NASA CR-134622
R-3015-3-1

DISASTER WARNING SYSTEM SATELLITE FEASIBILITY AND COMPARISON: WITH TERRESTRIAL SYSTEMS

VOLUME I - EXECUTIVE SUMMARY

by J. H. Spoor, W. H. Hodge, M. J. Fluk, and T. F. Bamford

Aerospace Systems Operation
of
COMPUTER SCIENCES CORPORATION

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center

Contract NAS 3-17795

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-134622		

4. Title and Subtitle

Disaster Warning System: Satellite Feasibility and Comparison wit! Terrestrial Systems
Volume I - Executive Summary

5. Report Date

September 1974

6. Performing Organization Code

7. Author(s)

John H. Spoor, W. H. Hodge, M. J. Fluk, and T. F. Bamford

8. Performing Organization Report No.

R-3015-3-1

10. Work Unit No.

9. Performing Organization Name and Address

Computer Sciences Corporation
Falls Church, Virginia 22046

11. Contract or Grant No.

NAS 3-17795

13. Type of Report and Period Covered

Contractor Report

12. Sponsoring Agency Name and Address

National Aeronautics & Space Administration
Washington, D. C. 20546

14. Sponsoring Agency Code

15. Supplementary Notes

Project Manager, J mes R. Ramler, Space Flight Systems Study Office, NASA Lewis Research Center, Cleveland, Ohio

16. Abstract

The Disaster Warning System (DWS) is a conceptual system which will provide the National Weather Service (NWS) with communication services in the 1980s to help minimize losses caused by natural disasters. The object of this study is a comparative analysis between a terrestrial DWS and a satellite DWS. Baseline systems satisfying the NOAA requirements were synthesized in sufficient detail so that a comparison could be made in terms of performance and cost. The cost of both baseline systems is dominated by the disaster warning and spotter reporting functions.

An effort was undertaken to reduce system cost through lower-capacity alternative systems generated by modifying the baseline systems. By reducing the number of required channels and modifying the spotter reporting techniques, alternative satellite systems were synthesized. A terrestrial alternative with the coverage reduced to an estimated 95 percent of the population was considered.

Volume I - Executive Summary
Volume II - Final Report
Volume III - Appendices

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Disaster Warning Satellite Broadcasting System Costing	~~U.S. Government and Contractors Only~~

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		--

PRECEDING PAGE BLANK NOT FILMED

FOREWORD

This document is Volume I of three volumes prepared for the NASA Lewis Research Center by the Computer Sciences Corporation (CSC) under Contract NAS3-17795. The CSC Project Manager was John H. Spoor. The primary members of the study team were W. H. Hodge, M. J. Fluk, and T. F. Bamford. Study participants included G. Pendleton, W. E. Andrews, P. K. Carlston, and B. F. Adams.

This study was managed by NASA for the National Oceanic and Atmospheric Administration (NOAA) under the technical cognizance of the NASA Project Manager, James R. Ramler, of the Lewis Research Center. The principal NOAA cognizant individual was Jack H. Puerner of the National Environmental Satellite Service. Valuable assistance and guidance from NOAA was provided by Bernard Zavos of the Office of Associate Administrator for Environmental Monitoring and Protection, Sam Grimm of the National Weather Service, Walt Castle of the Office of Policy and Planning, and Vern Zurick of the Environmental Research Laboratories.

TABLE OF CONTENTS

SECTION 1 – SUMMARY

The Disaster Warning System (DWS) is a conceptual system which will provide the National Weather Service (NWS) with communication services in the 1980s to help minimize losses caused by natural disasters. The communication services are grouped into four functions: disaster warnings, spotter reports, data collection, and coordination within the NWS.

The objective of this study was a comparative analysis between a terrestrial DWS and a satellite DWS. Baseline systems satisfying the NOAA requirements were synthesized in sufficient detail so that a comparison could be made in terms of performance and cost, including ten years of operation. Prior to synthesizing these systems, an investigation was made of the present and planned NWS structure, operation, and traffic flow relevant to natural disasters. An estimate, based on past data, of the number of warning messages in 1985 was used in a queueing model to obtain expected waiting times as a function of the number of warning channels.

Both the terrestrial and satellite baseline systems essentially satisfy the NOAA DWS requirements. The exceptions are: the terrestrial system does not provide ocean coverage, and the satellite system provides only five rather than 50 simultaneous voice channels to the spotters. The total system cost in constant 1974 dollars, including 10 years of operation, is \$1.00 B for the baseline terrestrial system and \$1.62 B for the baseline satellite system. The home receiver costs are not included; their unit factory costs are \$17.60 and \$31.20 in quantities of one million for the terrestrial and satellite systems, respectively. The cost of both baseline systems is dominated by the disaster warning and spotter reporting functions. The cost drivers for the disaster warning functions are the required number of simultaneous broadcasts for the satellite system and the extensive coverage for the terrestrial system. The major cost driver for the spotter reporting function is the large number (100,000) of transceivers that must be purchased and maintained for ten years; this impacts the satellite system more since it requires a more sophisticated (costly) transceiver.

An effort was undertaken to reduce system cost through lower-capacity, alternative systems generated by modifying the baseline systems. By reducing the number of required channels and modifying the spotter reporting techniques, alternative satellite systems were synthesized with total costs ranging from \$1.32 B to \$0.87 B. A terrestrial alternative with the coverage reduced to an estimated 95 percent of the population was considered; this reduced the total terrestrial system cost to \$0.84 B.

Further investigation of both the terrestrial and satellite systems is required to develop an optimum configuration and more detailed system definition on which to base a final system choice. Of particular importance is a reassessment of the DWS requirements in view of the cost and system performance sensitivities to the requirements.

SECTION 2 – INTRODUCTION

To achieve the national goal of reducing the damage and loss of life caused by natural disasters, several areas have been identified as needing significant improvements (References 1 and 2). This study is devoted to one of the key areas identified - communications - and specifically the communications means necessary to:

1. Rapidly disseminate disaster information within NOAA

2. Relay information of impending natural disasters to the appropriate National Weather Service (NWS) facility

3. Provide the ability to quickly and selectively issue warnings to the general public, public services such as the police and rescue units, and other interested organizations.

A communications system capable of accomplishing these tasks has been designated as the Disaster Warning System (DWS).

The objectives of this study were twofold: synthesize both a terrestrial and satellite warning system that would meet the NOAA requirements for a DWS and then perform a comparative analysis between these two systems in terms of cost and performance.

Presented first in this executive summary are the operational concepts of a terrestrial and a satellite DWS. The NOAA requirements for the DWS are presented and the baseline terrestrial and satellite systems that meet these requirements are described. Both systems meet nearly all the NOAA requirements for a DWS; however, the performance of these two systems are not directly comparable due to the inherent differences between the two approaches. General and specific performance and cost comparisons are presented. Costs include system implementation as well as ten years of operation. Also, funding schedules are shown through the ten years of operation and are given in terms of nonrecurring, acquisition, annual, and total costs. Finally, the major cost drivers of each of these baseline systems are presented.

One of the prime functions of a DWS is the issuance of warnings; thus, the estimation of the warning traffic in the mid 1980's is of basic importance and significantly impacts the DWS requirements. Warning traffic estimations have been investigated by both NASA Lewis Research Center and Computer Sciences Corporation. Some of the latest results determined by NASA Lewis Research Center are presented in the following text; these results show the expected delay times for various numbers of DWS warning channels as a function of the estimated number of warning messages.

It became apparent toward the end of the study that the baseline systems would be quite costly; therefore, attention was directed to synthesize less costly alternative systems and to investigate cost sensitivities. Since much of the study effort was directed toward the development of the baseline systems, the alternatives and cost sensitivities were derived from these systems. Also, a hybrid system combining a satellite system with terrestrial broad[illegible] was developed.

A summary which illustrates the ma[illegible] ost sensitivities is presented in terms of total costs for the baseline systems and their alternatives. Since the satellite portion of the satellite system has a large impact on total system cost, a summary of the major satellite characteristics, together with their research and development costs through protoflight, is included.

SECTION 3 – OPERATIONAL CONCEPTS

Before discussing the operational concepts of the terrestrial and satellite systems, some general operational concepts are discussed. The basic concept of the DWS is to provide the capability to transmit disaster warnings directly to inexpensive and easily operated home receivers. These home receivers will have the capability to be automatically demuted and to have an alarm initiated prior to the reception of the voice warning message. The issuance of these warnings will be from local NWS facilities which must have the capability for autonomous operation. Consequently, the collection of data from remote sensors and spotter reports must be readily and rapidly available at these facilities. Even though local autonomous operation is required, the capability for coordination communications among NWS facilities is necessary.

3.1 TERRESTRIAL DWS

Figure 1 illustrates the basic elements of a terrestrial DWS. Three types of NWS facilities are shown: the National Hurricane Center (NHC) in Miami, a Weather Service Forecast Office (WSFO), and a Weather Service Office (WSO). Other NWS facilities that perform the basic disaster warning functions include River Forecast Centers and their subsidiary River District Offices, NHC subsidiary Hurricane Weather Offices, and specialized facilities such as the National Meteorological Center and the National Severe Storms Forecast Center. The total expected number of NWS facilities in the mid 1980's is 300. Throughout this report, WSO is used as a general reference to these facilities.

