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DISASTER WARNING SYSTEM STUDY SUMMARY

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16. Abstract

The National Aeronautics and Space Administration (NASA) at the request of the National Oceanic and Atmospheric Administration (NOAA) has for the past several years been studying and defining communication satellite systems. The most recent study addressed a system that included NOAA internal communication requirements. A conceptual satellite system to replace or complement NOAA's data collection, internal communications, and public information dissemination systems for the mid-1980's was defined. Upon conceptual defination, the study was extended to determine program cost and cost sensitivity to variations in communications functions. The results of the program cost and cost sensitivity analysis are presented in this report.

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Background

In September, 1969 the Deputy Administrator of the Environmental Science Service Administration requested in writing that NASA consider the possibilities inherent in a direct broadcast satellite system for dissemination of warnings directly to the general public. The Deputy Administrator provided preliminary system requirements and proposed that NASA initiate a feasibility study of such a system. NASA's Lewis Research Center was given responsibility for the conduct of the study which was completed in 1970. The results of this study showed that a disaster warning satellite system was feasible with some advancement in technology. In the same year, a Disaster Relief Act was passed which committed the Federal government to major responsibilities in disaster preparedness, planning and assistance. Also in 1970, E.S.S.A. became the National Oceanic and Atmospheric Administration (N.O.A.A.) which has prime responsibility for detection, prediction, and warning of natural disasters.

In 1971, a joint NOAA/NASA working group was formed to oversee the development of a detailed set of disaster warning system requirements and direct further study efforts. NOAA formally submitted a system requirements document to NASA in mid-1972. These requirements, very briefly summarized in column 1 of table I, served as the basis for a NOAA-funded, NASA/LeRC-managed system study conducted by Computer Science Corporation (CSC). The CSC study considered satellite and terrestrial warning and data collection systems and was completed in 1974. It was found that adhering rigidly to the requirements developed in 1972 resulted in excessively high costs for both systems, over $1 billion for 10 years of operation.

In the 1974-75 time frame, LeRC personnel reviewed and analyzed the warning system requirements with the objective of establishing more cost-effective system concepts. Based on an analysis of NOAA warning message traffic and the cost experience gained by NOAA in the implementation of the Weather Radio Network, system requirements were refined (table I, column 2) while maintaining the service intent and much less expensive system concepts were developed.

The costs of system concepts based on the new requirements were approximately 40% of the CSC costs. The results of this LeRC study were presented to NOAA, OMB, OTP and others during 1975. Two main points evolved from these discussions which altered the scope of the DWS effort:

1. The value of performing only the warning function via satellite was questioned in view of the cost.

2. OTP suggested that, since satellite utilization for warning only was low, LeRC consider inclusion of NOAA internal communications as a part of the system.

During 1976, LeRC defined and costed a satellite system which would (table I, column 3):

1. Provide a capability for transmitting disaster warnings to the public.

2. Meet NOAA internal communication requirements.

3. Provide a capability for facsimile and teletype service to "small" commercial users.

The above communication/hazard warning system is the subject of the following material.

COMMUNICATION/HAZARD WARNING SYSTEM

System Study Objective

The study objectives were (1) to examine a dedicated Satellite System to replace, improve, or complement NOAA's data collection, internal communications, and public information dissemination systems for the mid-1980's (tables I and II) and (2) compare a dedicated satellite system with alternative methods of providing the same services.

System Requirements

The amounts of traffic (table III) were estimated for various communications services to establish design ranges for the satellite system. The basic communications services considered are: bulk data, data/coordination, warning, facsimile and teletype.

Bulk Data: The bulk data service is defined as a high speed data relay of large blocks of data between a few "national" centers or between a "national" center and a satellite command and data acquisition station (CDA). The projected design range for the service during the late 1980's is between $3 \cdot 10^6$ and $9 \cdot 10^6$ bits per second. The design range was established via discussions with NWS and NESS personnel. The lower limit approximates the current level of service for the polar orbiting system. The upper limit allows for expansion of weather satellite data generation of both polar and geosynchronous systems.

