unit Headquarters. These readings are taken at precisely prescribed times. The Ranger Unit transforms the

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* Total number varies from year to year. 150 stations were assumed as the base for this study.

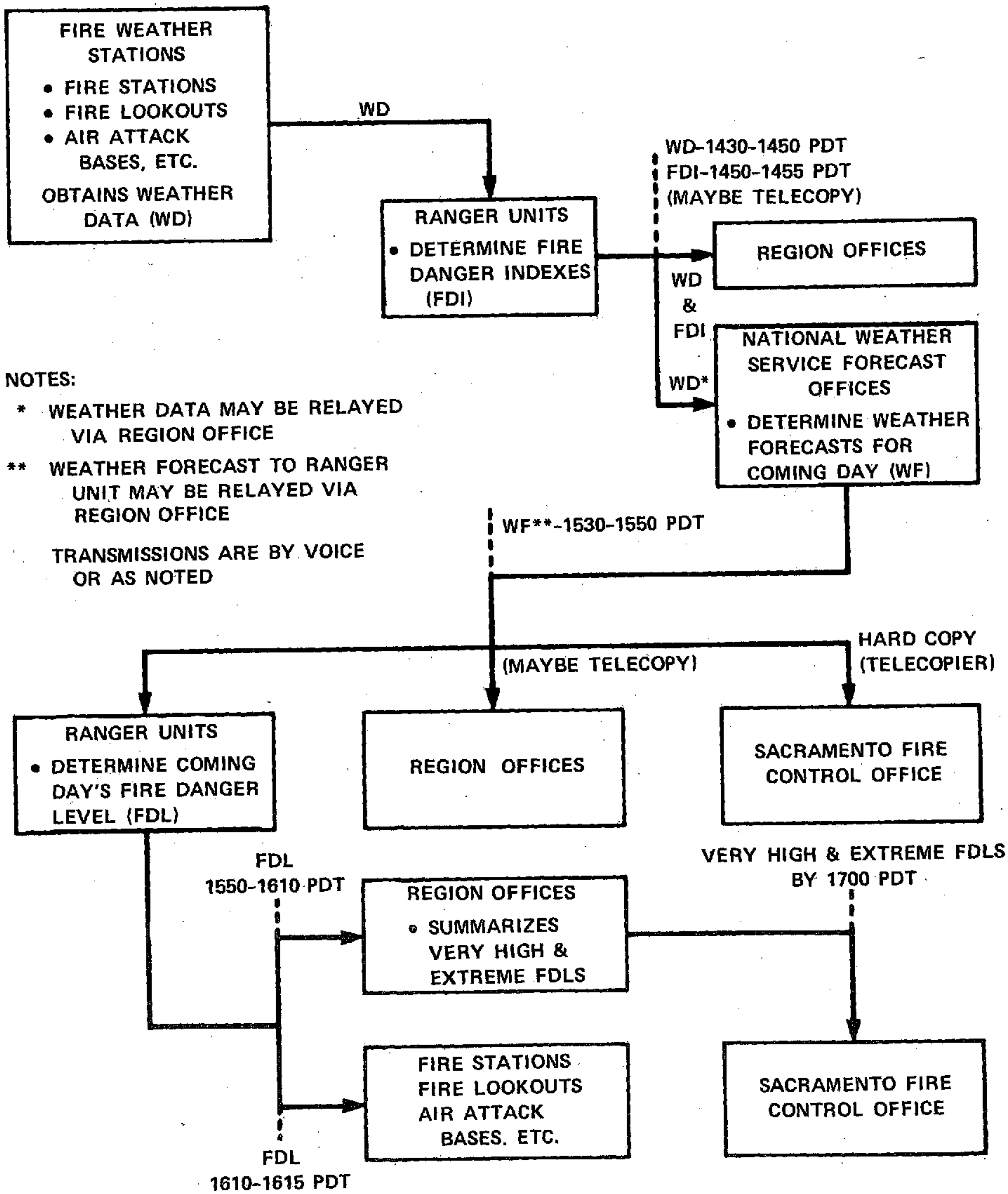
readings to fire danger indexes and forwards these to its Region Headquarters. The basic weather data is forwarded to the National Weather Service Forecast Office either directly from the ranger unit or through the region office. Forecasts* for the coming day by the National Weather Service are forwarded by telecopies to the Sacramento Fire Control Office and region offices simultaneously. The forecast may also be delivered to the ranger units concurrently or the forecast may be forwarded by the region offices to the ranger units. Ranger units use the forecasts to determine the fire danger levels for the coming day and transmit them to the region office and also (along with capsule summary of the weather forecast) to the fire stations, air attack bases, inmate camps, etc., under its jurisdiction. Region offices summarize and transmit these fire danger level predictions in the "very high" or "extreme" categories to the Sacramento Fire Control Office.

Figure 1 shows this flow of the weather data, weather forecast, fire danger index, and fire danger level information schematically. Also the times at which the information is currently transmitted appears in the figure. Examination of the figure reveals the complexity of the current data collection and transmitting system for fire weather data and its related derived information (weather forecast and fire danger indexes and levels). That is, a large number of personnel become involved in this process, considering that there are five regions, a total of 23 ranger units and 150 weather stations. Also, the communication network is tied up intermittently for approximately 4 to 5 hours in the afternoons and early evenings. The period immediately prior to this is when the humidity

* Complementary weather data from U.S. Forest Service and National Weather Service weather stations are used along with the CDF weather data in making the weather forecasts.

Figure 1

CURRENT CALIFORNIA DIVISION OF
FORESTRY FIRE WEATHER DATA FLOW



generally reaches the minimum for the day (early afternoon) and thus the period when the fire danger is highest for the day. Therefore the periods when personnel are taking weather data readings will coincide with the time when they should be on the alert for detecting fires.

Some of the above characteristics of the current weather data system suggest certain advantages by replacing this manual system with an automated system.

Estimated Cost of Current Manual System

Locations of the current 137 manual fire weather* stations being maintained by the California Division of Forestry are shown in Figure 2. These stations are located in the vicinity of CDF occupied facilities such as region offices, ranger units, fire stations, lookout towers, other special locations, etc. Since many of the lookout towers, fire stations, etc., are not manned during the winter months, data is not available from these stations during that period.

Cost associated with the current manual system is composed of the capital investment in the weather station itself and the recurring cost of observing, relaying and reducing the data. Each weather station costs on the order of $700** so 150 stations would represent an investment of $105,000. The recurring cost is composed of weather station maintenance and equipment replacement costs, manpower costs for observing, computing indexes and transmitting results, and the data transmitting cost (phone or radio). Weather station maintenance and equipment replacement costs per year are estimated to be $10,500 based on 10%[6] of capital cost.

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* Rounded to 150 for this study

** Estimate from Western Fire Equipment Company brochures

Figure 2

LOCATIONS OF CDF WEATHER STATIONS

Approximately one half hour* is spent by the observer at each station to make the observation, compute indexes and transmit the results to Ranger or Region Headquarters. This results in an annual manpower cost of $86,625 based on $4 per manhour and assuming that half the stations are operated year round and half of the stations are operated for one half the year. Data transmission costs are estimated as $30,375 per year based on 150 phone calls per day for half the year and 75 phone calls for the other half year. Each call is assumed to be three minutes long at a cost of 25 cents per minute. The estimated recurring cost per year thus totals $127,500.

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* Estimated by W. Innes, Meteorologist, CDF Sacramento, California

AUTOMATED FIRE WEATHER DATA SYSTEM

Introduction

Automating of weather stations is not a new concept. The U.S. Weather Bureau has been using weather stations with varying degrees of automation since the 1940's. But only in the last decade has the concept of truly automated weather data become a reality with recent advances in electronics and sensor technology.

The USDA Forest Service's Fire Meteorology Research Work Unit, located at Riverside, California, will have an experimental network of 13 remote weather stations[2] operating sometime in 1974. All the remote stations will be linked via radio or telephone to a base station either directly or, if required, through a relay station. Phone lines will be used to link the base station with the Data and Control Terminal in Riverside, California. Deployment of the remote stations will be in the San Bernardino National Forest. Their future plans call for deploying remote stations in Southern California from Santa Maria south to the Mexican border. Sierra Research Corporation* of Boulder, Colorado, has been awarded the contract for this system. Total cost for the system is approximately $135,000. Cost of the individual remote stations is expected to be on the order of $8,000. This U.S. Forest Service system is essentially being assembled from off-the-shelf components.

Ames researchers in early 1973 assembled a prototype automated weather station for obtaining wind speed, wind direction, temperature, humidity and fuel moisture data. They developed a new fuel moisture sensor and used standard components to build the other climatalogical data sensors. Output from these sensors are fed into an Earth Resources Technology Satellite (ERTS) Data Collection Platform (DCP) for transmitting. The antenna used for transmitting was built at Ames and is much smaller and cheaper than

* Bought out since by Ball Brothers Research Croporation, Boulder, Colorado, in 1974.

the standard ERTS-DCP antenna. This prototype remote automated fire weather station has been in operation at Sunol, California, Ranger Station since April 1973. Output from the automated station has been verified by manual readings from the standard CDF fire weather station also located there at the Ranger Station. Readings by these two diverse methods have been remarkedly consistent. Variations between readings (automated and manual) have typically been on the order of 1/2%.