The focal point of activity, as illustrated in Figure 1, is the WSO. Data concerning a potential natural disaster comes from various sources. In the illustration, data is sent from a reconnaissance aircraft via a radio link to the NHC in Miami and is relayed to an appropriate WSFO and WSO via terrestrial lines. A remote sensor is also illustrated connected via terrestrial lines (indicated by dashed lines) to the WSO. Whenever a threat of a natural disaster is considered imminent, spotters (illustrated by an automobile) will be alerted and sent to their assigned stations. If a major event such as a tornado is detected by a spotter or a river crest by a remote sensor, the information is relayed to the appropriate WSO. The information is sent from spotters via a radio link to an intermediate location where the information is relayed to the WSO via a terrestrial line. This information is evaluated at the WSO and, if necessary, a

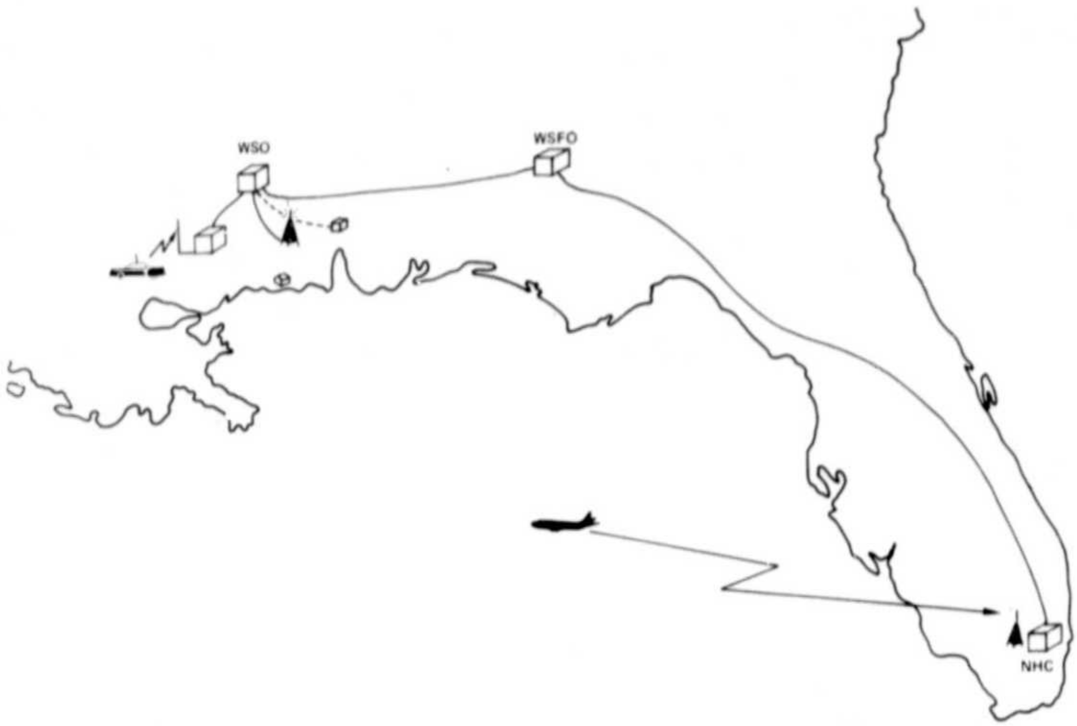


Figure 1. Operational Concept Terrestrial DWS

warning is selectively sent to the general public. The warning is relayed via terrestrial lines to a broadcasting facility where the message is broadcast. Prior to the voice warning message, an address is sent which demutes the selected receivers and an alarm is initiated within the home receiver. The alarm is followed by a voice warning message.

A local WSO has authority to issue warnings without references to a higher echelon within the NWS. However, the DWS will provide communications for coordination and preplanning among the various NWS facilities.

3.2 SATELLITE DWS

The basic elements of a satellite DWS are illustrated in Figure 2. The same end points are shown in Figure 2 as in Figure 1. They are: reconnaissance aircraft, remote sensor, spotter, WSO, and a home. With a satellite DWS, the relay points have been removed and all communications between these points go directly through the satellite. Note that all information goes to or comes from the WSO. Thus, the WSO will receive directly all information concerning a potential natural disaster. If necessary, the WSO will alert spotters to go to their stations. If a disaster is noted, the information is sent to the WSO via satellite. The WSO, as in the terrestrial concept, first sends a selective address to demute the appropriate home receivers, initiates an alarm, and then gives the voice warning message. Also, as before, the DWS provides communications for coordination and preplanning among the NWS facilities.

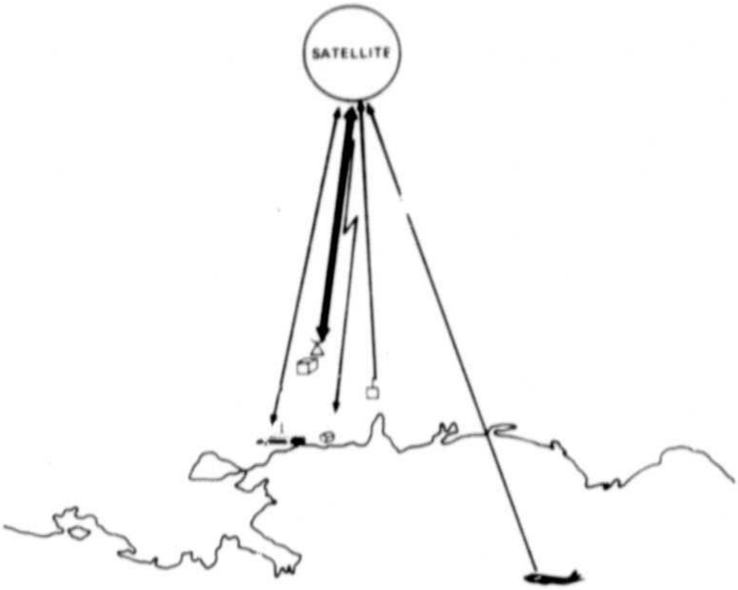


Figure 2. Operational Concept Satellite DWS

SECTION 4 – SYSTEM REQUIREMENTS

This section summarizes the NOAA DWS requirements originally transmitted to NASA on June 27, 1972 in a letter from the Associate Administrator of NOAA. The requirements presented herein are categorized as to functional requirements, required response to disaster types, operational requirements, geographical coverage, and capacity requirements.

The four DWS functional requirements are:

- Disaster warning
- Spotter reporting
- Data collection
- Coordination.

These four categories comprise the four distinct communication services provided by the DWS. Consequently, the description of the DWSs is given in terms of these four functional requirements.

Included in these requirements are the 15 information transmittal requirements specified by NOAA, which include capabilities during nondisaster periods as well as disaster periods and the nonmandatory requirement for broadcasting routine forecasts to the general public and mass media. Also included are planning among WSOs, rescue requests from spotters, data from reconnaissance aircraft, spotter alerts, preparedness information, and evacuation warnings.

A primary requirement is to provide the capability to rapidly and selectively warn the general public. The quantitative requirements for selectivity and rapidity for various types of natural disasters are:

Disaster Type	Smallest Area Warned	Message On-Line Upper-Bound
Tornado or Severe Storm	Part of county	1-5 minutes
Hurricane	Part of coast	1-15 minutes
River Flood	Part of state	15 minutes - 1 hour
Small Craft Warning	Part of coast (lake)	15 minutes - 1 hour
Winter Storm	Part of state	15 minutes - 1 hour
Others	Part of county	1 minute - 1 hour

The "Others" category includes flash floods, storm tides, unusual lake winds, live-stock advisories, frost, fog, radar summaries, special marine warning, and air pollution.

General system requirements include continuous 24-hour operation and immunity to natural disasters; this implies an autonomous power source to avoid total dependence upon commercially available power. Any NWS facility within the DWS (down to the WSO and equivalent levels) has the authority to independently issue warnings and the DWS must provide the capability for simultaneous warnings.

A key element in the DWS is the home receiver. In addition to low cost and easy operation, the receiver must be able to operate with an inside antenna and be activated (demuted) within 15 seconds after the message arrives. To avoid unnecessary warnings, the home receivers must have selective addressing capability. Since the DWS is to provide a service only when desired, a home owner operated on-off option must be provided.

The DWS geographical coverage requirements, illustrated in Figure 3, includes the area bounded from the equator to 50 degrees North Latitude and from 35 to 180 degrees West Longitude plus Alaska. The number of simultaneous warnings may be across this broad area or concentrated within a small area such as a portion of a state. The DWS must have a selectivity into any one of 20,000 areas and must be able to reach 99 percent of the population within any one of these areas during a disaster and 90 percent of the population during nondisaster periods. Since the 20,000 areas will be selected according to natural disaster potentials, areas will overlap in some cases; hence, each home receiver must have at least three addresses.

The DWS capability requirements are given for each of the four functional requirements. For disaster warnings there must be at least ten simultaneous voice messages. For spotter reporting there must be at least 50 (two-way) voice channels between the 100,000 spotters and their assigned WSOs. The data collection functions require 200 data channels during disaster periods and 200 channels for nondisaster periods. The estimated number of remote sensors is 20,000. The coordination functions require five duplex voice channels.

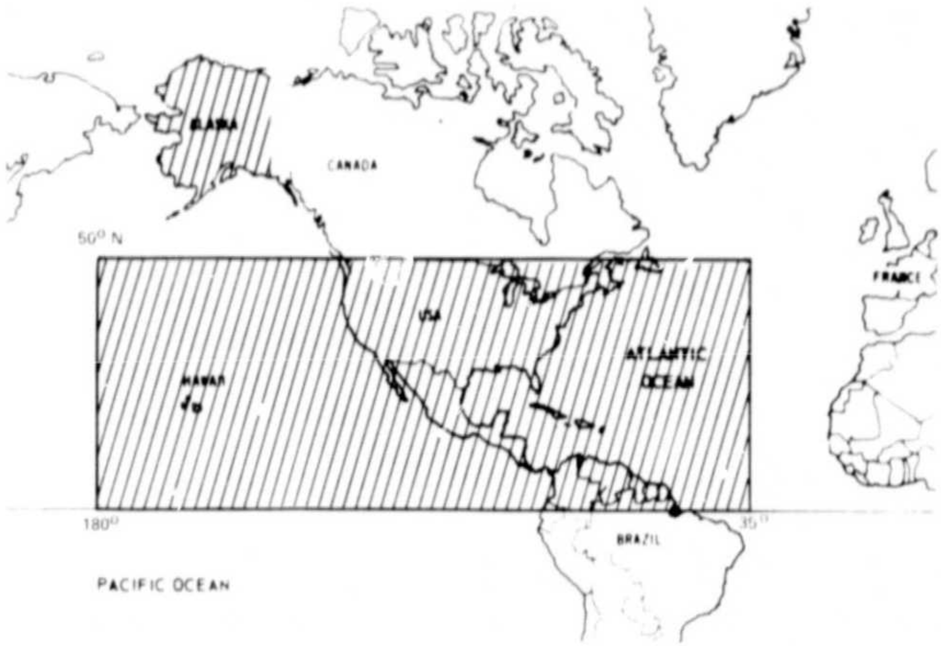


Figure 3. Geographical Coverage Requirement

SECTION 5 – BASELINE SYSTEMS

5.1 TERRESTRIAL

The baseline terrestrial DWS resulted from an analysis of various techniques to meet the NOAA requirements. A major investigation was conducted of possible techniques for terrestrial broadcasting to satisfy disaster warning requirements. The frequency bands investigated were low frequency (LF), high frequency (HF), and very high frequency (VHF); i.e., 30-300 kHz, 3-30 MHz, and 30-300 MHz, respectively.