Data/Coordination: The data/coordination service is defined as a medium speed (25×10^3 bits per sec) data relay and voice coordination service for the dispersal of satellite image products, graphiic materials and for data collection and "hot line" service internal to the NOAA organization. The projected design range for this service during the late 1980's is 60 to 120 channels. The design range is based on discussions with NOAA personnel and anticicpates increases in satellite and ground-based forecasting aids.

Warning: The warning service is defined as a direct satellite broadcast of emergency information to home receivers. This service would complement the planned (337 transmitter) NOAA weather radio network, and would cover those parts of the country where it is infeasible or impractical to install radio transmitters. The satellite capability would increase the population coverage from 91% for the Weather Radio Network alone to 99% for Weather Radio plus satellite coverage. Continuous weather information would not be broadcast through the satellite-only warnings. A single satellite channel (table IV) has been allocated for warning.

FAX, TTY: The facsimile and teletype services are specifically intended to meet the requirements of "small" commercial users. The traffic carried on these channels will be "plain language" products as used by utilities, radio and TV stations, and other external users. The projected requirements for the late 1980's are 60-80 channels for teletype and 20-40 channels for facsimile (table III).

System Concept

(Tables V, VI, VII)

The system concept (fig. 1) is based on providing all service from a single satellite equipped with batteries to provide for operation during eclipse periods. The satellite, located at 120° W longitude (fig. 2), will be visible from the contiguous 48 states, Alaska and Hawaii. A "hot spare", launched about a year after the first satellite, will be maintained to assure continuity of service. Since the warning channel utilization is low, the warning service preempts some lower priority services. Power for the warning channel will be drawn from batteries and other services as required. The satellite design incorporates engineering extensions of previously space-proven or space-qualified subsystems. No new technology is required.

The satellites will be designed for a seven-year life; it is anticipated that average replacement time will be 5 years (table V).

The ground segment (table V) consists of terminals at "national" centers, WSFO's and WSO's. With the exception of the antenna, all terminal hardware will be redundant (amplifiers, frequency converters, channelizing equipment, etc.). Peripheral equipment such as computers, and auxiliary power supplies are not considered as they are already in place in existing systems.

Frequency division methods will be employed to provide system access to the many WSFO's and WSO's. This is currently the most inexpensive means of providing multiple system access.

It was the intent during the system design to provide the FAX/TTY service to small, inexpensive, receive only user owned terminals. These small terminals would receive data directly from the satellite (much as the GOES-WEFAX system) and appear "transparent" to the user. That is, service via satellite would essentially appear no different than service via the telephone network.

System Description

Baseline System: The baseline system consists of the following elements and capabilities:

- Satellite
  - one warning channel
  - 120 data/coordination channels
  - 9 MBPS bulk data capability
  - 80 TTY channels
  - 40 FAX channels
  - control channels and pilot tones.
- Control center for system maintenance and assignment of satellite access.
- 4 "National" centers - each capable of accessing any satellite channel.
- 50 WSFO's - each capable of accessing:
  - the warning channel
  - 20 data/coordination channels
  - 10 TTY channels
  - 5 FAX channels
- 200 WSO's - each capable of access to:
  - 5 data/coordination channels
  - 2 TTY channels
  - 1 FAX channel

Note that bulk data is transmitted only between "national" centers and that warning responsibility rests with the "national" centers and WSFO's.

External to the above elements would be several thousand user-owned terminals for the reception of facsimile or teletype data.

Costing Method: Computer programs were generated to provide estimates of satellite development and fabrication costs, satellite recurring costs, and "turn-key" ground terminal costs. These costs are based on both historical and technical parameters and current state-of-the-art equipment prices.

Once basic satellite and [illegible] costs were estimated, a deployment schedule was developed to gener[illegible] estimate of the fiscal year phasing of costs.

Costs for alternative systems were estimated from current tariff schedules or from NOAA cost experience.