Data from the automated station currently follows a rather tortuous path to the user. Weather data from the automated weather station at Sunol are relayed by the ERTS satellite to NASA's Mojave Satellite tracking station. From the Mojave station, the data are sent through land lines to NASA's Goddard Space Flight Center in Greenbelt, Maryland, for user distribution. The "now" data are sent to Ames Research Center via land lines for processing (data reduction)or, in the case of hard copies, via U.S. Mail. Finally, the data are relayed from Ames to CDF - Sacramento via Datafax. Since the system is for an experimental project, the time when data are taken to the time when they are observed is of no real significance. Of real importance is that the system, as it exists, has worked very well. Minimum time from data relayed by the ERTS satellite to the time when the data are in the hands of CDF personnel in Sacramento is currently two hours.

Ames Research Center is currently working on a second generation prototype of an automated weather station. Development of sensors optimized for reliability, accuracy, power needs, maintainability and low cost are underway. All this development will be controlled so that the total system is optimized and not necessarily subcomponents. The station is being designed for maintenance-free operation for a minimum of one year. Field tests for this prototype will begin in the fall of 1974.

A new concept utilizing these automated remote weather stations has been identified by NASA for the California Division of Forestry (CDF) as a possible future system for fire weather data gathering, processing and dissemination. This concept was the outcome of discussions between Ames Research Center scientists and CDF personnel. The basic idea is to gather the data automatically and relay the data via a satellite data link to a base location (Sacramento) for processing and dissemination. A pictorial sketch of the system is shown in Figure 3.

Weather Station

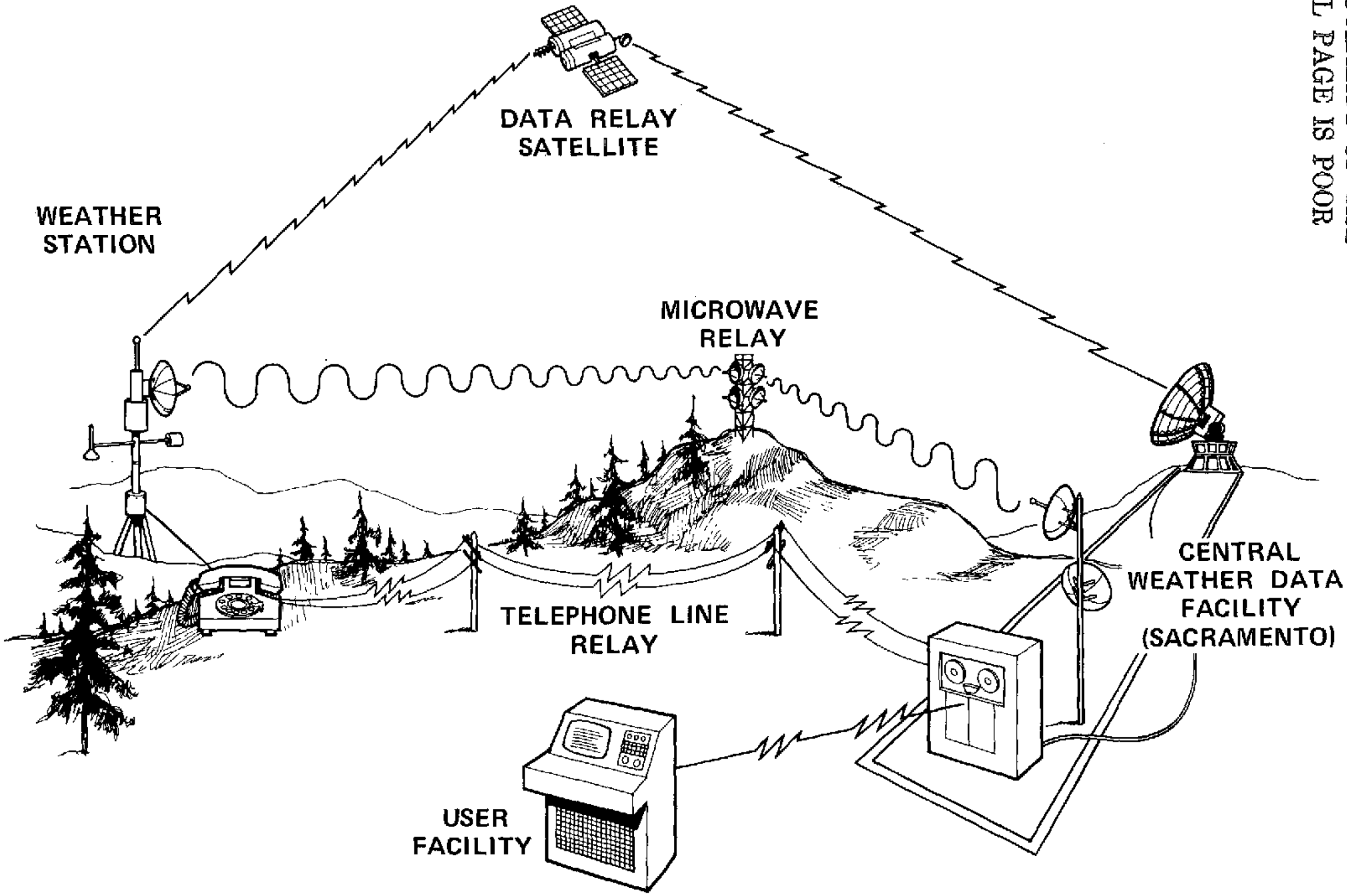
The weather station is that part of the overall automated system that takes readings of the weather and fuel moisture data at prescribed times or as often as required and transmits the data. Thus the weather station should be capable of "sensing" the desired weather data (sensor package), formating and transmitting the data, and have an independent power supply unit.

This study has assumed that the number of automated weather stations used initially would be 150 units. This assumption is compatible with the current number of manual stations.

Ideally, the placement of the automated weather stations should be the result of site surveys so that they are placed in locations which provide representative fire weather data for the region. Fortunately, the very nature of the automated stations makes then independent of external power and communication lines. They can therefore be readily moved from place to place without difficulty, although some difficulty in realizing this flexibility if telephone lines or microwave links are used for data relaying would be encountered.

Figure 3

AUTOMATED FIRE WEATHER DATA SYSTEM



General specifications based on data requirements identified by the "National Fire-Danger Rating System" for the weather station sensors are summarized in Table 6. A schematic diagram showing the major components of the weather station is shown in Figure 4. As seen in the block diagram there are four main subcomponents: (1) sensor package; (2) power supply; (3) electronics; and (4) antenna. The last two collectively are referred to as the Data Collection Platform.

The sensor package must minimally have the capability of sensing wind speed, wind direction, temperature, humidity and fuel moisture. These readings must then be coverted into electronic signals for transmission. Preliminary development of an integrated solid state sensor capable of measuring wind speed, temperature and humidity has been developed by the Systems Development Branch at Ames Research Center. Working prototypes are being fabricated by the Thunder Scientific Company. Several off-the-shelf sensors for detecting wind direction are readily available. An excellent fuel moisture sensor using a ceramic stock has been developed by the U.S. Forest Service Rocky Mountain Forest and Ranger Experiment Station.

The Data Collection Platform (DCP) portion of the weather station includes the analog-digital converter, multiplexer, transmitters and antenna. Data Collection Platforms with all of the above capabilities for use in the ERTS program were developed and two hundred units have been built and used successfully.

Prototype experience and design analysis by the System Development Branch at Ames Research Center indicate power needs per station to be less than 30 watts peak power, 10 watts average power. Ideally the power supply, in keeping with the maintenance-free capability of the other weather station components, should have at least a one-year life. Design of the power supply