Only the LF and VHF bands were considered applicable to a DWS since the HF skywave is not dependable for a DWS and can cause unpredictable interference on the reliable groundwaves. The basic difference between the LF and VHF bands is that LF broadcasting provides very broad coverage using large antennas and very high powered transmitters; whereas, VHF broadcasting is basically restricted to line-of-sight coverage resulting in relatively smaller antennas and lower transmitter powers. With the DWS requirement for at least ten simultaneous voice broadcasts within a relatively small area (portion of a state), the broad LF coverage requires ten voice-channels from each LF transmitter. The baseband bandwidth requirement is at least 40 kHz. Since high powered LF transmitter/antenna systems are narrow band, it is impractical to achieve the required bandwidth at LF. Thus, the VHF band is used for the baseline terrestrial DWS. Since little difference was found among the frequencies within the VHF band, it is most practical to expand the present NOAA VHF/FM system for DWS purposes.

The baseline terrestrial DWS concept is illustrated in Figure 4. This system consists of three distinct networks: one which services the data collection and coordination functions, a second which provides the means for disaster warnings, and a third for spotter reports. The terrestrial lines are illustrated as single lines; however, to increase system reliability, particularly during disasters, dual lines are used throughout the terrestrial networks.

As previously stated, the disaster warning functions will be performed by a terrestrial broadcasting network similar to the present NOAA VHF/FM facilities. Using a geographical distribution of the transmitters in a hexagonal pattern so that only three frequencies are necessary and a nominal radius coverage of 65 kilometers, approximately 750 transmitters will be required to cover 99 percent of the population. Since the VHF line-of-sight transmissions are highly terrain dependent, the precise number of transmitters required can only be determined after an extensive survey is conducted. Note that coverage is not provided to the ocean areas although extensive ocean coverage as included in the NOAA requirements. Extensive ocean coverage is generally incompatible with a terrestrial DWS.

With 750 transmitters, there are an average of 2.5 transmitters for each WSO. Since each transmitter has a coverage radius of only 65 kilometers, only two simultaneous transmissions per transmitter are necessary to meet the requirement for at

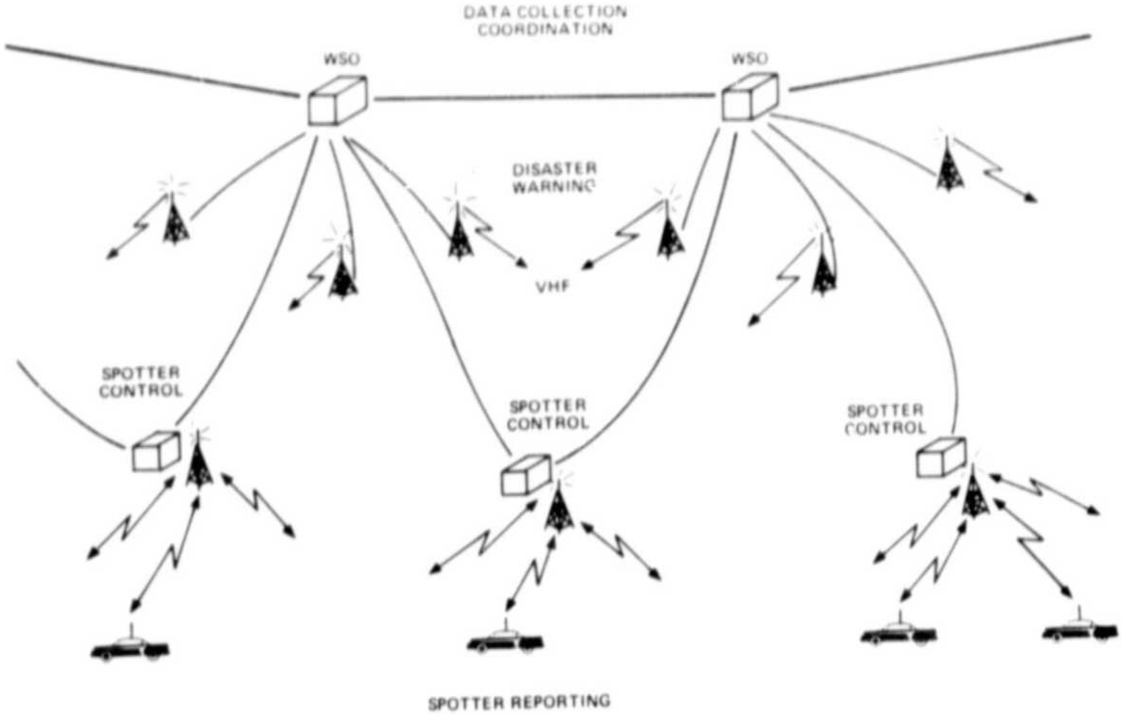


Figure 4. Terrestrial System Concept

least ten simultaneous transmissions in a small area; i.e., the area covered by five transmitters is considered to constitute the small area. The two voice channels are multiplexed onto a single carrier.

As illustrated in Figure 4, spotter reports are relayed to a WSO by a spotter control. Approximately 500 spotter controls are connected by terrestrial lines to the two closest WSOs. Radio line-of-sight links (two-way voice) are used between the spotter control and spotters. Each spotter control can receive up to three simultaneous voice transmissions, the maximum number needed to meet the capacity requirement within an area covered by a WSO. The spotter control will be manned only as required and will be supplemented by volunteers. The manning and deployment of spotters will be in response to an alert.

The operational concept of the terrestrial line network for the coordination and data collection functions is illustrated in Figure 5. This network of lines, dedicated exclusively for the DWS, is divided into four regional areas, each of which contains a regional headquarters. Each regional headquarters is fully connected to the other regional headquarters. The WSOs within each region are grouped into communities of interest (COIs) which are interconnected by a switching network. The WSOs within each COI are connected by dual lines (one normally used as backup) acting as a party line. There is a selective dialing capability which connects either individual

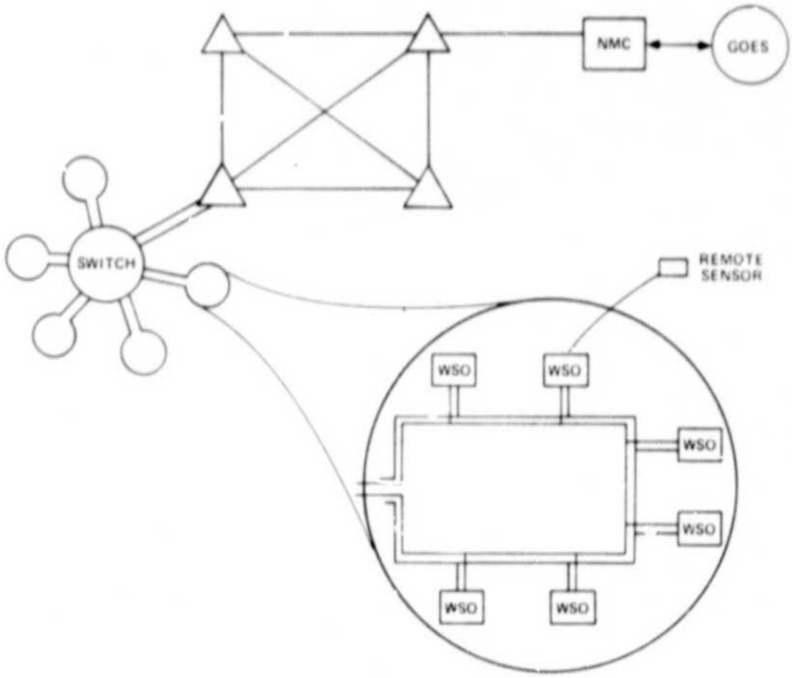


Figure 5. Coordination and Data Collection – Terrestrial

WSOs or a group of WSOs. Only one call per loop is possible at one time; however, ongoing calls can be interrupted. There is a self-control of the use of the party line. Calls between loops are established through the switching network. Once the call between loops is established, the two loops are connected and act as a single party line. If two loops are connected, a call from a third loop would get a busy signal. The switch provides some alternative routing capability for added reliability.

The data collection function is performed on the same lines as the coordination function. The separate line in Figure 5 is merely for illustrative purposes. The data can time share the voice band or can be sent in a band just below. Two sources of data are indicated in Figure 5. One is from a remote sensor connected to a WSO by a terrestrial line; the data can be obtained by request from the WSO. The other source is via the GOES system; the data must be requested from the National Meterological Center.

5.2 SATELLITE

In addition to analyses such as multiple access techniques, modulation and coding techniques, and transponder configurations, a major investigation was conducted on the choice of frequency selection for the warning messages to the general public. Since extremely large satellite transmitter power is required to effectively transmit directly to a home receiver, minimization of required power was the primary consideration in selecting frequency. The nominal frequencies of the three bands considered were 790 MHz, 2.6 GHz, and 12 GHz. The highest band, 12 GHz, was found to be unacceptable due to large attenuations caused by rainfall. This is particularly undesirable for a system like the DWS that is frequently subject to rain at critical times. Since satellite coverage and the home receiver antenna beamwidth are fixed (discussed in the following paragraphs), the antenna gains of the satellite and home receiver are independent of frequency. Thus, the primary difference between the 790 MHz and 2.6 GHz frequencies in terms of required satellite transmitter power is the difference in free space loss. The 2.6 GH frequency has about 10 dB more free space loss than that at 790 MHz; therefore, 790 MHz was chosen for the warning transmissions.

The baseline satellite system concept is illustrated in Figure 6. The warning messages are transmitted directly from the satellite to the home receivers at 790 MHz. The spotter reports go directly from the spotters to the satellite at 2.03 GHz. The data collection uplink at 400 MHz is the same as the present GOES system. The 6-GHz uplink from the WSOs contains warning and coordination traffic as well as the satellite system control (discussed in the following paragraphs). The downlink to the WSOs contains spotter reports, data, coordination, and system control traffic.

