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The Nation's River and Flood Forecasting and Warning Service

National Advisory Committee
on Oceans and Atmosphere

March 1983

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A Special Report to the President and the Congress

The Nation's River and Flood Forecasting and Warning Service

National Advisory Committee on Oceans and Atmosphere

March 1983
Washington, D.C.

NATIONAL ADVISORY COMMITTEE ON OCEANS AND ATMOSPHERE
3300 Whitehaven Street, N.W.
Washington, D.C. 20235

March 8, 1983

To the President and Members of Congress:

I have the honor to submit to you this special report, "The Nation's River and Flood Forecasting and Warning Service," prepared by the National Advisory Committee on Oceans and Atmosphere (NACOA).

The importance of an effective flood forecasting service cannot be overemphasized. Floods are the largest single cause of natural disasters in the United States. As you are aware, the recent floods in the southeastern United States and the floods in California and the Mississippi River Valley earlier this year caused hundreds of millions of dollars in damages. In our view, the Federal Government's present flood forecasting and warning system can be improved to alleviate some of the hardships caused by floods.

The report examines the flood services provided by the Department of Commerce through its National Oceanic and Atmospheric Administration. It contains our recommendations for enhanced public safety and reduction of losses through improvements to the services, including a recommendation for expanding critical volunteer citizen participation. The Committee hopes that our effort will assist you in providing the flood forecast and warning systems needed by our citizens.

Respectfully,

John A. Knauss

John A. Knauss
Chairman

TABLE OF CONTENTS

EXECUTIVE SUMMARY

During the single month of December 1982, flood losses along the Mississippi River Valley were estimated to reach the $1 billion mark. The States of Illinois, Missouri, Arkansas, and Louisiana bore the brunt of the floods. Flash floods and other types of floods occur at any time of the year practically everywhere in the United States. Floods in Connecticut in June 1982 caused estimated damages of over $275 million and 12 deaths.

Floods have a tremendous impact on our Nation's economy and on the safety and well-being of its citizens, causing average annual damages of nearly $2 billion and an average of 185 fatalities yearly. Flood damages have approached $4 billion twice in the past 12 years. But far more losses would occur, were it not for the river and flood forecasts and warnings provided by the Federal Government.

The National Advisory Committee on Oceans and Atmosphere (NACOA) believes improvements can be made in the Nation's river and flood forecasting and warning system that would increase the effectiveness of the service and reduce loss of life and property. The technology is available. We believe it is a worthwhile, cost-effective undertaking. According to some estimates, a 10-percent reduction in property damage is possible—this could save our economy $200 to $400 million annually.

The central core of the Nation's complex system of river and flood forecasting is the National Oceanic and Atmospheric Administration (NOAA) and its National Weather Service (NWS). NOAA is responsible for issuing river and flood forecasts and warnings to the public. The marginal cost of this program to NOAA is about $15 million per year.

The focus of this report is the NWS river and flood forecasting and warning service. We examine the changing requirements for services, especially the greater demands exerted by a growing population and urban developments in flood plains. We examine the dependence of the NWS river and flood forecasting on the weather systems and operations of NWS and on the facilities and information gathered by other Federal agencies, such as the U.S. Geological Survey, U.S. Army Corps of Engineers, and the Soil Conservation Service, in support of their respective mission needs. We see the need for an improved coordinating mechanism to ensure that this complex information network is as effective as possible under independently changing needs and resources of the agencies involved.

We believe there is a need to augment the rain guage data collection network, which consists largely of volunteer observers, by recruiting more volunteers and by installing automated rain gauges in sparsely populated areas

and in areas where data reporting rates higher than now provided are critical for flood forecasting. We estimate that the addition of automated rain gauges for the present network would cost about $15 million. Improvements also could be made in the volunteer observer reporting system by providing each observer with "Touch-Tone" telephones and thus, in a sense, "semi-automating" local reporting. These improvements would cost about $150,000 annually.

We are impressed by the local community flood warning systems that have been implemented at more than 650 communities. And, we urge the expansion of these programs that are funded by the communities which benefit from these customized local flood warnings.