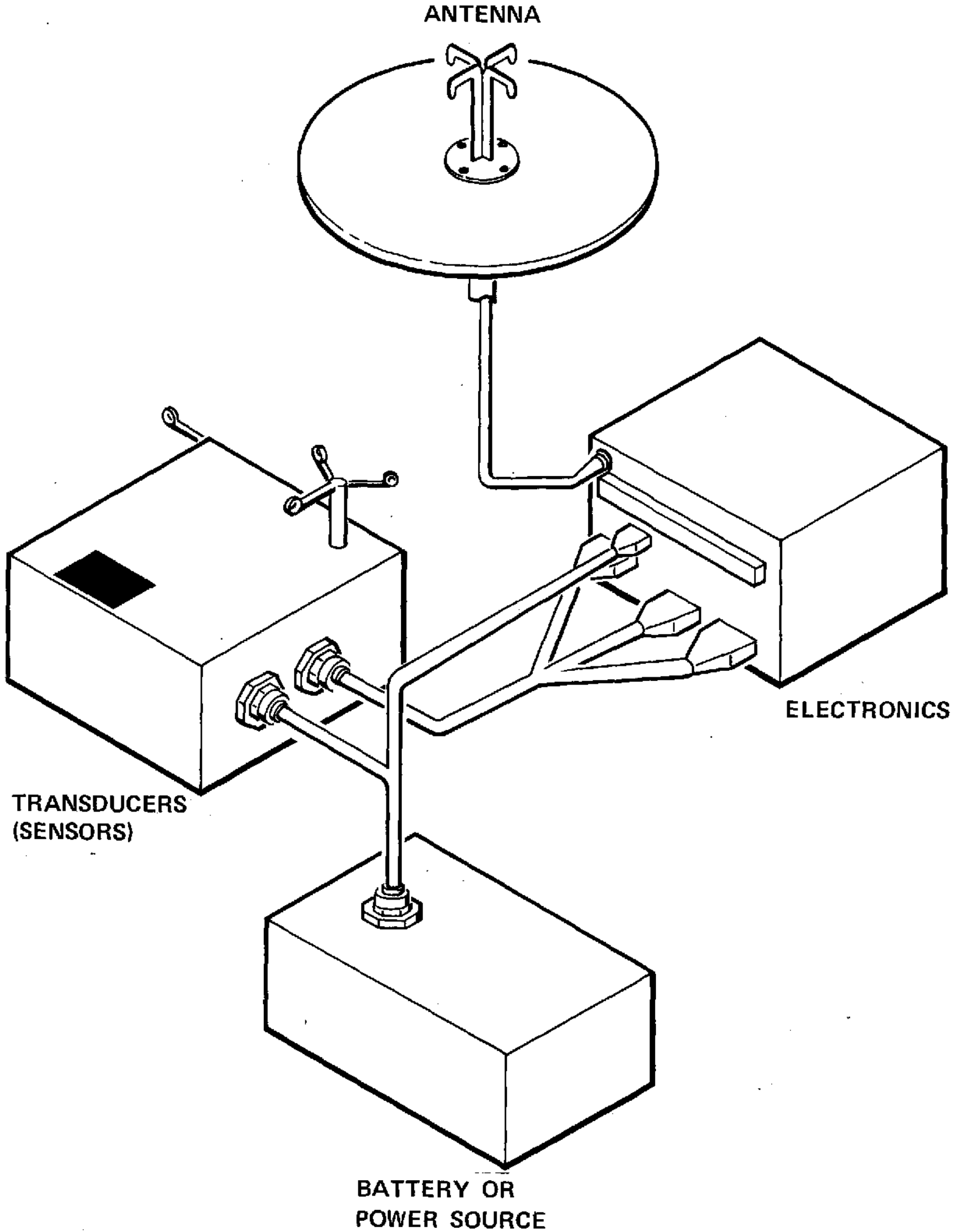
Table 6

SENSOR SPECIFICATIONS
AUTOMATED FIRE WEATHER STATION

Sensor	Range	Accuracy
Wind Speed	0 to 110 MPH	± 1 MPH to 32 MPH ± 10% > 32 MPH Threshold ≤ 1 MPH
Wind Direction	0° to 540°	± 5° (Threshold 1 MPH)
Temperature	-20° to 120°F	± 1°F
Humidity (Relative)	0 to 100%	± 3% to 50% RH ± 5% > 50% RH
Radiation (Net)	± 1.4 g-Cal/Cm^2/min	± 3% of Full-Scale
Fuel Moisture	0 to 25%	± 1%
Rainfall	0 to 10 in/24 hr.	N/A

Figure 4

AUTOMATED FIRE WEATHER STATION



must provide for easy replacement, e.g. unplug old unit and plug in new unit. For those stations easily accessible the one-year life for the power supply might be relaxed to take advantage of cheap power that can be supplied by conventional wet cell rechargeable batteries. For example, an automotive battery with a 120 ampere-hour rating will provide adequate power to the weather station for three to four months for once-a-day data gathering. Therefore the batteries will have to be replaced with a freshly charged battery on a regular replacement cycle of about three months. Total usable lifetime for these types of batteries with recharging range from 36 months to 60 months.

Data Relay

Information gathered and transmitted by the automated weather station must be collected at a central location, in this case Sacramento. Because of the long distances involved with intervening hills and mountains, it would be impossible to transmit from individual weather stations and expect the data to be received in Sacramento directly. Thus a means of relaying the transmitted data must be provided. Three potential methods are examined in this study: (1) Earth orbital relay satellites*; (2) ground based

* Two categories of earth orbital satellites can be used; low orbit satellites or geosynchronous orbit satellites. Low orbits are typically at altitudes in the 180 to 1800 Kilometers range (100 to 1000 nautical miles). For example, NASA's Earth Resources Technology Satellite (ERTS) at 930 kilometers (490 nautical miles) is in low earth orbit. Satellites in these orbits complete many revolutions in a 24-hour period. As the orbit altitudes increase, the number of revolutions the satellite makes around the earth in a 24-hour period decreases until at an altitude of 35,900 kilometers (19,300 nautical miles) the satellite completes one revolution thereby matching the earth's rotation. This orbit, requiring 24 hours for one revolution, is the geosynchronous orbit.

microwave relay; and (3) land lines (telephone lease lines).

Satellite. - In considering satellites for data relay, low earth orbits or geosynchronous orbits are possibilities. The relay distance between the weather station and central data facility is shorter for the low earth orbits so theoretically the transmission power requirements should be lower. Unfortunately, the distance advantage cannot be fully realized because the satellite is in view of the station only a few minutes on each orbital pass. The approximate period of each orbit is 90 minutes. If the orbit is inclined from equatorial, the satellite on each orbit passes over a different part of the earth, repeating the track after some number of passes (ERTS repeats its track every 18 days). The communication problem encountered by the short viewing time and appearance in different parts of the sky (viewed from specific earth locations) on each orbit can be compensated for in part by using wide beam fixed or narrow beam tracking antennas. Tracking antennas for the weather station are not feasible because of their high cost and because of the high power requirements for the tracking operation. In this mode, however, the transmitter power requirements would be minimized. Use of wide beam antennas would increase the transmitter power requirements but the total power would be substantially less than if a tracking antenna were employed.

Geosynchronous satellites such as GOES match the rotation of the earth and appear stationary in the sky when viewed from earth. This allows the weather stations to use a highly directional fixed beam antenna and keep the transmitter power requirements at minimal levels (comparable to power levels for low orbit satellites). Also, with the satellite in view at all times, flexibility in data gathering can be achieved. That is, data can be gathered as desired at frequent intervals during critical periods in the fire weather season as, for example, when Santa Ana winds occur in Southern California. Conversely data can be gathered less frequently such as in the rainy season.

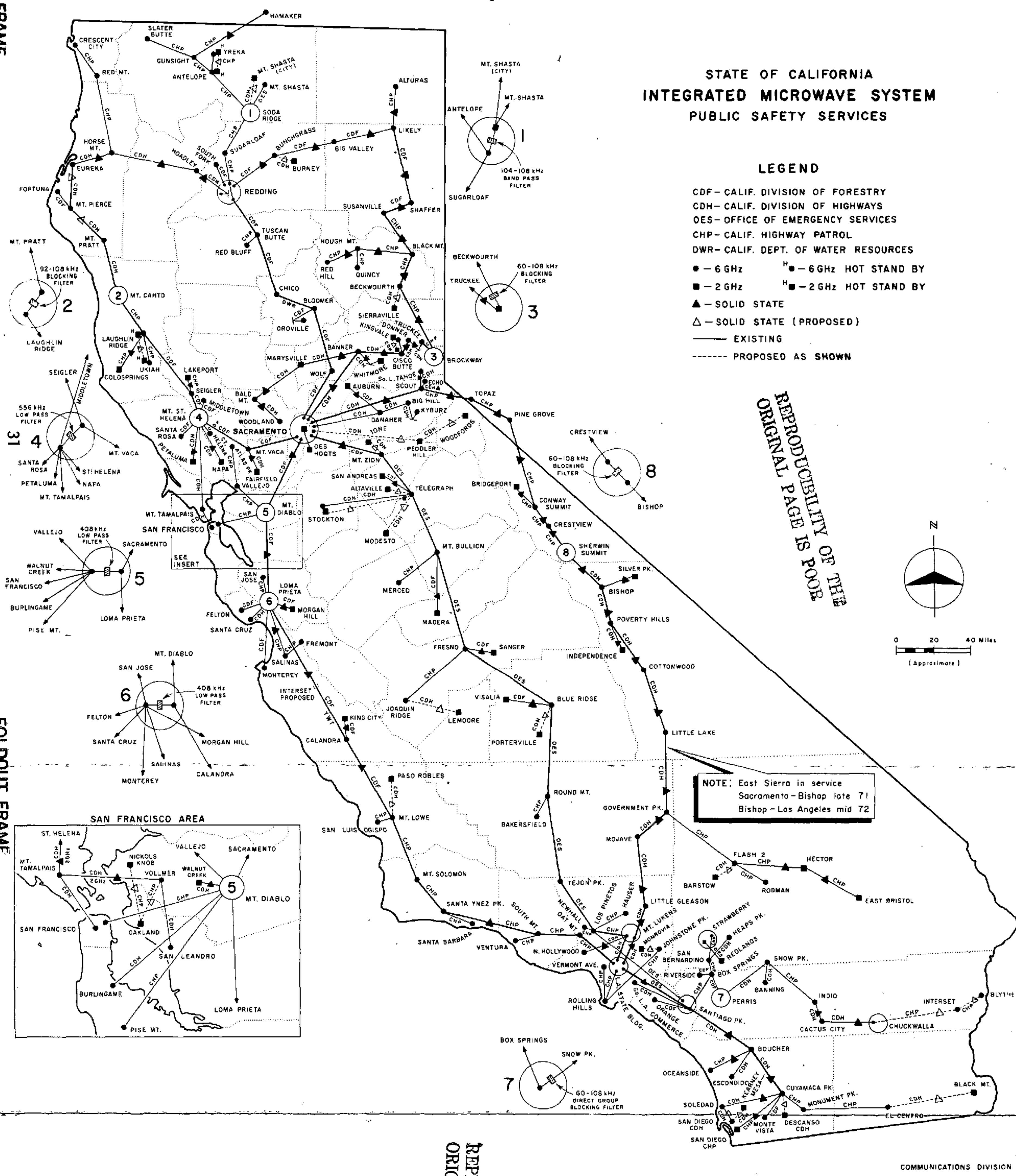
For the reasons above it appears that the best satellite choice for relaying weather data would be geosynchronous satellites.