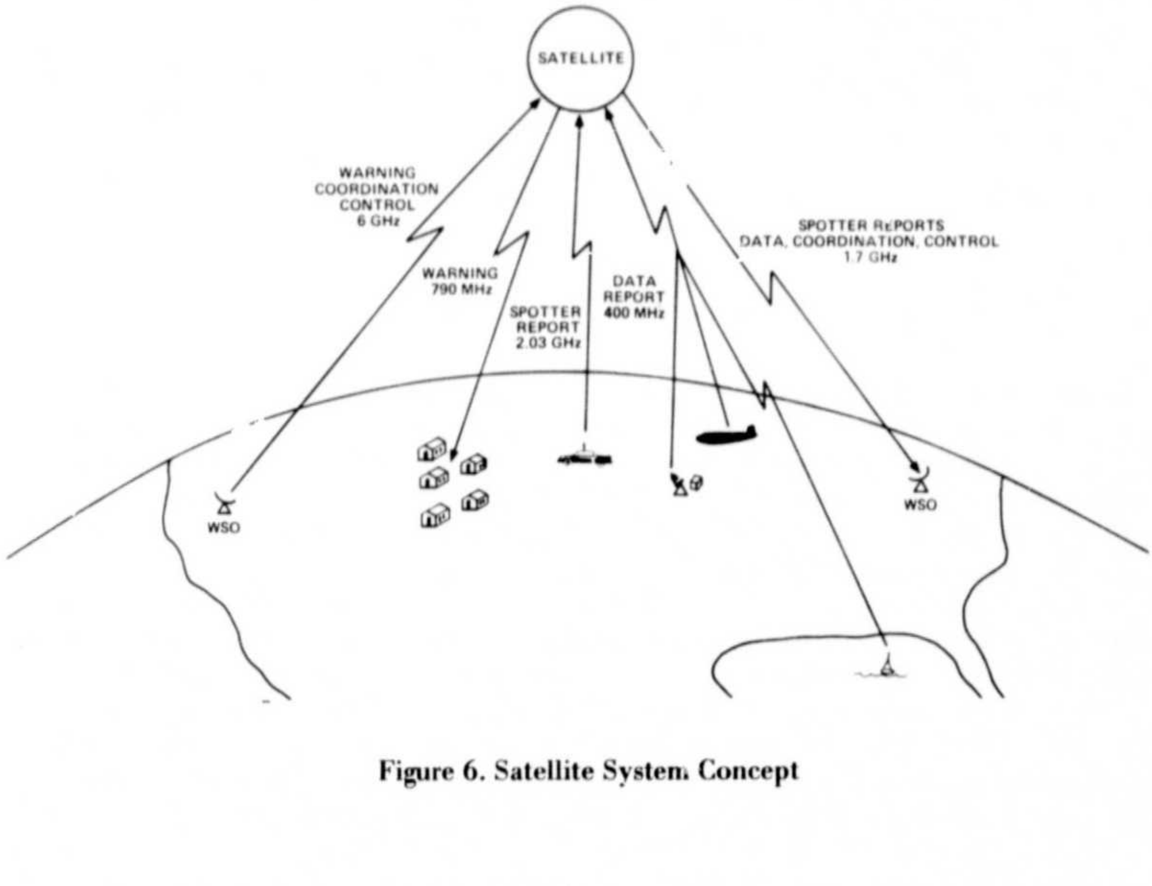


Figure 6. Satellite System Concept

To control the use of the satellite by a large number of low duty cycle ground users, the channel utilization of the satellite is controlled by a central control station* (CCS) as illustrated in Figure 7. From a coverage viewpoint the best geographical location of the CCS is in the western plains such as at Boulder, Colorado. The major system control is maintained by a dual channel time division access (TDA) link through the satellite between the CCS and the WSOs. The channel requirements of the WSOs (generally at their own request) are for disaster warnings, spotter reception, data reception, and coordination. The CCS also interfaces with the other ground users: demutes the home receivers prior to warning broadcasts, interrogates remote sensors for data, and, upon request from a spotter, assigns a channel for a spotter report.

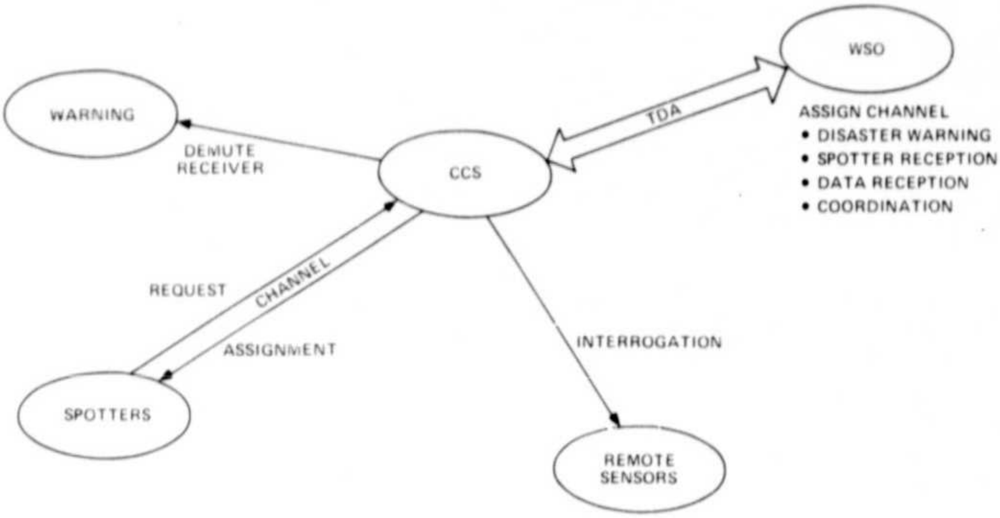


Figure 7. Satellite System Control

The baseline satellite system consists of two satellites in synchronous orbit separated by 20 degrees to avoid mutual eclipse. The home receiver antenna beamwidth must be wide enough to receive warnings from either satellite without requiring precise antenna pointing. A beamwidth of 70 degrees has been selected. The geographical coverage for disaster warning is illustrated in Figure 8 for satellites located at 110 and 130 degrees West Longitude. Each satellite will have a large (8.6-meter diameter) antenna with five feeds to provide the coverage illustrated (the contours are 4 dB below the peak antenna gain). As shown, the contours do not cover the ocean areas that are included within the requirements. However, since the principal users in these areas will be ocean vessels not limited by building attenuation and urban noise, these users will have access to the warning messages by utilizing higher gain antennas and more sensitive receivers. The area in north-central CONUS, which is 6.3 dB below the peak antenna gain, was used to determine the required satellite power.

*This same facility may be used to receive and monitor satellite telemetry as well as other satellite transmissions for system test, evaluation, and quality check.

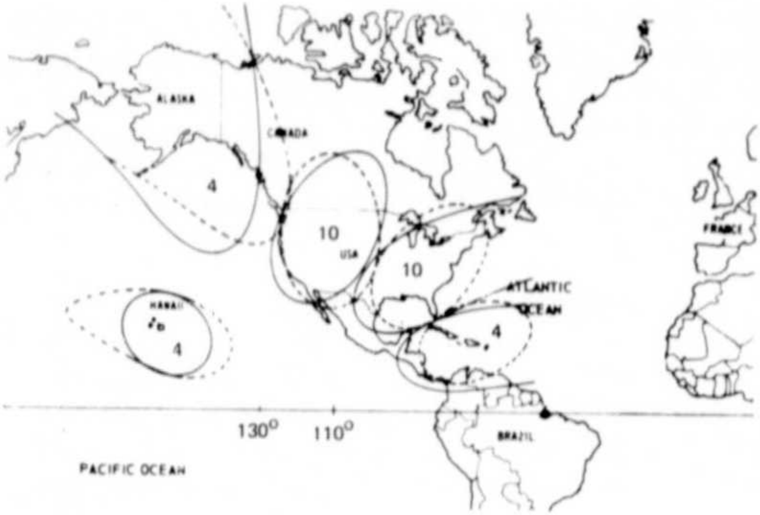
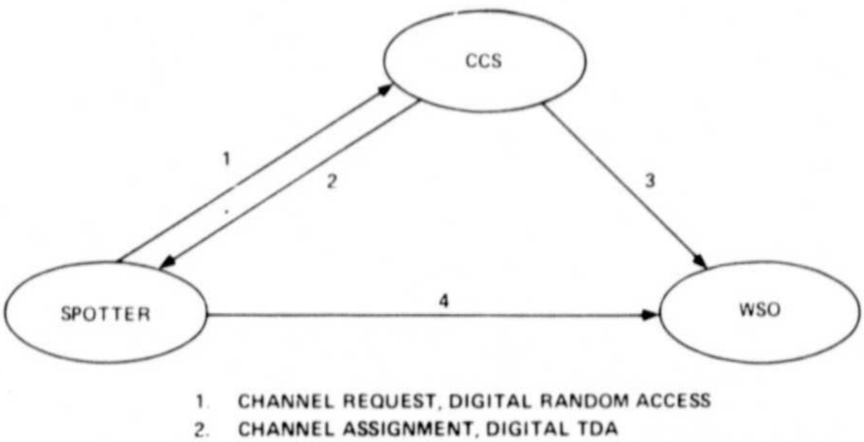


**Figure 8. Disaster Warning Coverage
(Five Simultaneous Transmitters/Satellites)**

Each satellite will be capable of transmitting five simultaneous warnings. Each beam over CONUS will handle up to five transmissions per satellite whereas the other beams can transmit up to two per satellite. The total number of transmissions possible for both satellites in each beam is indicated in Figure 8. Any combination of transmissions up to the limit for each beam can be transmitted with a maximum of five per satellite. Whenever either satellite is eclipsed or fails, the other satellite will provide the coverage at one-half system capacity.