Finally, we highlight a new concept we believe can improve local flood forecasting and warnings. In our examination of the history and structure of the National Flood Insurance Program (NFIP), we find no relationship between the NFIP insurance premiums and the availability, absence, or effectiveness of a flood forecasting and warning service for a specific community. It is our view that effective flood-related services, especially flood forecasting, would reduce losses, and thereby the cost of insurance. A community could use some of the accrued savings to institute the needed local flood warning system. The rest of the savings could be used to reduce flood insurance premiums. We believe, therefore, that there is merit in coupling flood insurance rates with the degree of flood forecasting and warning service and community preparedness programs.

INTRODUCTION

There were four major floods[1] in the United States in 1982. According to the National Oceanic and Atmospheric Administration (NOAA), these floods collectively claimed 150 lives and caused damage in excess of $2 billion. Fort Wayne, Indiana had its worst floods since 1913 as a result of spring snowmelt in March. New England suffered its worst flooding in 22 years, particularly in Connecticut where at least 12 people died. An unseasonal December storm struck the central Mississippi Valley causing massive flooding and nearly $1 billion in damage.

The potential average annual property damages from floods in the United States was estimated at $3.9 billion in 1975 (Water Resources Council, 1977)[2]. On the average, more than 300,000 people are evacuated from their homes or places of work annually, and about 185 lives are lost annually due to floods. One-sixth of all urban areas are in flood-prone areas; over 200,000 square miles in our Nation are subject to flooding.

Floods affect our economy. Agriculture, trucking, building, tourism, recreation, manufacturing, utilities and power generation, and other sectors of the economy are directly affected by flood conditions.

Floods have occurred over flood plains[3] for millions of years. The contest between man and flood over the use of this land has continued throughout this history. But "to be forewarned is to be forearmed"—to know *a priori* the likelihood of a flood enables man to take the measures necessary to avoid or mitigate the damages caused by the flood. The river and flood forecasts provided by the hydrologists of the present day forecasting service have antecedents dating back to the ancient Egyptians.

We recognize that land use practices and policies have had considerable impact on the exposure of our citizens to damaging floods through loss of property and loss of life. River channels were the primary means for travel and com-

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[1] In this report, a "flood" means a temporary condition of partial or complete inundation of a normally dry land area from the overflowing of the banks of rivers, tributaries, or of tidal waters, or from the unusual and rapid accumulation or runoff of surface waters from events, such as unusually heavy rain, ice-jam breakup, earthquake, or dam failure.

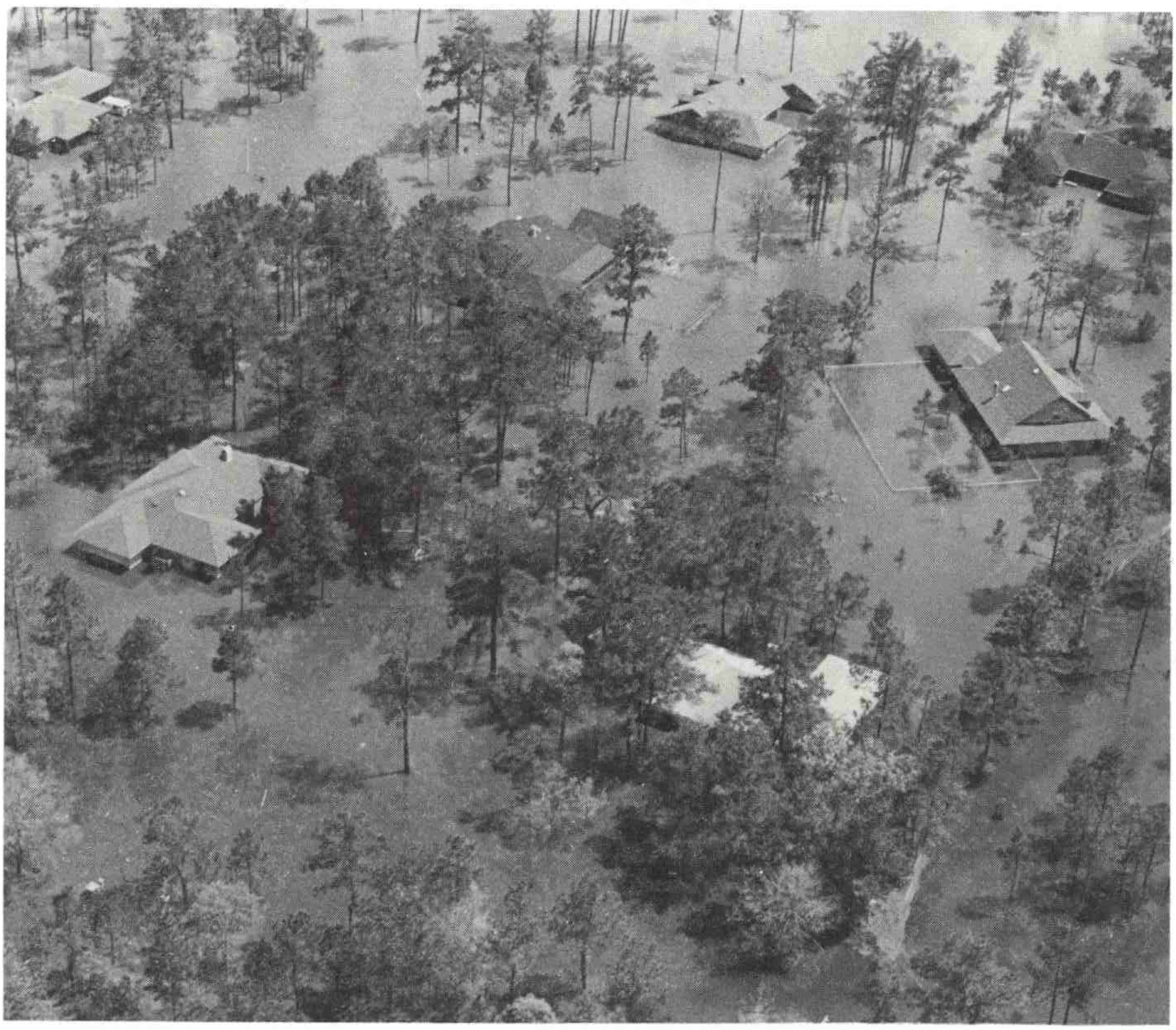
[2] The Water Resources Council (WRC) estimate made for 1975 was $2,243 million, given in 1967 dollars. This is the equivalent to about $3.9 billion 1975 dollars when adjusted by the Producer's Price Index. The losses reported by NOAA from 1972 to 1979 averaged $1.7 billion, with a high of $4.0 billion in 1979 (Bureau of the Census, 1981).