Microwave. - The State of California has an excellent State-owned microwave network. As shown in Figure 5, the relay stations, located on mountain tops, should, in general, be visible from the remote fire weather station sites. Therefore access of the microwave net for relaying the data from the remote data gathering sites will be possible. No technological problems in using this method for data relaying is expected; it is an existing system. The reliability for this system is 99.8%, as estimated by the State Communications Division.

The data link from the data gathering site to the microwave net can be accomplished by using microwave, VHF radio or land lines. The choice will depend largely on the individual site. Parameters such as: (1) existence of phone lines accessing the microwave network located close to or at the site; (2) distance from site to microwave net; and (3) frequency availability for microwave transmission. No technology problems are expected whichever option is chosen. In fact if the microwave network is used as the data relay method, the access link can very well be a combination of the above three methods, i.e. microwave, VHF radio and land lines.

Telephone lines. - Since all the current locations for the CDF weather stations have access to telephone land lines, telephone could be used as the data relay method. This concept requires the least capital expenditure. The required accessory equipment and lines could be leased from Pacific Telephone Company. The cost of leasing the equipment and telephone lines are shown in the following section.

Figure 5


STATE OF CALIFORNIA
INTEGRATED MICROWAVE SYSTEM
PUBLIC SAFETY SERVICES
LEGEND
CDF – CALIF. DIVISION OF FORESTRY
CDH – CALIF. DIVISION OF HIGHWAYS
OES – OFFICE OF EMERGENCY SERVICES
CHP – CALIF. HIGHWAY PATROL
DWR – CALIF. DEPT. OF WATER RESOURCES
● – 6 GHz
H● – 6 GHz HOT STAND BY
■ – 2 GHz
H■ – 2 GHz HOT STAND BY
▲ – SOLID STATE
△ – SOLID STATE (PROPOSED)
EXISTING
PROPOSED AS SHOWN
NOTE: East Sierra in service
Sacramento - Bishop late 71
Bishop - Los Angeles mid 72
SAN FRANCISCO AREA
SEE INSERT
N
0 20 40 Miles
(Approximate)
104-108 kHz BAND PASS FILTER
92-108 kHz BLOCKING FILTER
60-108 kHz BLOCKING FILTER
556 kHz LOW PASS FILTER
408 kHz LOW PASS FILTER
60-108 kHz DIRECT GROUP BLOCKING FILTER
SACRAMENTO
REDDING
FRESNO
BAKERSFIELD
SAN FRANCISCO
SAN DIEGO CDH
COMMUNICATIONS DIVISION
REDRAWN 10-21-71
D-250C

The advantage of using this system is the lower capital investment required for the central data facility. At the central data facility, instead of an antenna, a telephone receiver system would be the terminal end of the data relay link. Both the transmitter and antenna at the weather station would be unnecessary; instead a telephone dial-up system would be used as the entry interface of the data relay link.

One undesirable feature of this system is its inflexibility in siting. That is, the weather station cannot be moved readily to other locations; it must remain very close to the telephone line access point. One of the prime reasons for using an automated weather station, (i.e. the potential capability of placing the weather stations in remote locations best representing the region's environment) would be defeated.

Data Facility

Flow of data in the data facility is outlined in Figure 6. The data facility, as referred to in this study, is composed of two primary components, the receiving site and the computer complex.

Requirements for receiving and preprocessing of the data signal for the various data relay technologies discussed previously are summarized in Table 7. As seen, the equipment requirements in general for each data relay technique are similar. The technology requirement for receiving and preprocessing the data is straightforward and no problems are anticipated.

The signal (data) that is received at the receiving site is demultiplexed and extraneous noise filtered by the signal processor. When the signal (data) has been processed, it is sent to the computer facility for analysis. If the computer facility is unable to accept the data in real time, the data are sent to a temporary magnetic tape storage unit. The stored data are then fed to the computer at the earliest possible time.

Figure 6

FLOW OF DATA IN DATA FACILITY

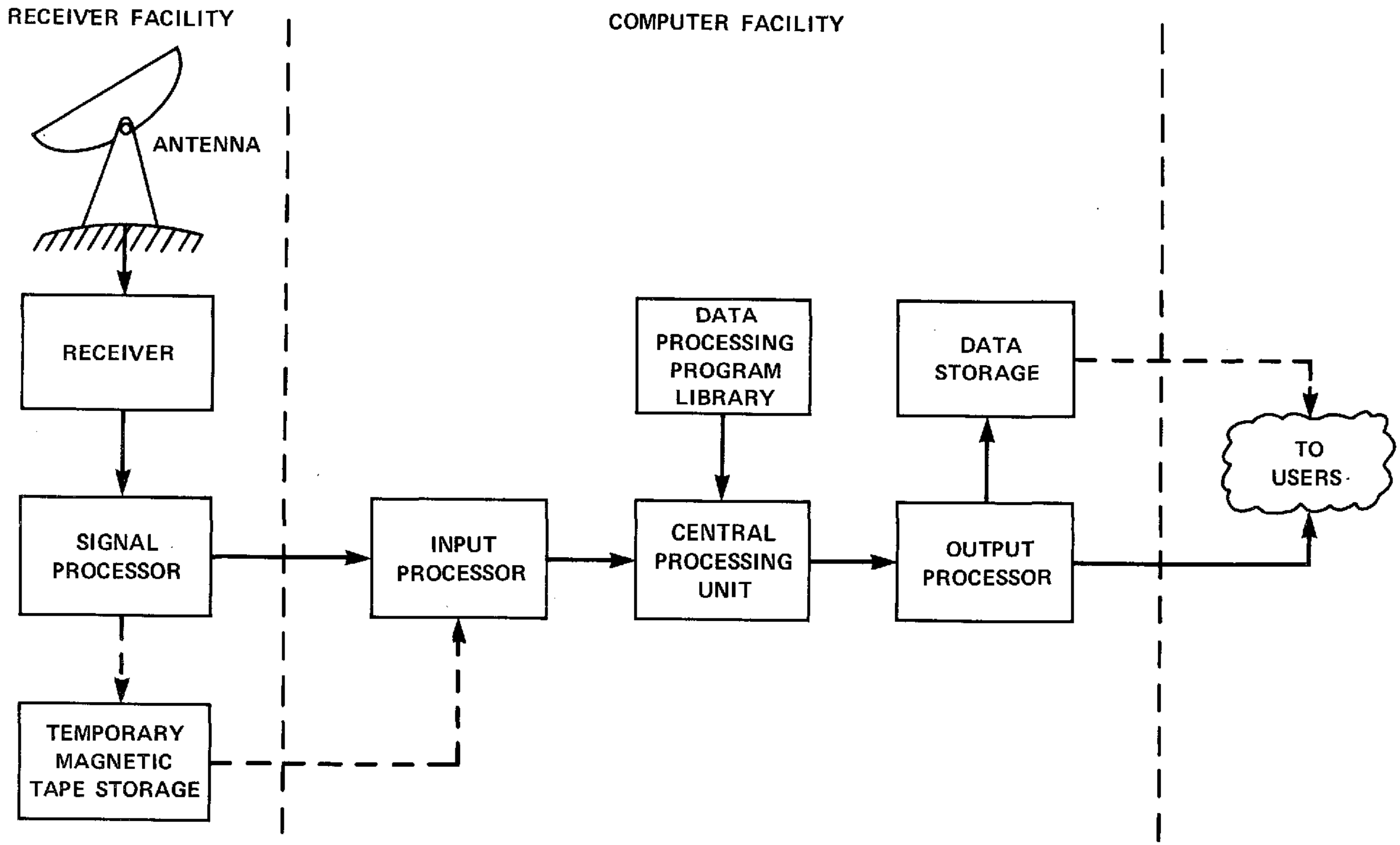


Table 7

DATA RECEIVING SITE EQUIPMENT REQUIREMENT

Relay Method	Receiving Site Equipment Needs
Satellite	a) Receiving Antenna
	b) Receiver (S Band)
	c) Signal Processor
	d) Line to Computer
Microwave	a) Demultiplexer Terminal
	b) Signal Processor
	c) Line to Computer
Telephone	a) Terminal
	b) Signal Processor
	c) Line to Computer

At the computer facility, appropriate programmed analysis of the data is done. (The computer can be programmed to do a multitude of analyses with the data as desired). One of the first things done with the data from each station is to store them together with all the previous data from that station so that a historical record of data for that station will be available at any time when desired. With the data safely stored, the computer can then be made to analyse the data and arrive at fire danger indexes for the different areas, highlighting those areas with very high and extreme ratings. These and other manipulations of the data when completed by the computer will be sent to storage and simultaneously out to the users (regions, ranger units, weather service, etc.). By having the output stored permanently, it would be available to users at any time.