The operational functions of the spotter reporting is illustrated in Figure 9. Once a spotter has been alerted and is on station, it can request a channel from the CCS by



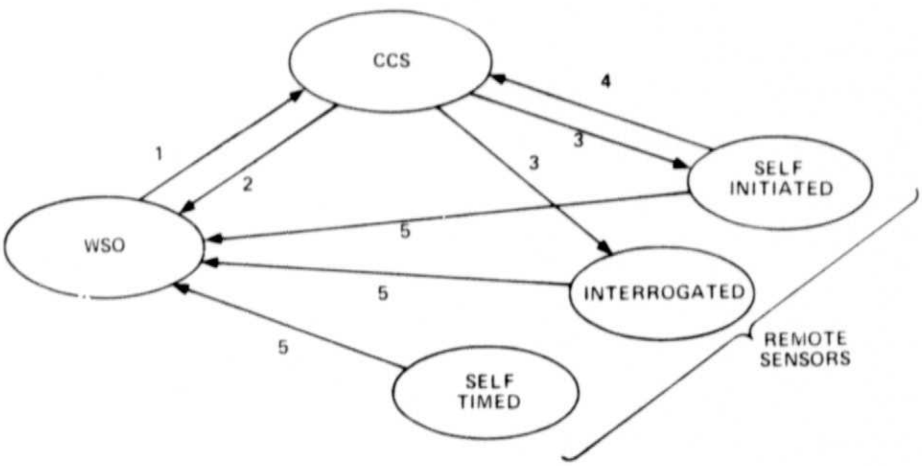
1. CHANNEL REQUEST, DIGITAL RANDOM ACCESS
2. CHANNEL ASSIGNMENT, DIGITAL TDA
3. RECEPTION CHANNEL, TDA CHANNEL
4. FM VOICE, 50 CHANNELS

WSO → SPOTTER, WARNING CHANNEL

Figure 9. Spotter Reporting – Satellite

sending his address via a digital random access channel. The CCS assigns a channel to the spotter via a TDA channel and at the same time notifies the recipient WSO of the channel assignment via the main TDA channel. Once the channel is assigned, the spotter reports by FM voice directly to the WSO. Up to 50 simultaneous spotter reports per satellite are possible. Voice communications from the WSOs to the spotter are accomplished by warning channels ([illegible] per satellite) that are in addition to those intended for warning the general public.

The data collection operational functions are illustrated in Figure 10. There are presently two types of remote sensors used with the GOES system: self-timed and interrogated. Both types can initiate a message whenever data exceeds a predetermined threshold. These three types of data transmissions are illustrated in Figure 10. For interrogating remote sensors, the WSO requests the CCS, via the main TDA channel, to interrogate the desired remote sensor. The CCS notifies the WSO of the reception channel and interrogates the sensor; the data is then sent directly to the WSO. For self-initiated data from an interrogable remote sensor, the sensor requests that the CCS provide an interrogation via a random access channel. The CCS notifies the appropriate WSO, interrogates the remote sensor and the data goes directly to the WSO. The self-timed remote sensors send the data directly to the WSO at a predetermined time and channel. Self-initiated data from a self-timed remote sensor is sent directly to the WSO using a random access channel. There are 200 data channels per satellite for disaster periods and an additional 200 for nondisaster periods.



1. INTERROGATION REQUEST, TDA CHANNEL
2. RECEPTION CHANNEL, TDA CHANNEL
3. INTERROGATION CHANNEL, DIGITAL TDA
4. INTERROGATION REQUEST, DIGITAL RANDOM ACCESS
5. DATA CHANNEL, 200 + 200

Figure 10. Data Collection – Satellite

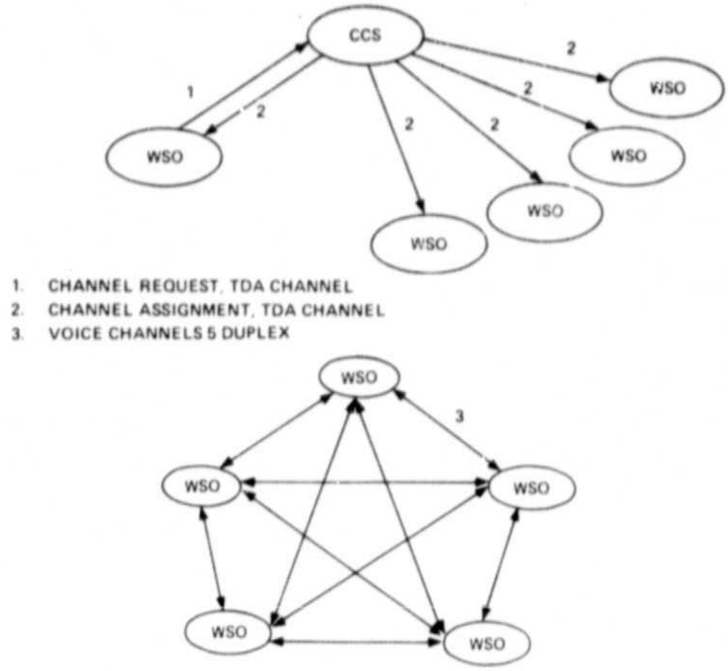
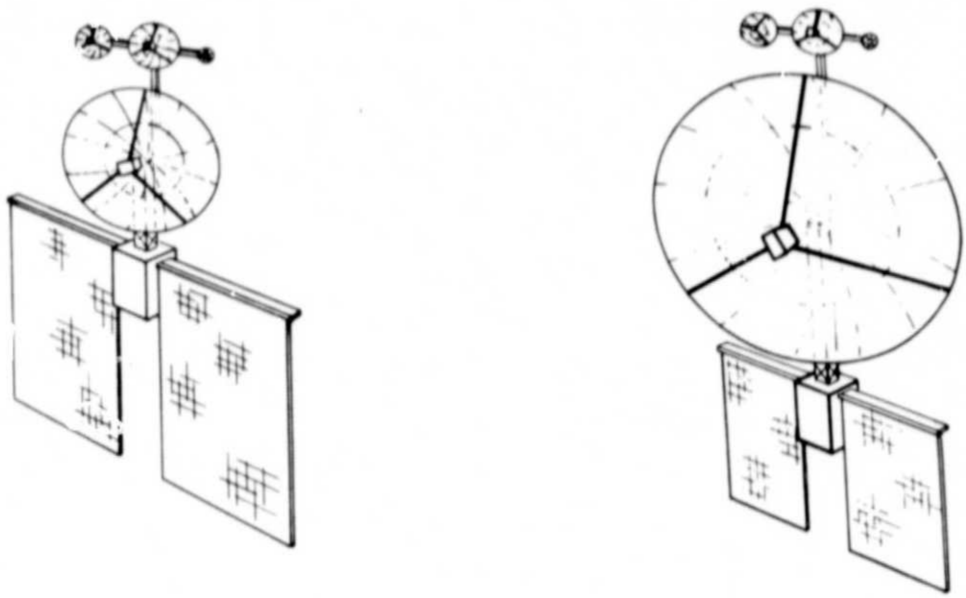


Figure 11. Coordination – Satellite

The operational coordination functions are illustrated in Figure 11. A WSO desiring a coordination conference, requests coordination channels from the CCS via the main TDA channel. The appropriate WSOs are notified by the CCS of the coordination channel assignments and then the WSOs are directly interconnected. Each satellite has a capacity for five duplex voice channels. If enough channels are available, several conferences can proceed simultaneously.

The general physical structure of the baseline satellite is illustrated in Figure 12(a). The warning messages are broadcast directly to the home receivers using the large antenna with an 8.6-meter diameter. The three smaller antennas (from left to right) provide northern hemispheric coverage for the 1.7- and 2.03-GHz transmissions, the 790-MHz warning messages other than to the general public, and the 6-GHz uplinks from the WSOs. As can be seen from Figure 12(a), a large solar array is required to supply the prime power.



a. Baseline Satellite b. Large Antenna Alternative

Figure 12. Satellite Sketches

To reduce the required transmitter power and consequently the prime power for broadcasting warnings to the general public, an alternative satellite using a larger antenna was considered. This satellite, illustrated in Figure 12(b), uses an antenna with a 16.8-meter diameter. With this larger antenna, coverage is provided using 12 beams. Since these beams are more directive, the energy outside the desired coverage areas is reduced. The three antennas for this alternative satellite are the same as before. As can be seen, the larger antenna results in a significantly smaller solar array.

5.3 PERFORMANCE COMPARISON

Even though both the baseline terrestrial and satellite systems essentially satisfy the DWS requirements, it must be emphasized that their performances are quite different. That is, when meeting some of the requirements, other capabilities may far exceed their respective requirements. To emphasize some of the major performance differences, the following general discussion is applicable to all four functional requirements.

The major difference between terrestrial and satellite systems is the difference in the three interrelated capabilities of coverage, connectivity, and capacity. Figure 13 illustrates a satellite system with a northern hemispherical coverage superimposed upon a terrestrial system. Coverage refers to the geographical extent to which communications is capable. As illustrated, the satellite has broad coverage which is essentially terrain independent. In contrast, the terrestrial system must have an extensive network to achieve similar coverage. Furthermore, the terrestrial system is terrain dependent, particularly line-of-sight broadcasting in mountainous regions. Broad terrestrial coverage over ocean areas generally requires broadcasting in the VLF and LF bands, implying the need for massive transmitting facilities.

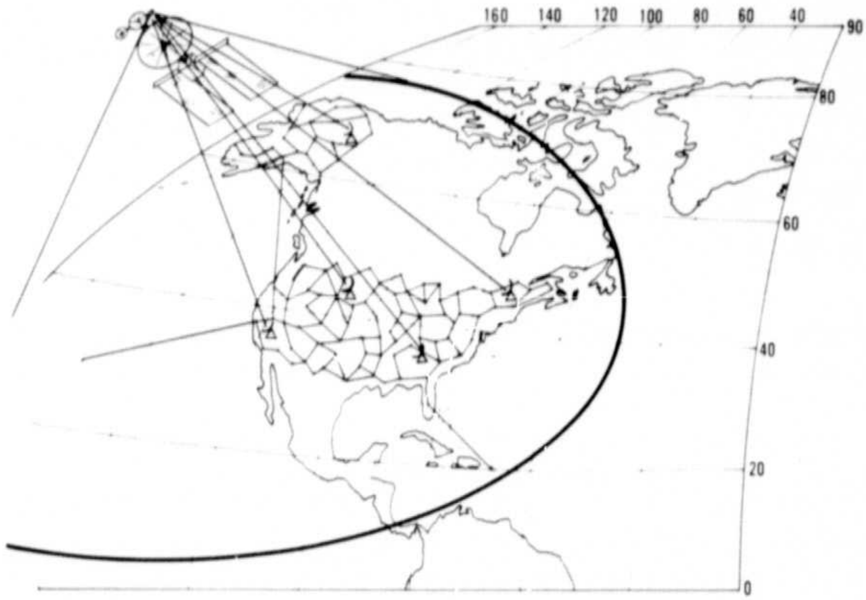


Figure 13. Satellite/Terrestrial Comparison: Coverage, Connectivity, Capacity

Connectivity refers to the possible configurations of connecting potential users. For a terrestrial system, the network complexity is nearly proportional to distance and the number of independent connections. For the satellite system, the physical locations of users within the coverage area has little effect upon satellite capability; there is little difference whether the ground users are 1 or 6000 kilometers apart. Also, the satellite is not affected by the number of ground stations as long as they do not simultaneously use the satellite. However, as the required simultaneous use increases, the required capacity increases; capacity being defined as the amount of simultaneous traffic that can be accommodated. For a satellite, increased capacity significantly increases its size and cost. Once an extensive terrestrial network is implemented, it inherently has a large capacity since separate and somewhat autonomous facilities were required to implement the network. Thus, a large number of simultaneous channels are available.