[3] An area that has or may be covered by floodwaters is a flood plain area. These are usually identified as those areas that could expect to be inundated by a 100-year frequency flood, a flood with only a 1-percent chance of being equaled or exceeded in any given year.

merce in the early days of our country. Canals, roads, and railroads followed these river channels along which cities were founded. Many of our early settlements and cities, and much of our Nation's development since then, have occurred in areas we now identify as flood prone.

This NACOA report reviews the Nation's flood forecasting and warning system which has, because of land use and development, become of considerable importance for public safety and property salvage. Specifically, we focus on the extent and adequacy of the services provided by NOAA. Through the hydrologic services program of its National Weather Service (NWS), NOAA is the Federal agency responsible for river and flood forecasting and warning services to the public.

It is important to keep in mind throughout this report that NOAA's hydrologic services are organizationally and functionally an integral part of the NWS weather forecasting system. All of the routine operations NWS requires for its weather services, such as the NWS radars, satellites, weather analyses



1983 Floods in Southern Louisiana.

CREDIT: Photo by Larry Ciko, *The Times-Picayune/The States Item.*

and forecasting, etc., are essential and are available to its hydrologic services. NWS advancements in new technologies for observations, computers, and communications affect the hydrologic services in the same manner as they affect weather services—improved service effectiveness.

A NACOA review completed in July 1982 examined the Nation's weather services. In that report, "The Future of the Nation's Weather Services," NACOA sets forth a series of findings and recommendations of direct relevance to weather services efficiency and effectiveness, which also are of direct relevance to the efficiency and effectiveness of NOAA's flood forecasting and warning services. The summary of our findings and recommendations from that report is given in Appendix A. It is our view that a modern National Weather Service able to detect, analyze, and predict weather phenomena at all time and space scales is essential for effective flood predictions and warnings.

Our earlier statement that NOAA's hydrologic services depend significantly on NWS weather service technology is not meant to imply that flood forecasting and warning services do not have technology requirements beyond those available from NWS base systems. There are several areas where new technology specifically directed to hydrologic service applications is important. Among these are efficient automated guages and stations that can relay their information through satellite platforms, interactive graphic display systems to improve the effectiveness of flood forecasts and warnings, and interface terminals to access non-NWS data and information sources.