User - Data Display Equipment

Weather data collected from the field and the predicted fire danger indexes will be disseminated to the regions, CDF headquarters in Sacramento and other interested parties. They are collectively referred to here as the Users. Those parts of the raw and analysed data applicable to individual regions and Sacramento (CDF) can be disseminated easily and automatically by programming the computer. The choice of whether to do this automatically as the data are processed or whether to have the users access the computer via remote terminals will be one of individual choice and probably dictated by cost.

Remote access computer terminals using printer or video display or both could be used for data display at the user's facility. Remote access computer terminals with video display are expensive but provide high flexibility to the user. For example, data from previous days can be obtained directly by the user from the computer if necessary. Also, plots showing trends of fuel moisture (or any other parameter) can be accessed from the computer and visually inspected. These kinds of capabilities will benefit the forestry personnel by allowing them to obtain quickly and observe without effort all pertinent fire weather data and thus allow them more time and more information for making important decisions. But unless CDF fire regions foresee a need for having a remote access computer terminal with video display for other purposes (such as for timekeeping, payroll, personnel records, equipment and personnel status, etc.), to share the terminal cost, the computer terminal's capability would not be fully utilized, and the cost would be difficult to justify. A simple teletypewriter type terminal would be slower and much more limited in its utility but would be much cheaper and thus more easily justified for single purpose application, such as fire weather data display.

COST ESTIMATES FOR AUTOMATED SYSTEMS

Introduction

Costs for the subsystems of the Remote Automated Fire Weather Data System have been estimated and are summarized in this section. The results have been determined based on historical, current and future costs obtained from documents (6,7, and 8) and personal contacts with individuals in both federal and state governments and industry. The intent of this analysis is to determine approximately the cost of each major component as well as the overall cost for the system.

An automated remote fire weather data gathering network and system as discussed here can be expected to take about five years to design and implement as a working system. Therefore, the costs that are estimated in this study may be conservative in relation to the cost of an actual system installed in the future. This is assuming that costs follow the historic cost trend of electronics and computing equipment where substantial reductions have occurred over the years. (The price paid for a piece of new equipment may be higher than the equipment it replaces but the new equipment will, in most cases, have additional capabilities and be more reliable. Thus, on an overall basis, it may be more economical). Therefore the costs obtained in this study are intended to primarily provide a "ballpark" estimate to help evaluate the feasibility of the concept and are intended to aid in planning future efforts in this area. Estimated costs for the system are shown in Table 8. Each of the major components is discussed below.

Weather Station

The cost of the complete remote automated fire weather station, ready for placement in the field and including communications equipment, is estimated to be between $3,000 to $5,000 per unit depending on production rate.

Table 8

SUMMARY OF ESTIMATED COSTS

	Cost - Dollars: Non-Recurring	Cost - Dollars: Recurring Per Year
Weather Station	450,000[1]	31,500[2]
Communication Relay		
A) Telephone	---	13,800[3]
B) Microwave	8,250[1]	8,800[4]
C) Satellite		
1) Dedicated	---	21,000
2) Shared	---	1,100[5]
Data Facility		
A) Date Receiving		
1) Telephone & Microwave	30,000	3,000[6]
2) Satellite		
a) Dedicated	60,000 - 120,000	7,500 - 15,000[7]
b) Shared	3,000 - 6,000[5]	375 - 750[7]
B) Computer (Time)	---	1,000 - 20,000
User Facility Terminal		
A) Teletype	9,000[8]	900[6]
B) Video With Hard Copy	48,000[8]	6,000[7]

(1) Cost for 150 units.
(2) Maintenance and replacement cost based on 7%[6] of initial cost.
(3) Based on one data transmission per day regardless of number of readings taken. Cost would be higher for multiple transmission per day.
(4) Includes maintenance and use charge.
(5) Based on 5% share of cost of leasing one voice channel.
(6) Maintenance and replacement cost based on 10%[6] of initial cost.
(7) Maintenance and replacement cost based on 12.5% of initial cost.
(8) Cost for six units.

This cost range was obtained as follows: upper range cost was estimated based on sensor package cost of $2,000, data collection platform (DCP) cost of $2,000 and miscellaneous cost of $1,000. The estimated sensor package cost is based on the cost of $1,000 per unit paid by Ames Research Center for the first combined prototype solid state sensor unit (wind speed, temperature and humidity). Cost for this unit is expected to be reduced to $100 to $200 when produced in quantity. DCP cost is based on the approximate $2,000 per unit paid for the 200 units built for the ERTS program*. This cost can also be expected to be reduced to about $1,500 per unit with higher production rates. Miscellaneous costs cover assembly costs as well as provisions for a power supply. If the lower costs shown above for the components of the weather station are totaled, the lower cost of the cost range, $3,000 per station, is obtained. This lower figure is probably the more likely unit cost for a system of 150 automated stations required for replacing the current manual stations. The total cost will be on the order of $450,000. Maintenance and replacement costs are expected to cost approximately $31,500 per year. This recurring cost has been estimated as 7 percent of initital cost ($450,000), as used by the military[6]. These costs were summarized in Table 8.

Data Relay Systems

Communication relay costs cover the cost of getting the data from the remote fire weather station to the data facility in Sacramento. Costs for capital equipment, where required, as well as operation and maintenance, rental or prorated use fees as appropriate for each alternative concept have been included.

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* This is in contrast to the current $7,000 cost of a "hand-made" DCP compatible with SMS/GOES.

Summary costs for data relay using telephone, microwave, or satellite were shown in Table 8. Major non-recurring costs are not expected in any of these three concepts*.

Satellite costs. - The required data relay time will either be obtained free from a government satellite (e.g. GOES) or purchased from a commercial satellite (e.g. RCA and Western Union). Thus the only cost for this concept is the recurring rental costs if a commerical satellite is used.

Commercial domestic communication satellite service was inaugurated by RCA in December 1973[8]. Western Union Corporation has also launched one commercial domestic communication satellite in the summer of 1974 and expects to launch a second satellite in the fall of 1974. Rate for leasing one voice channel (4 kilohertz bandwidth) from the RCA system is $20,400 per year. For the maximum sampling rate of once an hour expected for the remote fire weather system less than an hour per day use of the communication channel is required, thus if the cost is prorated it would be about $1,100 per year. The RCA system has a receiving antenna in San Francisco so the collected data received there could be transmitted to Sacramento via the state's Automatic Telecommunication Switching Service (ATSS), for approximately 5 cents per minute. One year cost for handling an hour of data per day on the ATSS network will be approximately $1,100. Therefore the overall cost would be on the order of $2,200 per year for this satellite relay system. The more technically desirable concept of installing a receiving station in Sacramento and prorating the channel leasing cost would reduce the overall data relay cost to $1,100 per year.

Microwave Costs. - As mentioned earlier, the State of California owns a statewide microwave network. Thus the only non-recurring cost is for the

* This assumes that the non-recurring costs of the relay satellite are borne by the Federal Government or domestic satellite contractors.

terminals which will provide access to the existing network. Cost of these terminals are about $55 each, as estimated by the state's Communication Division.

The recurring cost for maintaining the interface equipment for accessing the microwave network and the prorated cost of using the microwave network is about $8,800 per year. Maintenance cost estimated by the California Communication Division for the 150 interface equipment items (weather station to microwave network) is about $8,300 per year ($55 per unit per year). Use cost for the microwave network is $6 per route mile per year per 4 kilohertz channel slot (one voice channel). The total channel miles required was estimated to be on the order of 1,500 to 2,000 route miles and one channel slot would be adequate. The network use cost for dedicated channel is therefore about $9,000 to $12,000, which makes the overall microwave system cost per year about $17,000 to $20,000. But the remote fire weather system does not need a dedicated channel; for once-a-day data gathering, a total of approximately two minutes is required. Even with the maximum frequency of data readings expected of once per hour, less than an hour of microwave net time is required. Thus, assuming that only the prorated cost will be charged to the remote fire weather system, the cost of the network is reduced to approximately $400 to $500 per year. The total cost is then on the order of $8,800 per year.

Telephone Cost. - All the necessary equipment to provide the data relay service for this concept is owned and serviced by the telephone company. Therefore non-recurring costs are not expected.

For the case of the telephone, the cost has been estimated based on one report per station per day with an average cost of 25 cents per report. The average cost of 25 cents has been arrived at based on 5-7 cents per minute main intercity telephone trunkline cost and 15-20 cents per minute for accessing the trunkline. Also included in arriving at the average 25 cents per minute cost is the high cost of areas such as Auburn, Placerville, etc., where trunklines are not available and calls average about 30 cents per minute. The ATSS system has a minimum minute charge for each call. Thus, for the 150 stations providing data once a day, the cost is $13,800 per year. The cost will increase proportionately with increased frequency of data sampling.

Data Facility

Effectively the data facility equipment requirements for the three concepts (satellite, microwave and telephone) are essentially similar. The only significant exception is the antenna required for the satellite concept. Discussion of cost for the data facility will be divided into the data receiving facility and the computer facility. The data facility costs were summarized in Table 8.