Three other performance factors that are compared are immunity to natural disasters, system response time, and system control. Other than physical destruction of the ground terminals, the satellite system is immune to natural disasters. By providing for alternate WSOs to perform the duties of WSOs that have been damaged, the total system is essentially immune to natural disasters. The immunity of a terrestrial network to natural disasters is uncertain due to the variability of its survivability. Long haul lines are quite survivable, (except for damaging earthquakes) being primarily buried cables, whereas local exchanges are much more vulnerable. The baseline satellite system response time is extremely fast whereas the terrestrial system response time is quite cost dependent. With unique dedicated lines, the response time of the terrestrial system is essentially instantaneous and very costly. Utilizing a single control point, the CCS, the system control of the satellite system is very good. Since many of the operations of the terrestrial network are locally autonomous, establishment of a central system control would be complex and costly.

5.4 COST COMPARISONS

Figure 14 presents total cost by element and system (far right column) for the baseline terrestrial and satellite systems and also estimates of the percentage of element costs that can contribute to the system functions. The costs are in terms of constant 1974 dollars and include the cost of ten years of operation. Those elements common to both systems are the public information and warning receivers, (warning receivers other than home receivers, data collection platforms, remote sensors) and the spotter equipment (spotter transceivers for the satellite system and all spotter systems for the terrestrial system). The other elements of the terrestrial system are the warning network, which includes the terrestrial broadcasting facilities and lines connecting them to the WSOs, and the terrestrial network, which connects the WSOs for the coordination and data collection functions. The other elements of the satellite system are the satellite itself and the ground terminals. The total terrestrial system cost is \$1005M. For the terrestrial system, each element cost can be assigned 100 percent to a system function except for the terrestrial network which is evenly split between the data collection and coordination functions. The functional percentages of the total costs are also shown. The disaster warning function attributes the highest percentage (37 percent) followed by the spotter reports and data collection. The coordination function percentage is small, and the home receiver cost is not included. The estimated unit factory cost for the two-channel receiver is \$17.60 for quantities of one million. Corresponding retail prices range from \$50.00 to \$55.00.

FUNCTION / ELEMENT	DISASTER WARNING (%)	SPOTTER REPORTS (%)	DATA COLLECTION (%)	COOR-DINATION (%)	TOTAL ($ M)
WARNING NETWORK	100	0	0	0	375
TERRESTRIAL NETWORK	0	0	50	50	144
PUBLIC INFORMATION & WARNING EQUIP.*	100	0	0	0	3
DATA COLLECTION PLATFORM	0	0	100	0	186
SPOTTER EQUIPMENT	0	100	0	0	297
TOTAL	37	30	26	7	1005

* HOME RECEIVER COST NOT INCLUDED
ESTIMATED UNIT FACTORY COST: $17.60
FOR QUANTITIES OF 1 MILLION

a. Baseline Terrestrial System

FUNCTION / ELEMENT	DISASTER WARNING (%)	SPOTTER REPORTS (%)	DATA COL-LECTION (%)	COOR-DINATION (%)	TOTAL ($ M)
SATELLITE	90	8	1	1	700
GROUND TERMINALS	95	3	1	1	73
PUBLIC INFORMATION & WARNING EQUIP.*	100	0	0	0	3
DATA COLLECTION PLATFORM	0	0	100	0	173
SPOTTER GROUND EQUIPMENT	0	100	0	0	666
TOTAL	44	45	11	–	1615

* HOME RECEIVER COST NOT INCLUDED
ESTIMATED UNIT FACTORY COST: $31.20
FOR QUANTITIES OF 1 MILLION

b. Baseline Satellite System

Figure 14. Baseline Function and Element Costs

The total satellite system cost is $1615M. Since the disaster warning requirements dominate the satellite and ground terminal design, most of the element costs are attributed to the warning function. The functional percentages of the total cost illustrate the dominance of the warning and spotter reporting functions. The reason the spotter reporting costs are so high is that 100,000 transceivers must be purchased and then maintained over ten years. The estimated unit factory cost for the 10-channel home receiver is $31.20 for quantities of one million. The corresponding retail prices range from $50.00 to $98.00.

A comparison of the results in Figure 14 shows that the primary cost differences are for the two most costly functions: disaster warning and spotter reporting. In both cases the baseline satellite system costs are about twice the baseline terrestrial system costs. Thus, from an overall cost viewpoint, the disaster warning and spotter reporting functions are of primary concern.

Figure 15 provides the funding schedules for the baseline systems. Again, the costs are presented in constant 1974 dollars. Both schedules include a ten-year operation. Since the satellite system requires a longer lead time before operation, its schedule is five years longer. The costs are broken into nonrecurring, acquisition, annual, and total, with cumulative costs given in parentheses. The satellite launch schedule maintains a minimum system reliability such that there is a useful space system life after ten years. This useful life, valued at $145M, is subtracted from the total system cost. The much larger nonrecurring and initial acquisition costs of the baseline satellite system are quite apparent from Figure 15. In the later years of the schedule, the yearly total costs are nearly the same for both systems. Also, most of the yearly costs for the terrestrial system are annual costs, whereas, for the satellite system, the yearly costs are more nearly equally divided between annual and acquisition costs.

Some of the major cost drivers for the terrestrial system are the extensive coverage, complete connectivity, and fast response time. The extensive coverage, particularly for the warning function, requires a large number of transmitters, terrestrial lines to the transmitters, and consequent facility maintainance. In Figure 15(a) the annual costs are a significant percentage of the total costs, particularly in the later years. The degree of connectivity is directly related to the mileage of terrestrial lines required; these incur an annual cost. Fast response time dictates dedicated lines with little or no sharing which again means additional terrestrial line mileage and increased annual costs.

Some of the major cost drivers for the satellite system are the number of simultaneous transmissions, use of small ground terminals, and use of real-time voice communications. The satellite costs increase rapidly as the number of simultaneous high powered warning transmissions increase. Related to these increasing costs is the need for high-powered satellite transmitters to compensate for the use of small ground terminals and for signal attenuation by buildings. Real-time voice communications requirements restrict the multiple access and modulation techniques that can be considered. FM

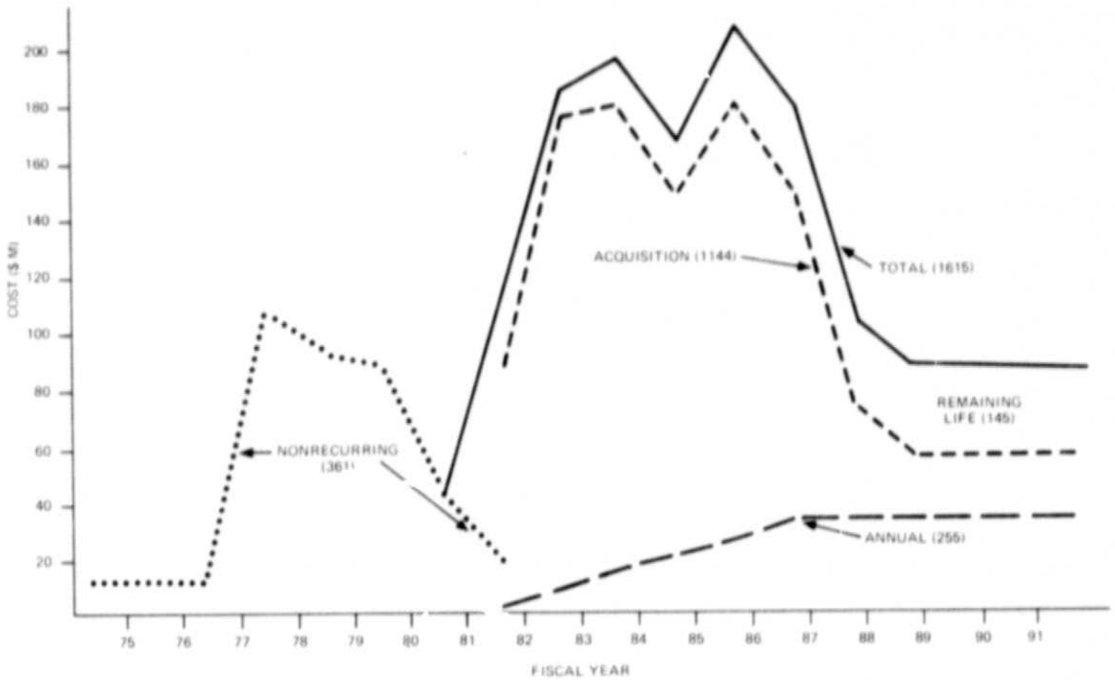


Figure 15a. Baseline Satellite Funding Schedule (74$)

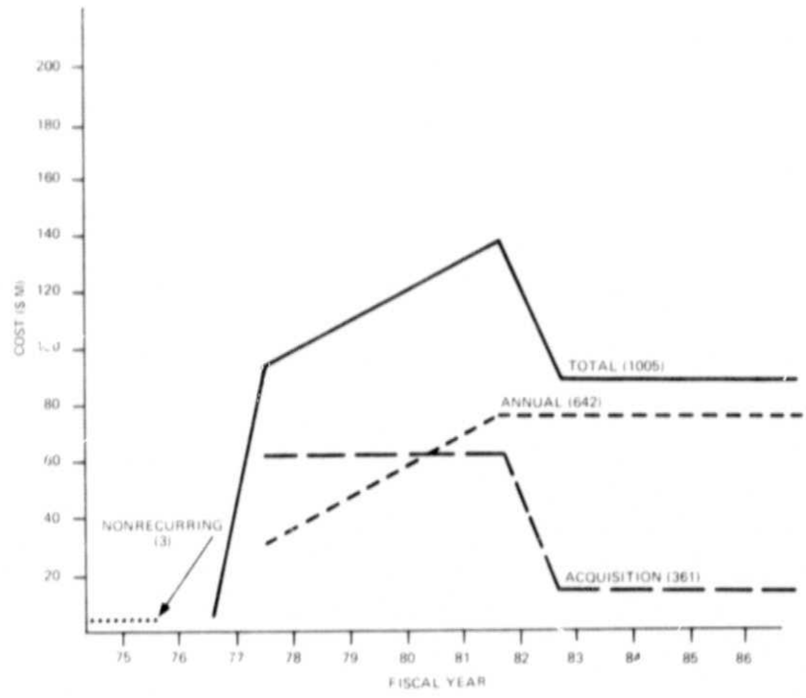


Figure 15b. Baseline Terrestrial Funding Schedule (74$)

with frequency division multiple access is essentially required. However, these techniques are inefficient for such a system which consists of a large number of low-duty cycle users.