Element Costs: The estimated costs for each element of the satellite system in 1977 dollars is summarized below for the baseline system:

S/C Development plus protoflight	\$36.2 M
S/C Recurring	\$10.6 M
Launch	\$ 8 M
Control Center	\$ 5.2 M

\- OPERATIONS COSTS (1)

Control Center	\$740 K/year
National Centers	\$52 K/terminal/year
WSFO's	\$19 K/terminal/year
WSO's	\$14 K/terminal/year

\- External User Terminals (not included in total program cost)

FAX	\$2 K/terminal
TTY	\$1 K/terminal

Deployment Schedule (table VI): A deployment schedule was developed based on the following:

- The national centers, control center, and one-half the WSFO terminals would be installed prior to the first satellite launch.
- The remaining WSFO terminals would be installed during the first year of satellite operation.
- WSO terminals would be installed at a uniform rate over 4 years beginning in the third operational year.

Total Program Cost (table VII): Total estimated cost for the satellite system is \$159 M over a 13-year period which includes 3 years for initial satellite and ground terminal acquisition and 10 years of system operation. Once the system is "in place", after year 5, the estimated average yearly cost is \$8.3 M. The \$8.3 M includes \$4.6 M/year for operating costs and \$3.7 M/year for satellite replacement assuming a 5-year satellite replacement cycle.

Responsibility (tables VI and VII): It has been assumed that NASA will budget for the design, development and fabrication of the protoflight and spare satellites and launch the protoflight. NOAA will budget for all subsequent spacecraft, launches, and all ground systems.

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(1) Personnel costs not included.

Cost Sensitivity: Because of uncertainties in projecting required communications capacity and the extent of the terrestrial network to be implemented, a cost sensitivity analysis was also conducted. The results are summarized below for variations about the Baseline System:

Item	Impact on 10-Year Program Cost (1977 $)
Add or eliminate WSO terminals	~$200 K/terminal
Increase or decrease bulk data rate	~$400 K/$10^6$ bits per second
Increase or decrease number of data/coordination channels	~$180 K/channel
Increase or decrease number of FAX channels	~$130 K/channel
Increase or decrease number of TTY channels	~$ 40 K/channel
Provide for 100% utilization of the warning channel without interrupting lower priority services	+$ 16 M
Eliminate warning capability	-$ 3.6 M

The sensitivity study reveals that substantial changes in the number of terminals deployed and the system communications capacity are required to significantly impact the total program cost. The study also shows that satellite redesign to accommodate varying utilization of the warning channel will affect the program cost by no more than 10%.

Alternatives (Table VIII)

NOAA currently provides all services considered for the satellite system using both terrestrial facilities and commercial satellites. Therefore, it is important to compare the service costs of the alternative systems with the satellite system cost.

The costs for extensions of NOAA current communications systems to provide service equivalent to the satellite system were estimated. The yearly costs for the alternative systems are summarized below in 1977 dollars:

Service	Cost of Existing Systems	Cost of Increment Necessary to Equal Baseline Sat. Capacity	Total Yearly Cost
Warning	*	$3 M	$ 3 M
Bulk Data	$ .8 M	$1.4 M	$ 2.2 M
Data/Coordination	$1.5 M	$3.2 M	$ 4.7 M
FAX/TTY	$2.7 M	$ .6 M	$ 3.3 M
Totals	$5.0 M	$8.2 M	$13.2 M

*The planned (337 transmitter) NOAA weather radio network is common to both the satellite system and the extended terrestrial system.

The total yearly cost (as shown on page 6) would continue indefinitely as long as the service was desired.

CONCLUSIONS

At NOAA's request, NASA-LeRC has investigated alternative means of meeting projected NOAA communications requirements in the mid-to-late 1980 time period. It has been shown that, although initially capital intensive (table VII), the annual cost for providing projected services with an "in-place" NOAA-owned dedicated satellite system is considerably less than the cost of providing equivalent services using combined commercial terrestrial and satellite techniques; $8.3 M/year for the NOAA-owned system and $13.2 M/year for the commercial alternatives (table VIII). In the deployment schedule assumed, all the ground terminals would be "in-place" after the fifth year of system operation.