Data Receiving Facility Costs. - Non-recurring data receiving facility cost for the satellite data relay system is expected to vary from $60,000[6] to $120,000[6] depending on system capability (e.g. larger antenna for better reception). Included here are equipment for data receiving, signal processing and demultiplexing as well as a magnetic tape storage unit. Antenna costs are about $30,000 for a small (12 foot diameter) one. The cost includes the drive system for aligning and tracking requirements. Installation of a satellite receiving station can probably be justified only if it is to be used for other purposes as well as for receiving remote fire weather data. Needs of the fire weather data system can be met with a 5% share of the time. Thus the prorated non-recurring costs are $3,000 to $6,000. The higher cost is the more likely because the additional capability and flexibility of the higher cost system would be required for expanded use.

The non-recurring cost for telephone and microwave receiving site equipment is estimated to be $30,000[6]. This will cover the receiving terminal, the signal processor and demultiplexers as well as a magnetic tape storage unit.

The recurring cost for the satellite data relay receiving facility is about $7,500 to $15,000 per year. This results from assuming 12.5% of initial cost as the expected maintenance and replacement factor. A higher factor has been used than those from reference 6 because of the higher sophistication of the equipment. The prorated 5% share based on use of the facility results in the fire weather data system cost share of $375 to $750 per year.

In comparison the telephone and microwave data relay receiving facility recurring cost is $3,000 for maintenance and replacement cost. A factor of 10%(6) of initital cost is used.

Computer Facility Costs. - Existing state computer facilities would be used. Therefore, the only non-recurring cost is that of installing a line, tieing the data receiving facility to the computer. This cost will be minimal since the data receiving facility is expected to be installed in the Resources Building at 1416 Ninth Street in Sacramento and this building already has a computer facility.

Recurring cost for computing time for data analysis, storage and dissemination are estimted to be about $1,000 per year for once-a-day sampling and $20,000 per year for once-an-hour sampling. The cost has been estimated based on computational times of 5 seconds per set of samples of fire weather data using a large general purpose digital computer currently in use.

User - Data Display Equipment

The cost of the equipment necessary for the user to receive processed data from the centralized data facility in Sacramento is dicussed below. Users for determining cost have been limited to California Divison of Forestry Headquarters in Sacramento and the five region headquarters (for a total of 6 user facilities). If additional users were added, the increased cost can be calculated easily by using the per unit cost given below. Summary of these costs were shown in Table 8.

Access to the computer is via a remote access terminal. A teletype terminal can provide this capabiility as well as printed copies of the output. A terminal of this type can be purchased for about $1,500. Although the speed is somewhat slow it is adequate for the small amount of computer output data to be printed at the user facility. This terminal will also provide access to the computer for other purposes such as current and historic fire weather data.

A video screen terminal for displaying processed data with provisions for hard copies when required could also be used. Each will cost about $8,000 and will have capabilities much greater than the teletype terminal. It will be faster, more versatile and be able to display data graphically. For example, a graph showing the trend in fuel moisture for the previous "x" days can be displayed for quick viewing to aid early analysis. With all the fire weather data centrally stored in Sacramento and readily accessible via the remote terminal, users will not need to retain hard copies on file.

The recurring cost is composed of the maintenance and replacement cost. Based on 10%[6] of initial cost, the teletype units will require $900 per year to keep the six units operating. For the more advanced video display unit, the recurring cost factor was assumed as 12.5% of initial cost which results in an annual cost of $6,000 for the six units.

Cost Comparisons

For comparative purposes the results shown in Table 8 have been rearranged as shown in Tables 9, 10, and 11. By rearranging the cost thusly, the overall costs for the remote automated fire weather data system for the three data relay technologies are more easily compared. Both the minimum and maximum

Table 9

MINIMUM - MAXIMUM EXPECTED COST USING
SATELLITES FOR DATA RELAY

	Costs - Dollars			
	Minimum Cost		Maximum Cost	
Subsystem	Non-Recurring	Recurring Per Year	Non-Recurring	Recurring Per Year
Weather Station	450,000	31,500	450,000	31,500
Communication Relay	---	1,100	---	21,000
Data Facility	3,000	1,375	120,000	35,000
Data Receiving	(3,000)*	(375)	(120,000)	(15,000)
Computer	---	(1,000)	---	(20,000)
User Facility	9,000	900	48,000	6,000
Total Cost	462,000	34,875	618,000	93,500

* Numbers shown in parentheses are the cost breakdowns

Table 10

MINIMUM - MAXIMUM EXPECTED COST USING
MICROWAVE FOR DATA RELAY

	Costs - Dollars			
	Minimum Cost		Maximum Cost	
Subsystem	Non-Recurring	Recurring Per Year	Non-Recurring	Recurring Per Year
Weather Station	450,000	31,500	450,000	31,500
Communication Relay	8,250	8,800	8,250	8,800
Data Facility	30,000	4,000	30,000	23,000
Data Receiving	(30,000)(1)	(3,000)	(30,000)	(3,000)
Computer	(---)	(1,000)	(---	(23,000)
User Facility	9,000	900	48,000	6,000
Total Cost	497,250	45,200	536,250	69,300

(1) Numbers shown in parentheses are the cost breakdowns

Table 11

MINIMUM - MAXIMUM EXPECTED COST USING
TELEPHONE FOR DATA RELAY

	Cost - Dollars			
	Minimum Cost		Maximum Cost	
Subsystem	Non-Recurring	Recurring Per Year	Non-Recurring	Recurring Per Year
Weather Station	450,000	31,500	450,000	31,500
Communication Relay	---	13,800	---	13,800
Data Facility	30,000	4,000	30,000	23,000
Data Receiving	(30,000)[1]	(3,000)	(30,000)	(3,000)
Computer	(---)	(1,000)	(---)	(20,000)
User Facility	9,000	900	48,000	6,000
Total	489,000	50,200	528,000	74,300

(1) Numbers shown in parentheses are the cost breakdowns

cost ranges for the satellite concept.

If the minimum costs for the three data relay technologies are examined, it is seen that the satellite concept will have the lowest capital requirement and lowest recurring cost, followed by the microwave and the telephone concepts. The non-recurring cost is slightly ($18,000) higher for the microwave system than for the telephone system but the lower recurring cost for the microwave system will in a few years overcome the cost disadvantage. Therefore, the microwave system can be judged slightly less costly than the telephone system.

The cost comparison for the maximum cost cases shows the satellite the most expensive, followed by the telephone and microwave systems, respectively. The change in economic order of the concepts results from the inclusion of a more elaborate data facility and with no cost sharing assumed for the satellite concept. Such an eventuality is not likely to occur but the costs have been shown in this fashion to indicate the upper bound on costs. If joint use for the satellite data recieiving facility cannot be realized the low cost facility can be chosen.

The difference between maximum and minimum cost for both the microwave and telephone concepts result from increased computation time (maximum sampling rate) and more sophisticated data display equipment at the user facility. The increase in computation time is to allow for processing 24 data sets per day, versus one data set per day. For the satellite concept the difference includes in addition to the above, the full versus shared cost of the communication relay charges and full versus shared cost of a more elaborate data receiving facility.

No increase in the communication relay charges occur for any of the three concepts as the number of data sets increases from one to 24 data sets per day because each has the capability of transmitting the maximum rate of data gathered within the minimum time charges, e.g. each station can easily transmit the maximum frequency of data readings of 24 per day within the minimum time charge of one minute if the telephone is used. But some special arrangement to either send the data as a block or be charged only for the total time used per day and not for 24 sets of 150 individual calls for each day would have to be negotiated. No increase in charges in the case of the microwave system is expected. The charges paid for using the network cover the range of expected usage time. Also for the satellite the shared cost covers the range in expected usage very adequately, although the maximum cost shown in Table 9 is for 100% use of the communication relay by the fire weather data system.

The variation between the minimum and maximum overall non-recurring cost for the telephone and microwave data relay concepts in each case is seen to differ by less than 9%. For the satellite relay concept the variation is slightly over 33%. The maximum cost is not very likely for the satellite concept; a more practical maximum cost would be $558,000. This will result from using a $60,000 data receiving facility instead of the $120,000 unit. This would then reduce the cost range to about 21%.

To simplify the cost-benefit analysis in the following section, the costs for the three automated fire weather data concepts (Tables 9, 10 and 11) are summarized for comparison in Table 12. The values indicate that the satellite data relay concept has the lowest cost if the minimum costs for the three automated concepts are compared. If the maximum expected costs are compared it is seen that the satellite concept has the highest cost. (Details on the high cost for the satellite concept was explained earlier in the section). This shows that the cost ranges for all the automated systems are spanned by the minimum and maximum cost for the satellite data relay concept. Therefore, the cost comparison between

Table 12

COST COMPARISON: AUTOMATED FIRE WEATHER DATA SYSTEM - COMPETING TECHNOLOGIES

	Minimum Cost, $		Maximum Cost, $	
	Non-Recurring	Recurring Per Year	Non-Recurring	Recurring Per Year
Satellite	462,000	34,875	618,000	93,500
Microwave	497,250	45,200	536,250	69,300
Telephone Lines	489,000	50,200	528,000	74,300

Note: Current manual system has a capital value of about $105,000 and annual recurring cost of about $127,500 the automated and manual fire weather data system will be made using the satellite data relay concept costs.

The cost comparisons between the manual and automated fire weather data systems are summarized in Table 13. The total operating cost per year including equipment replacement, maintenance and amortization, as well as the normal operating costs, have been considered.