SECTION 6 – WARNING TRAFFIC*

6.1 WARNING TRAFFIC MODEL

Most of the standard queueing models are based upon an exponential service time which is not applicable for the warning traffic data (see Paragraph 6.2). A survey of available queueing models showed that one developed by Lajos Takacs was more generally applicable to the disaster warning traffic. The constraints on this model are: a Poisson distribution of message arrival, prior knowledge of average service time, and an infinite number of servers (channels). The model was extended to an arbitrary number of channels by assuming there is no storage time. Rather than forming a queue, a percentage (nearly 100 percent) of the messages that cannot be serviced return for service. From this new model, a Markovian process was developed which was proven to be ergodic and the stationary probability distribution of the traffic loading was determined and verified by extensive digital simulation. This model was used on the warning traffic data to obtain the waiting time statistics that are presented in the following paragraphs.

6.2 WARNING TRAFFIC PARAMETERS AND WAITING TIMES

The results presented here are based upon data which NWS provided, including 6 years of monthly warnings, all warnings sent during Agnes, several thousand teletype messages (December 1973), and the warnings issued during the tornado disasters of 3 April 1974.

Based upon this data, the warning message arrival distribution was demonstrated to be Poisson in all cases, thus validating the applicability of the model. The service (broadcast) times for hurricane messages were found to have a log-normal distribution while all other types of warning messages have uniform distributions. The longest average service time, which is used in the presented results (during December), was 1.18 minutes.

Even though the results of a regression analysis showed a linear growth in the number of warning messages, the growth pattern is expected to subside as the number of spotters ceases to grow. Nevertheless, to obtain a conservative estimate for 1985, the upper 95-percent confidence bound on this linear extrapolation of December (worst-case month) traffic is used to obtain a rate of 21,000 messages per month. Furthermore, an additional 2000 messages a month, representative of a hurricane of the magnitude of Agnes,

---

*G. F. Hein of NASA Lewis Research Center developed the traffic model and provided the results presented in this section.

are added to the December 1985 estimate so that the upper bound arrival rate is 23,000 messages per month. To illustrate the sensitivity of the arrival rate, results are also presented for a rate of 15,000 messages per month.

The frequency of delays and channel utilization are shown below for different numbers of channels. The two values given are for two arrival rates in messages per month, 23,000/15,000. Reduced numbers of channels will cause delays in the issuance of disaster warnings. The probable effects caused by these delays must be considered with respect to the costs of providing these channels which is shown in Section 7. Some initial investigations have been done on more efficient utilization of the available channels. Two potentially useful techniques are a condensation of message length to minimize message duration, and an assignment of priorities according to message type and required response time.

Number of Channels	Frequency of Delays		Channel Utilization (%)
	0.5-1 minute	1 min.	
4	1 week/2 months	1 month/8 months	15.6/10
6	4.4 years/Never	41 years/Never	10.4/6.7
10	Never/Never	Never/Never	6.3/4

SECTION 7 – ALTERNATIVE SYSTEMS

This section presents alternative systems which satisfy the DWS requirements, and other systems for reduced DWS requirements. These alternative systems are presented primarily in terms of their costs so that the cost sensitivities to the major cost driver requirements are shown. The satellite system alternatives are presented first, followed by the terrestrial system. Finally, a hybrid system which uses both satellite and terrestrial elements is presented.

7.1 SATELLITE ALTERNATIVES

Figure 16 presents satellite costs through protoflight and per flight unit as a function of the number of simultaneous warning transmissions for two satellites. As the number of simultaneous transmissions decrease from 10 for the baseline system, the costs decrease from \$348M to \$291M and \$161M for six and four simultaneous transmissions, respectively. The rapid decrease in cost between four and six simultaneous transmissions is caused by reduced research and development and launch costs since satellites providing four transmissions are closer to the present state-of-the-art.

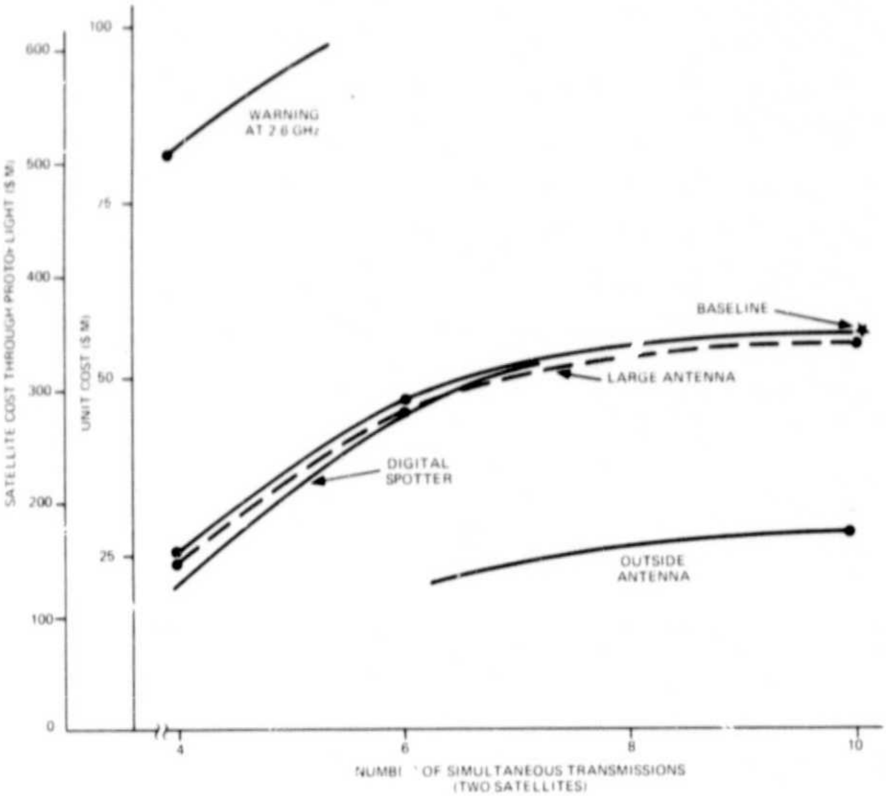


Figure 16. Satellite Cost Sensitivity

The costs for satellites using the larger antenna (16.8-meter diameter) are only slightly less than those of the baseline system. The significant decreases in transponder transmitter power and solar array size are nearly offset by the increased antenna structure and channelization required for 12 beams. However, there is a redirected emphasis in research and development from high powered transmitters and power sources to larger antennas. Also, with the larger antenna, solid state power amplifiers with their relatively greater reliability and smaller weight can probably be used rather than tubes.

As the number of simultaneous transmissions decrease to four, the spotter reporting function becomes a larger contributing factor to the overall satellite. To reduce its impact on the satellite, a spotter reporting technique utilizing digital rather than voice techniques was developed and the resulting costs are shown in Figure 16. The percentage of satellite cost reduction is small and becomes insignificant as the number of simultaneous transmissions increase; however, there are potentially large cost savings in the terrestrial portion of the spotter network.

As previously stated, one of the first major decision points in the satellite system synthesis was the frequency choice for the warning transmissions to the general public. To determine the cost sensitivity of that choice, a satellite system broadcasting at 2.6 GHz was considered. If the home receiver's antenna beamwidth is maintained at 70 degrees, the difference between broadcasting at 2.6 GHz and 790 MHz is basically a difference in free space loss, which is slightly more than 10 dB. Since the required coverage determines the satellite antenna gain, the antenna for the higher frequency is smaller. There is some evidence that building attenuation is higher at 2.6 GHz than at 790 MHz; however, the same building attenuation is used for this comparison. As shown in Figure 16, the satellite cost increases drastically for broadcasting at 2.6 GHz; hence there are sound economical reasons for using the lower frequency band.

One of the DWS requirements which significantly affects satellite cost is the requirement to have the home receiver's antenna inside. From available data, 15 dB was allowed for building attenuation and link margin in the baseline system. To illustrate the cost sensitivity, 10 dB was deleted from the baseline system to account for an outside antenna. This results in a significant decrease in satellite cost as shown in Figure 16.

7.2 TERRESTRIAL ALTERNATIVES

One of the major cost drivers for the terrestrial system is the coverage requirement for terrestrial broadcasting of warnings to the general public. Figure 17 gives an estimate of the population coverage as a function of the number of transmitters. A precise curve can be derived only after a detailed topography survey and estimates of expected population densities in the mid 1980s are obtained.

Also shown in Figure 17 are the total costs for the terrestrial warning functions as a function of the number of transmitters and for the continuous manning of 1.0, 0.4, and 0.2 men per transmitter facility. Included in these costs are the acquisition of the transmitting facilities and the annual costs over ten years of operation, which includes the leasing of dual terrestrial lines, connecting terminations between the WSOs and the transmitting facilities, and facility maintenance. The baseline system of 750 transmitters (an average of 2.5 per WSO) and a manning of 0.4 (1 man per WSO) costs $376M. Reduction to a 90-percent population coverage reduces the cost to $150M. The cost dependency upon the manning is readily apparent from the results shown in Figure 17. It is apparent that a detailed analysis is necessary to minimize the total warning costs by investigating the relationships among transmitter reliability, acquisition costs, and required maintenance.