The present national weather system is a complex mix of interdependent public and private services that has evolved over the years to provide the United States with effective weather services for the protection of the public and for its safety and welfare. This kind of mix serves the public interest well. We believe the Nation's hydrologic services are similarly a complex mix of interdependent public and private services that has served the country well. The central role in flood forecasting and warning is that of NOAA through the NWS hydrologic services program, a role fortified by the critical dependence of that service on all NWS weather service related operations.

NOAA performance also depends on important information provided by the U.S. Geological Survey (USGS), the U.S. Army Corps of Engineers (COE), the Soil Conservation Service (SCS), and others—information developed routinely as part of broad water resource responsibilities yet crucial to flood forecasts and warnings. The private communications media are the primary disseminators of the NWS river and flood forecasts and warnings. And, there are private and other industries using observational data and forecast products routinely provided to the public by NWS.

With respect to staffing and funding problems, we cite the following work of a select committee convened by the National Academy of Sciences (NAS, 1980) which analyzed the NWS budget and personnel history from 1967 to 1979:

> ... The expansion of services under severe budgetary restrictions was in part due to a strong effort to automate, to reduce the need for increasing the staff whenever possible by using computers and computer driven communications and graphics. The Committee notes, however, that the understaffing, particularly by professional meteorologists and hydrologists, cannot continue without seriously compromising the value of the weather and hydrologic information to the users.

We concur with this view in our examination of river and flood forecasting services.

Other issues addressed in this report include the coverage of the observational network, the local community flood warning systems, deficiencies in the present system, technological improvements, and the flood insurance program.

We also introduce a concept that relates the benefits of flood forecasting and warning services to certain aspects of the National Flood Insurance Program. While we recognize that this federally subsidized flood insurance program involves a complicated set of problems concerning social, economic, and political aspects, we also believe there is considerable merit in examining the relationships between the costs of insurance and the level of flood forecasting service available to specific flood-prone communities.

Finally, having outlined the areas of the Nation's flood forecasting and warning service addressed in this report, we should note several areas we did not address. This should not be taken as indicating low priority areas, but rather, a lack of adequate time, coupled with our specific focus on NOAA's river and flood forecasting and warning services, narrowed our examination to its present scope. First, we do not address water resources management even though NOAA's hydrologic services are part of the Nation's total water resources management effort, and that overall this effort involves important work conducted by many agencies which provide critical flood-related information. Similarly, we did not review the land-use policies and programs that may have created some of the flood problems affecting the public today. Third, storm surge forecasts resulting from hurricanes are not included, since such forecasts are provided by NWS meteorologists. NWS hydrologists, however, do work closely with the analysts of such phenomena and use the products of storm surge forecasts in their estimates of river flood stages in estuarine areas. Nor did we address the forecasts for dam failures or breaks although NWS hydrologists do provide dam break flood potential analyses using computer models developed within the NWS Hydrology Research Laboratory. The warnings of floods that may result from dam breaks, however, are the responsibility of NWS.

Other areas not addressed but which we believe are essential to the future progress and effectiveness of the NWS hydrologic services are: (1) basic research performed at universities and research centers; (2) the education and training of hydrologists; and (3) the general community flood preparedness programs that are under the aegis of several agencies. NACOA clearly recognizes, however, that sound community action must work hand-in-hand with NOAA's river and flood forecasting and warning services if maximum effectiveness from the overall effort is to be achieved.

CHAPTER 1

The Importance of an Effective River and Flood Forecasting Service

Flood Damages

Even as this report was being prepared, a disastrous series of floods were occurring in the Mississippi River and its tributaries in December 1982 and into January 1983. Early newspaper accounts (December 9, 1982) had reported damage estimates of over $500 million with at least 36,000 persons forced to evacuate their homes in Illinois, Arkansas, and Missouri. Over 8 million acres of land were under water at the peak of the floods. More recent estimates indicate damages of nearly $1 billion.

According to the Federal Emergency Management Agency (FEMA), during the five years ending in September 1981, the President declared 106 major disasters areas as a result of flooding. These disasters exceeded more than $1 billion in eligible outlays for the recovery, repair, and replacement of facilities and for the assistance of individuals (Holmes, 1981). The resulting expenditures amounted to nearly 85 percent of the FEMA budget for these 5 years—making floods the most significant natural disaster.