No capital investment is shown for the manual system because the system is already in existence. As seen in Table 13, the automated system is much cheaper to operate than the manual system. In fact, for the low cost case it is significantly cheaper.

Table 13

COST COMPARISON: AUTOMATED VERSUS MANUAL
FIRE WEATHER DATA SYSTEMS

Cost Item	Manual System Cost $ Per Year	Automated System First Year Cost - $ Per Year	Automated System Cost - $ Per Year
Replace & Maintain Equipment*	10,500	34,000 - 72,500	34,000 - 72,500
Data Gathering (Manual)	86,500	---	---
Data Communication	30,500	1,000 - 21,000	1,000 - 21,000
Initial Equipment Cost Amortization	---	462,000 - 618,000	---
Total Cost Per Year	127,500	497,000 - 711,500	35,000 - 93,500

* Estimated based on historical data to be 10% for manual and 12.5% for automated system of total initial capital cost

COST-BENEFIT ANALYSIS OF AUTOMATED SYSTEMS

Some of the tangible benefits to be derived from an automated fire weather data gathering system are summarized in Table 14. Each of the seven areas listed are direct and real benefits that accrue with the installation of the automated fire weather data system. Unfortunately, an adequate means of quantifying these benefits on a dollar basis does not exist. But these benefits do result in savings as estimated later in this section.

The best reason for changing from the current manual fire weather data system to an automated system would be the economic benefits; that is, if the new system will result in substantial direct savings because of lower operating cost. Figure 7 shows the operating cost advantage of

Table 14

BENEFITS: AUTOMATED FIRE WEATHER DATA SYSTEM

1. Eliminate current tedious manual task of taking weather data (data readings must be taken at the same time each day) and also become independent of human errors.
2. Frequency of data sampling can be increased or decreased readily as required (current manual system is geared to once a day and change will be difficult).
3. Provide early automatic flagging of developing danger and increase the frequency of sampling automatically.
4. Become the basis for systematically closing, and justifying such closings, high danger areas to logging and recreational use.
5. Continuity of fire weather data will provide invaluable historic data for analysing fires and fire weather.
6. Good continuous historical data will provide the basis for developing a possible long-term computerized predictive capability of fire weather in localized areas.
7. Computer stored data will be readily accessible and independent of people when stored centrally in a computer.

the automated system over the current manual system. As seen if the low cost case for the automated system is assumed correct, the recurring cost savings per year over the manual system is $92,500. If the automated system is penalized with the investment value of $105,000 for the manual system (assuming they have no salvage value when replaced by the automated system), the total initial cost will be $567,000 ($100,000 plus $462,000) and system cost breakeven* for the automated system will occur in approximately six years of operation.

When the pessimistic case is assumed for the automated system, the automated system is $34,000 cheaper per year than the manual system. Again, if the investment value of $105,000 for the manual system is added to the initial cost of $618,000 for the automated system, the initial overall cost will be $723,000. Breakeven** for the automated system will not occur for 21 years.

The results indicate that the automated system is economically desirable for the low cost case but not desirable for the pessimistic case based on breakeven periods.

The accrued value in terms of dollars for the benefits (listed in Table 14) derived from an automated fire weather system is not readily quantified. Discussions with CDF personnel indicate that as a conservative estimate, reduction in losses on the order of 1 to 5 percent should be possible. An average of 128,500 acres are burned per year based on data from 1962 through 1971 and the average loss per acre (as shown in Table 1) exceeds $118. Thus the average cost per year is $15,163,000 from fires. Savings of 1 to 5 percent by having the automated fire weather system translate into $151,500 to $785,000.

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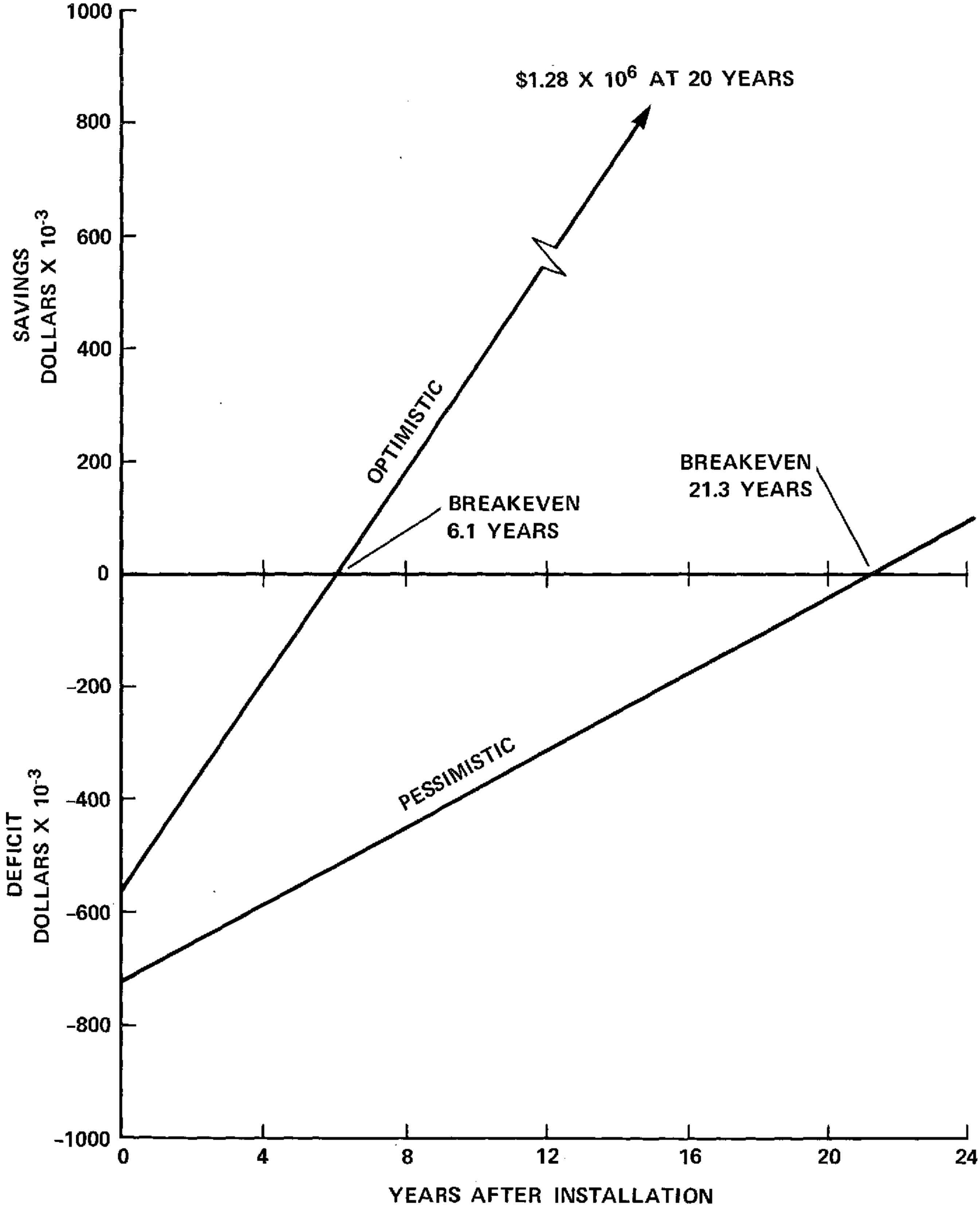
* Discounting of future cost or savings have not been included; result of discounting appears later in the section

** Discounting has not been used

Figure 7

OPERATIONAL COST ADVANTAGE OF AUTOMATED SYSTEM OVER MANUAL SYSTEM



When the above savings from reduced fire losses are added to the operational cost advantage for the automated system, the results shown in Figure 8 are obtained. Savings from the low cost or optimistic case will accrue at the rate of $850,500 per year ($92,500 plus $758,000) while the savings for the pessimistic case will accrue at $185,500 per year ($34,000 plus $151,500). As seen in Figure 8 breakeven* occurs at less than one year and less than four years, respectively, for the optimistic and pessimistic cases.

These results show that when benefits are included in the cost comparisons, the overwhelming desirability of the automated system over the manual system is clear even for the pessimistic case.

A more conventional approach to the cost breakeven analysis results in the curves shown in Figure 9. In this case the investment of $105,000 already in the manual system is ignored. The total initial cost of the new system is the initial investment. Therefore the curves start at negative values of $462,000 and $618,000, respectively, for the optimistic and pessimistic cases. The curves here have been corrected with a 10% discount factor** applied for future savings. In addition historical fire losses (see Table 1) used in estimating savings expected from reduced fire losses have been corrected to 1973 inflation. But the format of the curves are the same as those shown in Figure 8. Breakeven occurs in half a year for the optimistic case and in slightly over three years for the pessimistic case.