7.3 HYBRID ALTERNATIVE

A combined system, illustrated in Figure 18, was considered, which minimizes the satellite cost by using terrestrial warning. The warning messages from the satellite at 1.7 GHz are received by a small receive-only terminal (1.5-meter diameter antenna)

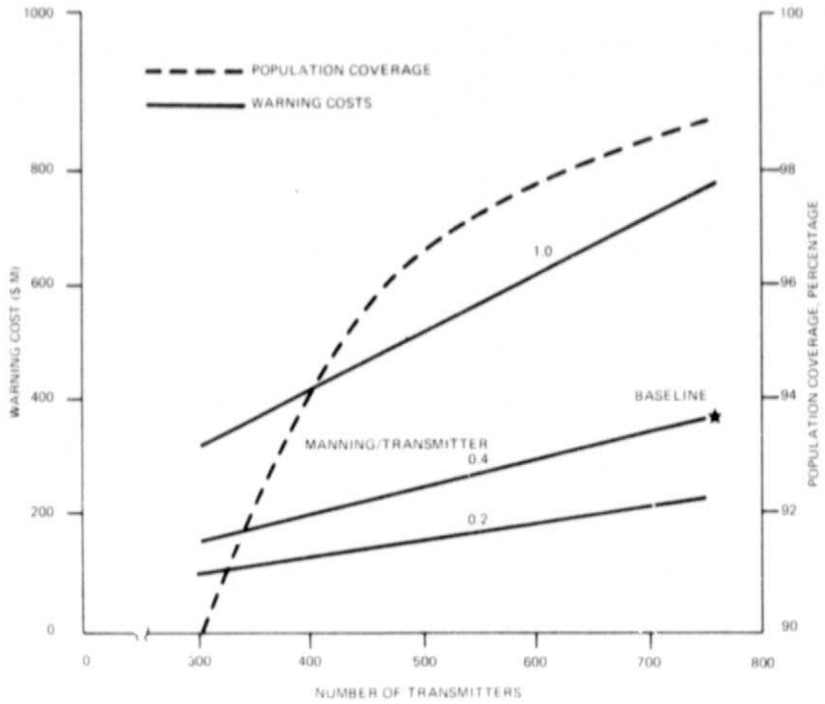


Figure 17. Terrestrial Coverage Cost

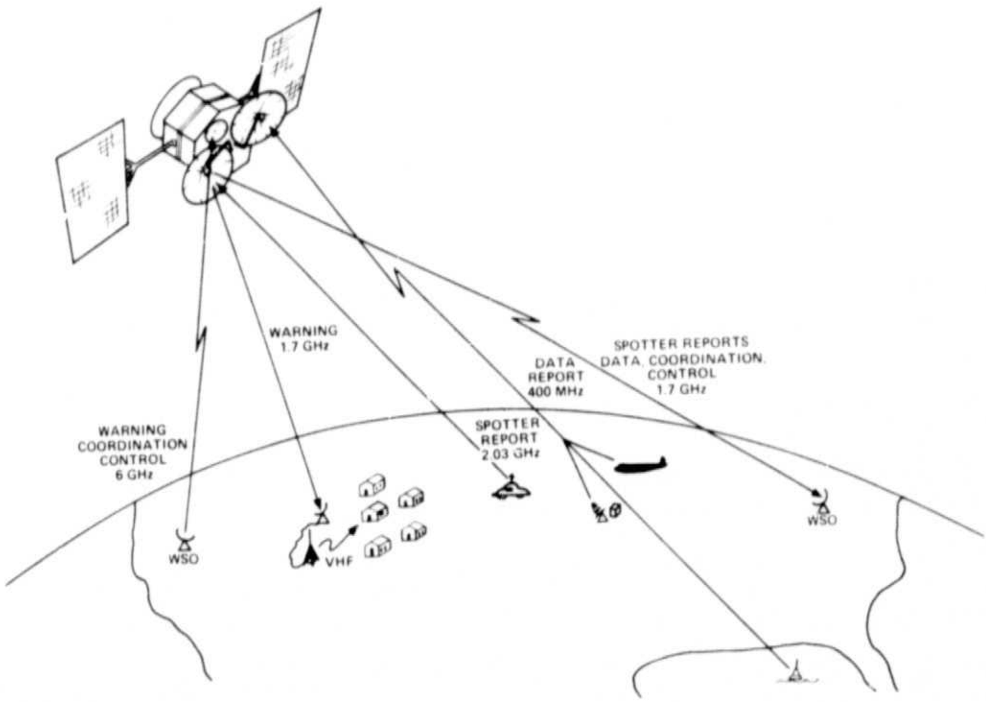


Figure 18. Hybrid System Concept

located at each terrestrial transmitter. Additionally, since the satellite transmitter power is small, the multiple beam coverage can be used for reception of the spotter reports which reduces the spotter transceiver costs. The other fundamental requirements are implemented as they are in the baseline satellite system. The hybrid system was developed by a variation of the baseline satellite system and has not been optimized to minimize total system cost.

With the warning messages being received by relatively high gain antennas (compared to the home receiver antennas in the baseline satellite system), and with no building attenuation, the required satellite transmitter power per channel is less than 1 watt; consequently, numerous simultaneous transmissions can be achieved. The hybrid satellite was configured to simultaneously transmit 15 warnings into both the eastern and western CONUS beams and an additional ten transmissions into each of the Caribbean, Hawaii, and Alaska beams.

For the hybrid system as configured, the satellite weight and costs are the smallest of any other satellite alternatives at 750 kilograms and $95M. However, the savings in the satellite portion are more than offset by the increased terrestrial costs with the estimated total system cost being $1440M. A significant reduction of the total system cost may well be achievable by optimizing the total system rather than by primarily reducing satellite costs.

SECTION 8 – SUMMARY AND RESULTS

The baseline systems and their alternatives are summarized below with the total system costs, including ten years of operation. As previously shown, the baseline

SYSTEM	SYSTEM COST ($B)
Satellite	
Baseline	1.62
Reduced Warning Channels	1.32
Large Antenna	1.30
Digital Spotter Link	1.02
Terrestrial Spotter	0.87
Terrestrial	
Baseline	1.00
Reduced Coverage	0.84
Hybrid	1.44

satellite system cost is \$1.62B. For a reduced number of simultaneous transmissions, (four instead of ten for two satellites), the total system cost is reduced to \$1.32B. Since the number of possible frequencies to the home receiver is reduced to four, the unit factory cost is reduced from \$32 to approximately \$22 assuming a linear relationship for the cost as a function of the number of channels. The remaining satellite system alternatives are for successive variations to the satellite. By using a larger antenna (16.8-meter diameter) for the warning transmissions, the system cost is reduced to \$1.30B. Next, a digital spotter reporting technique is considered with estimated cost reductions for the spotter transceiver so that the system cost is reduced to \$1.02B. Finally, the spotter reporting function is removed from the satellite and the baseline terrestrial spotter reporting technique is used; the total system cost is then \$0.87B.

Only a reduced coverage alternative is shown for the terrestrial system. For a coverage reduction to 95 percent, the system cost reduces from the baseline cost of \$1.00B to \$0.84B. As previously stated, the hybrid system cost is \$1.44B.

Figure 19 shows some of the basic satellite parameters for the different satellite alternatives. The number of warning channels (simultaneous transmissions) is for two satellites and the other parameters are for a single satellite. The research and development costs given are through protoflight including launch. The reduction of the number of channels (simultaneous transmissions) signficantly reduces the satellite prime power requirements and weight which correspondingly decreases the cost. The large antenna significantly decreases the prime power requirements but only slightly reduces the weight. Use of digital spotter reporting significantly reduces both the weight and prime power requirements. Little additional reduction occurs when removing the digital spotter capability. The hybrid satellite is significantly different from the other satellites and is well within the present state-of-the-art.

ALTERNATIVE	NUMBER OF WARNING CHANNELS (two satellites)	POWER PER CHANNEL (W)	SOLAR ARRAY POWER (kW)	SATELLITE WEIGHT (kg)	COST (\$ M)	
					R&D	UNIT
Baseline	10	427	15.5	3650	348	58
Reduced Warning Channels	4	427	6.6	1710	161	36
Large Antenna	4	89	4.2	1540	152	34
Digital Spotter Link	4	89	2.3	1150	129	29
Terrestrial Spotter	4	89	2.2	1140	128	28
Hybrid	120	0.4	2.4	750	95	22

Figure 19. Satellite Characteristics

The comparative performance of the terrestrial and satellite systems is summarized according to the four functional requirements: disaster warnings, spotter reports, data collection, and coordination. Disaster warning with the satellite system provides broad coverage but is capacity-limited with substantial cost savings resulting as the number of required simultaneous transmissions are reduced. The terrestrial system can provide an overall high capacity since it consists of a large number of independent transmitters each capable of sending two simultaneous messages. However, the terrestrial system is coverage-limited with coverage from 90 to 99 percent of the population requiring more than twice as many transmitters. The satellite system essentially provides broad ocean overage whereas the terrestrial system cannot.

The spotter reporting costs for both systems are strongly driven by the large (100,000) number of spotters. The satellite system requires a more sophisticated transceiver and the resulting costs are higher. The satellite system is thus impacted more adversely than the terrestrial system with a large number of spotters. Some cost reductions are possible by using digital rather than voice techniques.

The last two functions are a small percentage of the total system cost. The data collection function is ideally suited to a satellite system. The terrestrial system is slightly more expensive and has a slower response time since a rather extensive terrestrial network is required to connect the WSOs to the points where the data is collected. Much of this data would be collected using a satellite system such as the present GOES. No costs are charged against the terrestrial system for such a satellite data collection capability.

The coordination function can be relatively easily implemented by a satellite as long as the capacity does not greatly exceed the required 10 duplex channels. The costs to provide the coordination function with a terrestrial system are approximately an order of magnitude greater than that required with a satellite system. However, the terrestrial cost for the coordination function are small compared to the total system costs. The terrestrial system has a greater capacity capability but is somewhat coverage-limited.

REFERENCES

1. Disaster Preparedness, Executive Office of the President, Office of Emergency Preparedness, January 1972.

2. A Federal Plan for Natural Disaster Warning and Preparedness, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, June 1973.