It should also be noted that, with the exception of warning, current commercial satellite systems could provide the special services needed to meet the projected requirements. For example, RCA-Americom recently demonstrated direct broadcast of wire services for Associated Press and United Press International. Determination of costs associated with such leased services was not pursued in this study. Detailed discussions with service suppliers would be required to firmly establish costs. However, based on a preliminary assessment, the cost of commercial satellite service would exceed the cost of a NOAA-owned satellite system by an amount proportional to profit margins and overall risks assumed by the suppliers.

<u>Satellite System</u>

- Initially capital intensive
- After initial capitalization - provides service at less cost than alternatives.
- Flexibility exceeds the alternatives - NOAA can increase sites served with minimum impact on the system.
- Increasing communications capability within this system does not significantly increase system cost.
- Provides consumer services at equivalent or reduced cost (i.e., consumer total terminal investment of $4 K would be paid back in 40 months at $100/month).
- System would provide services to all NOAA divisions and be centrally controlled.

- NOAA can control systems costs directly (labor, hardware, software).

Alternatives

- Funding proportional to capacity growth - system expansion is as-needed.
- System expansion is more costly than with satellite system.
- Requires no major changes in current NOAA methods of obtaining service.
- NOAA does not exercise control over system costs - tariffs are established by service supplier.

The key consideration in the selection of advanced communications systems is the projection of required services. It is the accuracy of these projections which determines how the above observations should be weighed.

TABLE I

SERVICE EVOLUTION

1972	1974	1976
9,000 PRIORITY WARNING MESSAGES PER MONTH	9,000 PRIORITY WARNING MESSAGES PER MONTH	1,000 - 2,000 PRIORITY WARNING MESSAGES PER MONTH
10 WARNING CHANNELS	3 WARNING CHANNELS	1 WARNING CHANNEL
100,000 FIELD SPOTTERS	5,000 FIELD SPOTTERS	NO FIELD SPOTTER NETWORK
COMMUNICATIONS FOR COORDINATION	COMMUNICATIONS FOR COORDINATION	COMMUNICATIONS FOR - COORDINATION - DATA TRANSMISSION - IMAGE TRANSMISSION - SMALL USER SERVICES

TABLE II

COMMUNICATION/WARNING

SYSTEMS STUDY

OBJECTIVES:

- EXAMINE A SATELLITE SYSTEM TO REPLACE, IMPROVE, OR COMPLEMENT NOAA'S DATA COLLECTION, INTERNAL COMMUNICATIONS, AND PUBLIC INFORMATION DISSEMINATION SYSTEMS FOR THE MID-1980'S.
- COMPARE A DEDICATED NOAA-OWNED SATELLITE SYSTEM WITH ALTERNATIVE METHODS OF PROVIDING THE SERVICES.

APPROACH :

- DEVELOP PROJECTED SERVICE MODEL
- DEVELOP SATELLITE SYSTEM CONCEPT
- EXAMINE ALTERNATIVE SYSTEMS
- COMPARE COSTS

TABLE III

CURRENT & PROJECTED CAPACITY REQUIREMENTS

SERVICE	DESCRIPTION	CURRENT CAPACITY	PROJECTED (1985-1990) CAPACITY
WARNING	DIRECT TO HOME BROADCAST	337 TRANSMITTER NETWORK ~91% COVERAGE	99% COVERAGE
BULK DATA	COMPUTER - COMPUTER TRANSFER	2.6 MBPS	3 - 9 MBPS
DATA/COORD.	IMAGE DATA RELAY, VOICE, AFOS	20 CHANNELS	60 - 120 CHANNELS
FAX	DIRECT FAX TO SMALL USERS	~10 CHANNELS	20 - 40 CHANNELS
TTY	DIRECT TTY TO SMALL USERS	~50 CHANNELS	60 - 80 CHANNELS