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* Discounting has not been used

** Based on Standard Federal Reserve procedure

Figure 8

OVERALL COST ADVANTAGE OF AUTOMATED SYSTEM OVER MANUAL SYSTEM

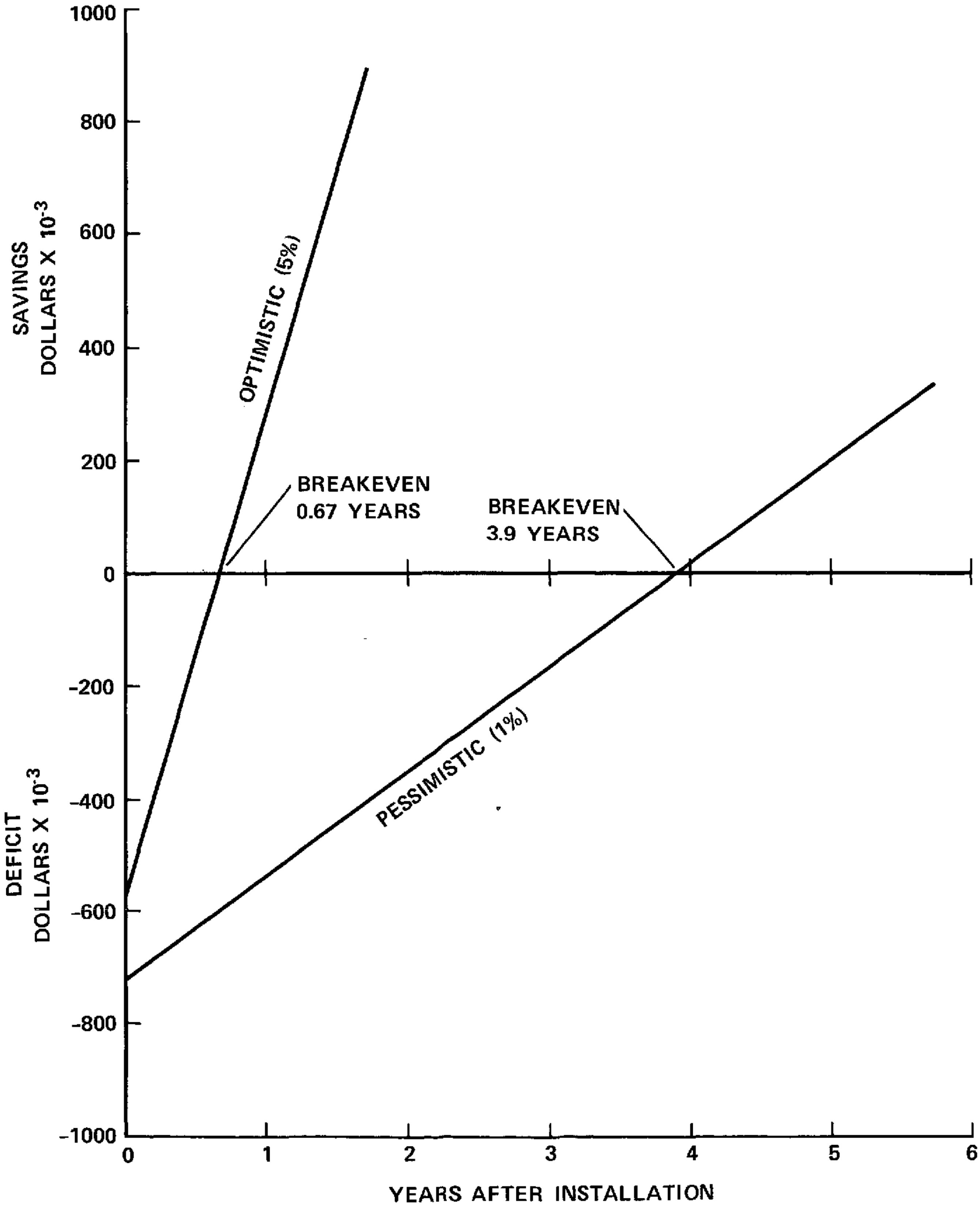
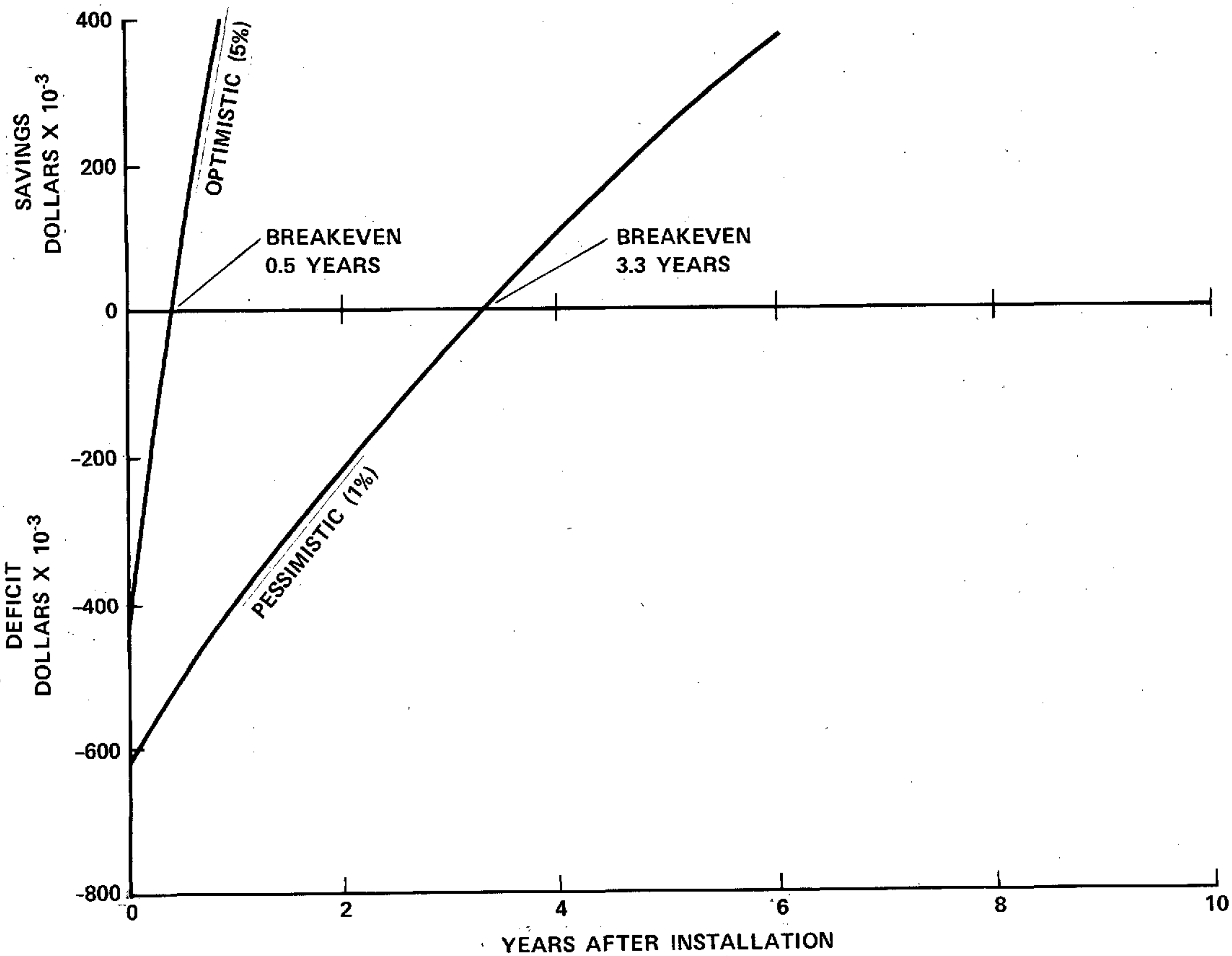


Figure 9

AGGREGATE COST ADVANTAGE FOR AUTOMATED SYSTEM OVER MANUAL SYSTEM (FUTURE SAVINGS DISCOUNTED 10% PER YEAR)



OTHER APPLICATIONS OF
AUTOMATED FIRE WEATHER SYSTEM

As shown previously, the economic advantage of an automated fire weather data system is substantial. This section discusses some related areas that could benefit from the installation of systems similar to the automated fire weather system. The utility of this capability can exceed the specific application considered in this study.

Table 15 is a short listing of additional applications that will benefit from an automated fire weather system. The list is not exhaustive but is intended to show the extended potential for the system. Additional sensors may be required to fulfill the needs for each of the application areas and may have to be developed or modified from current existing sensors. The mating of the new sensors into the basic platform should be as straightforward as the mating of the sensors for the fire weather station previously fabricated at Ames. Other segments of the automated system, with the possible exception of the computer programs for automated data processing and display, should pose no problem. Software (computer programs) for data processing and display will have to be developed independently.

As seen in Table 15 the use of an automated weather and related data system has wide applications potential. The future of these systems is very bright. They provide a means of effectively monitoring those parameters indicative of general environmental quality (an area of vital concern to all of us), as well as those that will enhance the preservation of natural resources (forest, water, etc.) and provide increased production of farm products.

Table 15

EXTENDED APPLICATION POTENTIALS FOR THE AUTOMATED FIRE WEATHER SYSTEM

Application	Application Area
Water	Watershed Monitoring
	Stream & River Condition
	Reservoir Condition
	Recreation
	Water Quality
Weather	Specialized Studies (Micro & Macro Weather)
	General (Day to Day)
	Remote Locations (Land - Sea)
Pest	Agricultural Pests - Insects
	Farm
	Forest
	Agricultural Pests - Animals
	Agricultural Pests - Vegetative
Pollution	Water
	Air
Wildlife	Habitat Monitoring (Animal, Fowl, & Fish)

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