Floods are common in the United States, as illustrated in Table 1, which lists the major severe floods that occurred only during the months of May, June,

Table 1.—Examples of Recent Floods for May-August, 1982

Date	*Place*	*Damage Estimates*	*Fatalities*
August 23	McDonald Island, California	$3.3 million	none
August 23	Clark County, Nevada	*	2
August 16-17	Southeast Tennessee, Northwest Georgia	*	5
August 12-13	Kansas City, Missouri	"Extensive"	2
August 11	Wagon Hound Canyon, Utah	$100,000	none
August 8-9	Allentown, Pennsylvania	$4 million	1
July 29	Yerington, Nevada	$1.5-2 million	none
July 15	Law Lake, Colorado	$21 million	2
June 25	Oberlin, Kansas	*	2
June 15	Mills County, Iowa	*	1
June 4-6	Connecticut	$277 million	12
June 4-5	Rhode Island	3.3 million	3
May 25	Southeast Kansas	*	2
May 14-17	North Central Oklahoma, Central Texas	*	5

* No estimate available.

SOURCE: National Weather Service, 1982, Natonal Oceanic and Atmospheric Administration.

July, and August. Damage estimates shown represent local estimates reported only a day or so following the flooding. Although estimates for several areas are not available, those shown total over $310 million in damages with 40 fatalities. The Connecticut floods in June 1982 alone account for most of the damage costs and most of the fatalities.

The magnitude of the flooding problem extends beyond even this listing. The wide-spread flooding disasters caused by single events, such as Tropical Storm Agnes in 1972 and Hurricane Camille in 1969, which amounted to billions of dollars in damages, can overshadow significantly the damage impact of even a series of major floods as shown in Table 1. At the other end of the damage scale, a series of relatively smaller flooding situations can cause significant cumulative damages and public safety problems. For example, in May 1982 the Tulsa River Forecast Center (RFC) issued over 1,000 flood forecasts in Oklahoma and Texas for more than 65 communities that experienced flood property damage of over $10 million.

Flood Damage from Tropical Storm Agnes, U.S. Route 1 at Elkridge, Maryland (Patapsco River).

CREDIT: National Guard.

Our point is that flood disasters and the resulting damages and human hardships are not occasional events nor geographically isolated. Moreover, we do not expect by decree or otherwise to eliminate floods that threaten lives and property. These will go on. We do believe, however, that effective flood forecasting combined with effective community preparedness programs can reduce property damage and can save lives.

In 1975, the Water Resources Council (WRC) identified 20,813 flood-prone communities with areal extent of at least 10 acres. Of these, 6,148 were places with populations of 2,500 or more. Figure 1 illustrates the WRC regions; Table 2 lists the number of flood-prone areas in each region.

In its 1977 report on flood damages, the WRC estimated that flood damage in 1975 amounted to about $3.9 billion (see footnote #2 on page 1.) The estimates were provided by the Soil Conservation Service for drainage (upstream) areas of less than 400 square miles and by the U.S. Army Corps of Engineers for downstream areas generally over 400 square miles. Damage areas included urban and agricultural properties as well as damage to utilities, roads, railways, homesteads, forests, grasslands, parks, refuges, etc.

The WRC report also projected damage estimates for the years 1985 and 2000 on the basis of four future alternative situations. The alternatives were (1) the status quo, that flood plain management would remain as it existed when the report was prepared; (2) some increase in regulations; (3) the maximum practical regulation; and (4) a modified program of flood plain regulations

Figure 1.—Water Resources Council Regions of the Continental United States.

SOURCE: Water Resources Council, Washington, D.C.

Table 2.—Communities with a Flood Problem

Geographic Area	Water Resources Council Region	Communities with a Flood Problem: All Places	Communities with a Flood Problem: Places of 2,500 or More Population
		—Number—	
New England	0100	1,158	498
Middle Atlantic	0200	3,194	870
South Atlantic Gulf	0300	2,156	721
Great Lakes	0400	1,294	747
Ohio	0500	2,593	658
Tennessee	0600	441	117
Upper Mississippi	0700	1,823	536
Lower Mississippi	0800	809	192
Souris-Red-Rainy	0900	188	19
Missouri	1000	1,221	228
Arkansas-White-Red	1100	734	237
Texas-Gulf	1200	1,099	309
Rio Grande	1300	412	60
Upper Colorado	1400	144	19
Lower Colorado	1500	311	52
Great Basin	1600	213	52
Columbia-North Pacific	1700	1,270	212
California	1800	1,027	487
Alaska	190	325	20
Hawaii	2000	271	34
Caribbean	2100	130	70
United States		20,813	6,138

Source: Water Resources Council, 1977, Washington, D.C.

implemented at a rate faster than the current rate but not up to maximum practical level, and structural measures installed at a slower rate than in the past. The regulations referred to are those included in the Flood Insurance Act of 1968, the Flood Disaster Protection Act of 1977, and the National Disaster Relief Act of 1974, which provide for the adoption and use of legal tools to control flood plains, including zoning, construction requirements, and some tax incentives or subsidies to encourage implementation.