TABLE IV

PROJECTION - WARNINGS

- NOAA WEATHER RADIO

NUMBER OF TRANSMITTERS	MESSAGES/MONTH
110	1200
220	2200
330	3000

- SATELLITE DESIGN - 3000 MESSAGES/MONTH

STATISTIC FOR SINGLE CHANNEL

MESSAGES/MONTH	FREQUENCY OF DELAYS IN EXCESS OF	
	1 MIN.	5 MIN.
2000	1/WEEK	1/YEAR
3000	4/WEEK	3/YEAR
4000	1/DAY	5/YEAR

TABLE V

SATELLITE SYSTEM CONCEPT

SPACE SEGMENT :	SINGLE SATELLITE SYSTEM - 7 YEAR LIFE	
	5 YEAR LAUNCH CENTERS - AVERAGE	
	ON-ORBIT SPARE	
	LOCATION - 120^{o}W	
GROUND SEGMENT:	1 CONTROL CENTER	
	4 "NATIONAL" CENTERS	- 20' ANTENNA
	50 WSFO'S	- 15' ANTENNA
	200 WSO'S	- 15' ANTENNA
	USER OWNED TERMINALS	
	- FAX, TTY	

TABLE VI

DEPLOYMENT SCHEDULE AND RESPONSIBILITIES

DEPLOYMENT

YEAR	-3	-2	-1	0	1	2	3	4	5	6
SATELLITE DEV./FAB.	X	X	X							
LAUNCH				X	X				X	
NATIONAL CENTERS (4)			X							
CONTROL CENTER			X							
WSFO'S (50)			25	25						
WSO'S (200)						50	50	50	50	

RESPONSIBILITIES

NOAA

- SPARE LAUNCH
- SUBSEQUENT S/C AND LAUNCHES
- GROUND TERMINALS
- CONTROL CENTER AND OPERATIONS

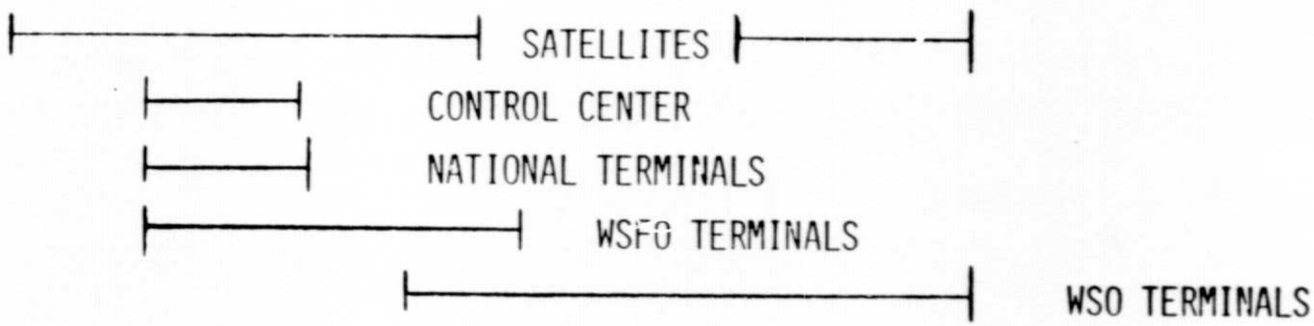
NASA

- SATELLITE R&D - PROTOFLIGHT AND SPARE
- PROTOFLIGHT LAUNCH
- FIRST YEAR OPERATIONS AND TESTS

TABLE VII

SYSTEM COSTING

(1977 $M)



YEAR	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	TOTAL
NOAA		1.7	9.3	13.0	10.2	8.8	13.2	17.7	11.2	*4.6	*4.6	*4.6	*4.6	103.5
NASA	4.3	14.8	16.8	11.2	8.5	—	—	—	—	—	—	—	—	55.6
TOTAL	4.3	16.5	26.1	24.2	18.7	8.8	13.2	17.7	11.2	*4.6	*4.6	*4.6	*4.6	159.1

* ANNUAL OPERATING COST. - $4.6 M

AVERAGE ANNUAL COST FOR SATELLITE REPLACEMENT - $3.7 M

TOTAL YEARLY "IN-PLACE" SYSTEM SERVICE COST - $8.3 M

TABLE VIII

SATELLITE AND ALTERNATIVE SYSTEMS COST COMPARISON

(YEARLY $M - 1977)

SERVICE	DEDICATED SATELLITE SYSTEM	PRESENT SYSTEMS OPERATING COSTS
CURRENT SYSTEMS		
BULK DATA	---	0.8
DATA/COORDINATION	---	1.5
FAX/TTY	---	2.7
		5.0
		COSTS TO UPGRADE PRESENT SYSTEM
WARNING		3.
BULK DATA		1.4
DATA/COORDINATION		3.2
FAX/TTY		0.6
	8.3	8.2
YEARLY TOTALS	8.3	13.2

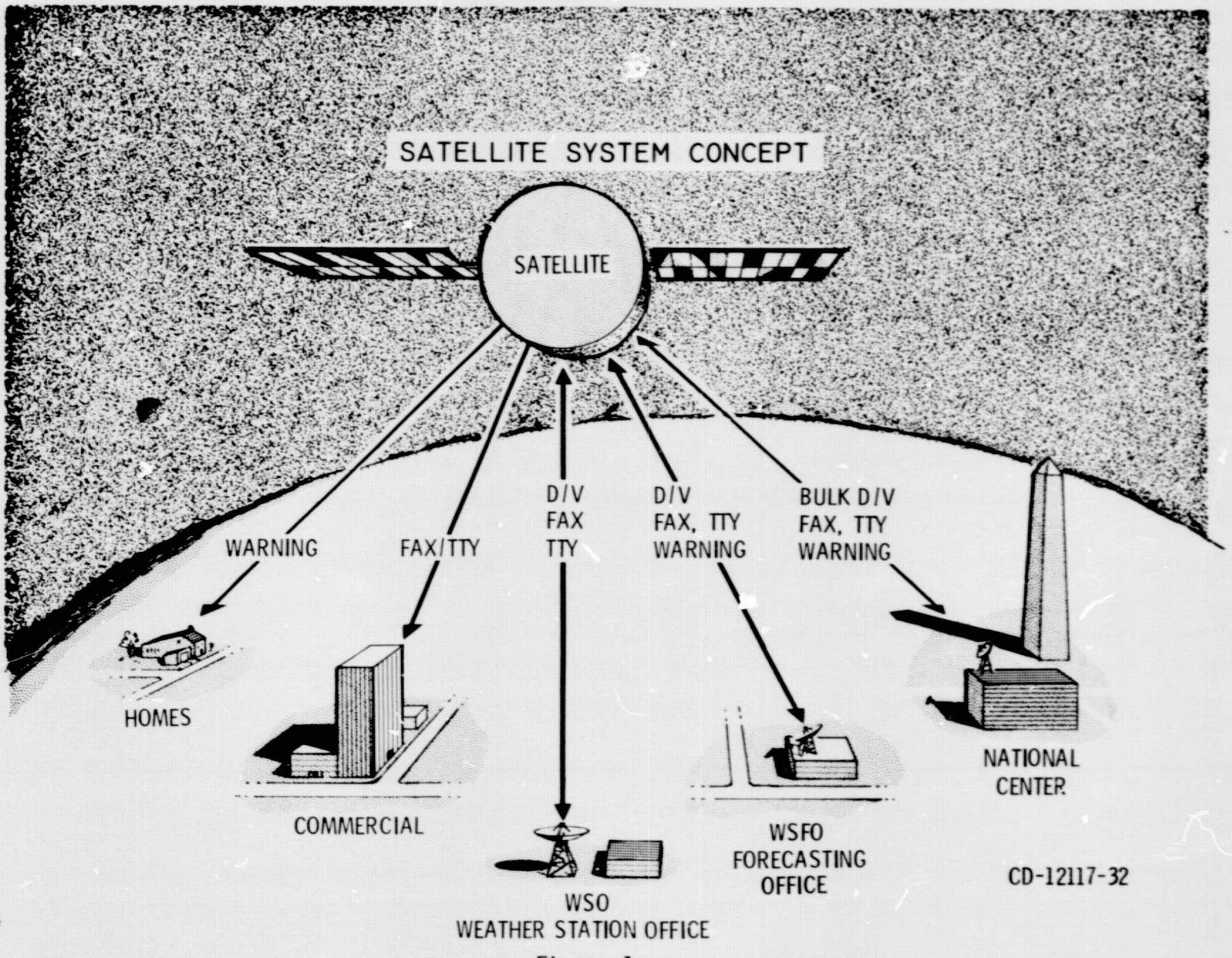


Figure 1.

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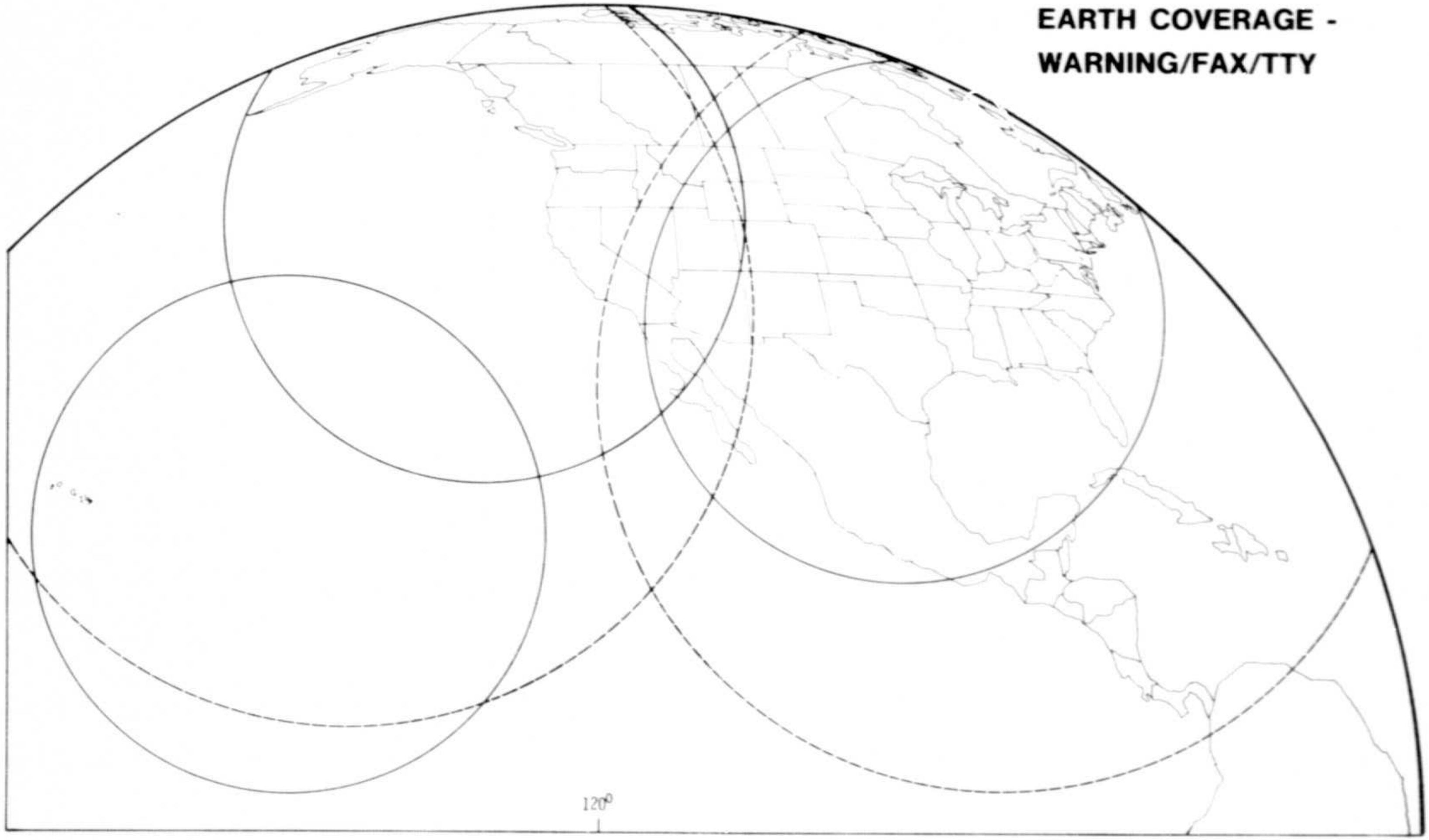
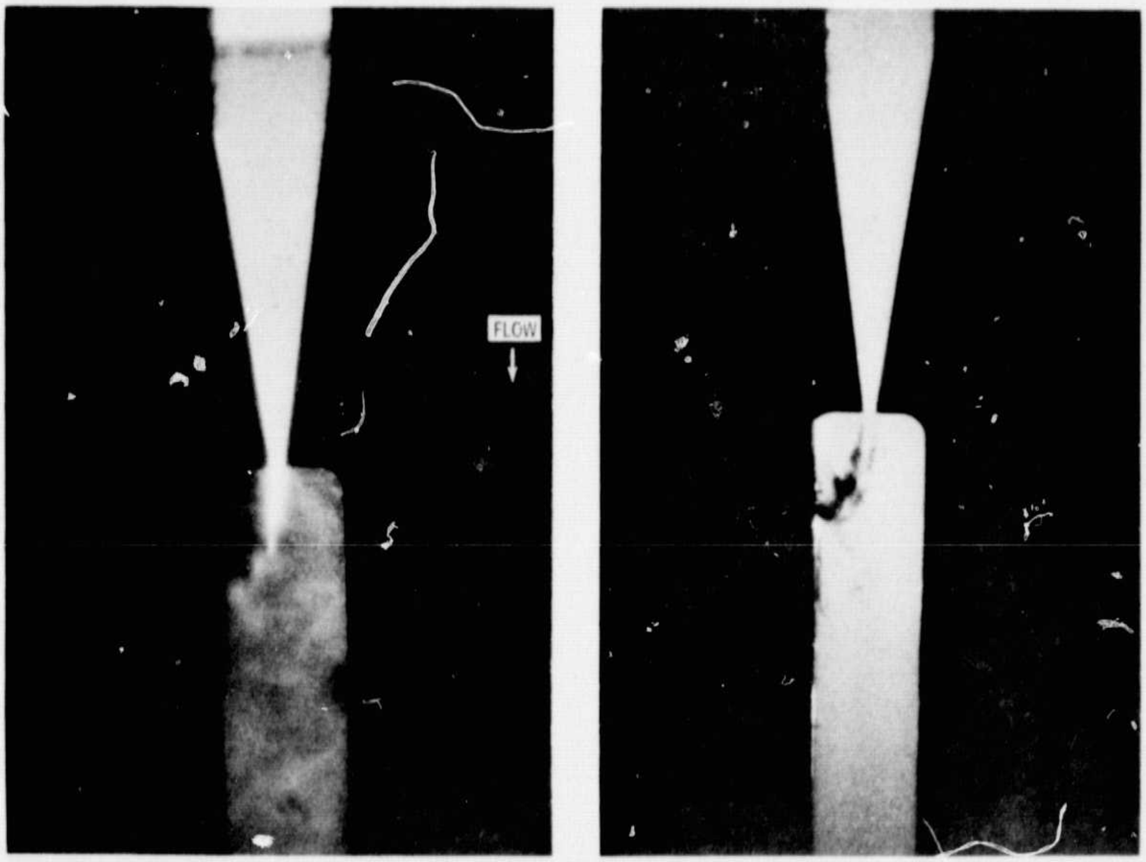


Figure 2. - Satellite location and coverage.



(a) C_{N_2} = 0.62 cc/gm.

(b) C_{N_2} = 0.02 cc/gm.

Figure 13. - Flow of water containing dissolved nitrogen through a converging nozzle.

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