The WRC chose alternative (4), the modified program, as most likely, and projected flood damages for 1985 that would amount to $4.21 billion when adjusted to 1975 dollars. This contrasted to the status quo estimate, alternative (1), of $4.60 billion in 1985, also adjusted to 1975 dollars. The primary reduction in damage was attributed to urban areas, with little change for agriculture.

Recent experience shows that the modified case projected by the WRC in 1977 might be somewhat optimistic. Flood damages in 1979 were about $4 billion.

Flood plain regulations have lagged, and implementation of structural measures has been largely dormant. On the other hand, WRC flood damage review and projections did not consider potential effects from improved flood warning and evacuation programs.

Flood Management Schemes

There are four kinds of national flood management programs. The most traditional type, which takes 10 to 25 years to implement, deals with "structural" management, including dams, dikes, levees, channels, diversions, etc. These are usually earthen or concrete structures built mainly by the U.S. Army Corps of Engineers, Bureau of Reclamation, and the Soil Conservation Service.

A second program has been emphasized in the past two decades. This consists of a variety of "non-structural" elements, such as flood plain management, local zoning, a subsidized National Flood Insurance Program, and upstream land management programs.

A third flood management program consists of a variety of Federal/State community preparedness programs for action before, during, and after flooding. These range from ad hoc actions to comprehensive operationally ready programs involving the Federal Emergency Management Agency, the National Guard, State Police, Red Cross, town engineers and public work forces, local elected officials, etc.

The fourth flood management program is NOAA's River and Flood Forecasting and Warning Service, which employs about 300 people with a budget of about $15 million per year. Essential to this program are the many contributing services and products developed by other offices or agencies for their respective mission requirements. Paramount among these are the weather and precipitation forecast operations of NWS, and the river and water resource information provided by the operations of the U.S. Army Corps of Engineers, the U.S. Geological Survey, and the Soil Conservation Service. Thus, the annual cost of $15 million noted above is the incremental additional cost required by NOAA to operate its NWS river and flood forecasting and warning service and to provide other services, such as water supply forecasts and information useful to river navigation.

These four flood management schemes have different emphases, ranging from managing the flood waters to warning the people. Their objectives are to keep floods away from people, to discourage people from building in flood plains, to promote timely community preparatory action, and to provide adequate flood warnings. The basic elements are:

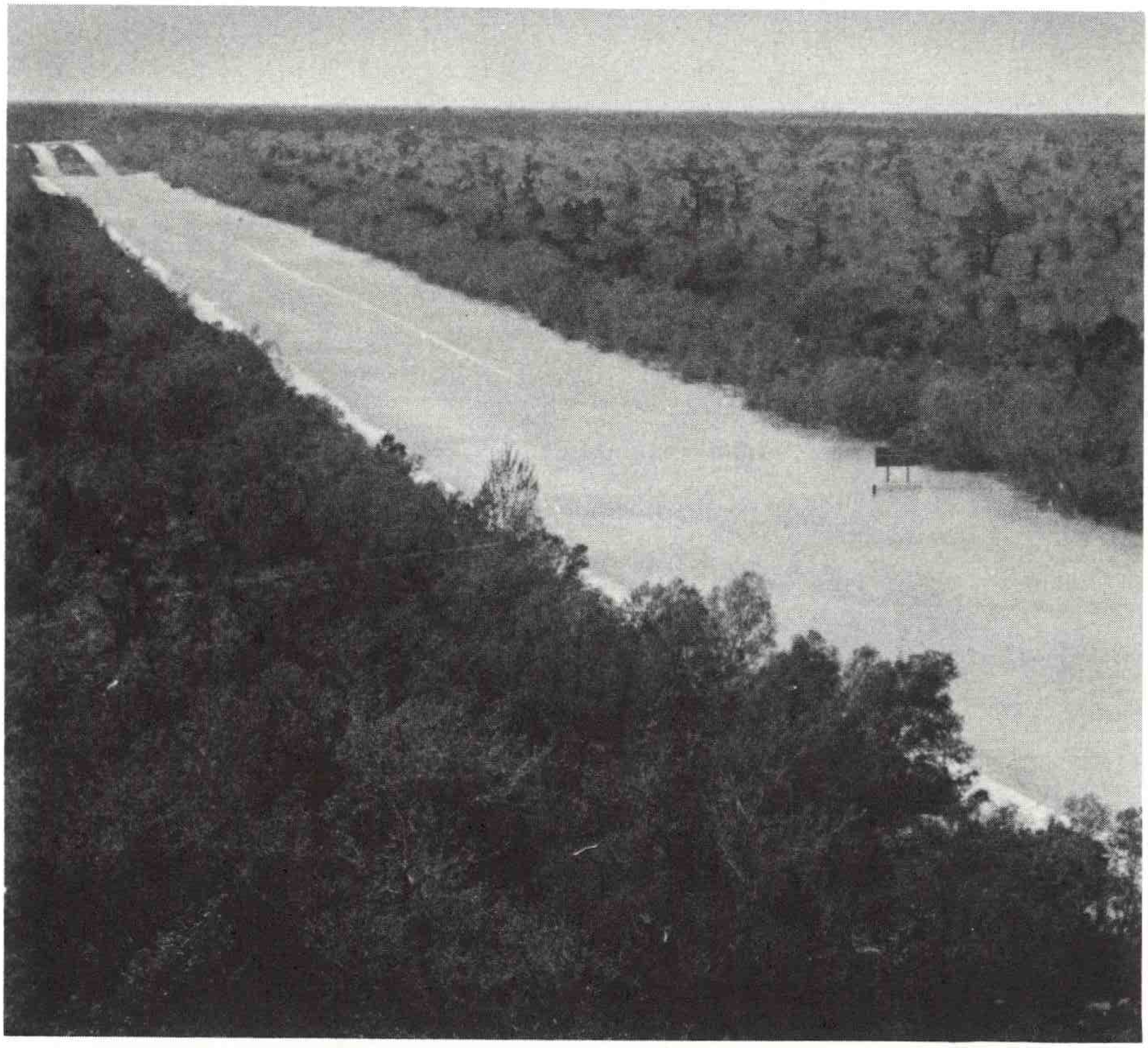
- Flood control reservoir systems to reduce peak flows;
- Levies and dikes to guide and confine the spread of the flood waters;
- Local zoning ordinances to control development in flood plains;
- A subsidized National Flood Insurance Program to provide incentives for flood plain management (this program does not include

incentives for provision of enhanced flood forecasting services nor for community preparedness programs);

- Community preparedness and action programs designed to reduce the flood's effects; and
- A national river and flood forecasting and warning service.

Ideally, all four management schemes should be coordinated and scaled to each individual flood-prone community. However, this has rarely happened, because the components of flood management each relate to other aspects of our overall national water resources policies.

The increasing interest of the Administration over the past few years on the roles of the government and private industry in the provision of a variety of services to the public also may affect how services are provided in the future. This has considerable significance on flood forecasting and hydrologic services, since the Nation's weather services performed by NWS, from which the



Interstate Highway 10, looking west, 1983 Floods in Southern Louisiana.

CREDIT: Photo by Larry Ciko, *The Times-Picayune/The States Item.*

bulk of the products and information necessary for flood forecasting are provided, are among those services under discussion for modification and possible reduction of Federal involvement.

There does not exist an effective Federal mechanism to resolve water policy issues involving national flood management and flood forecasting. The Water Resources Council, an interagency coordinating body that has some responsibilities for these, has not addressed, over the years, many of the complex issues involved, even though in 1975 it did assess flood damages and made projections of future damages. We will discuss this later when we review interagency coordination in Chapter 3.

Changing Requirements for River and Flood Forecasting

The basic structure for the present hydrologic forecasting service of NWS was initiated in 1946, only 37 years ago. The Weather Bureau was established by Congress in 1870. For the Bureau's first 70 years or so, flood forecasting functions were performed by meteorologists who rarely had adequate training in hydrology. In 1946, NWS employed 12 hydrologists and staff for 2 River Forecast Centers (RFCs) at Cincinnati, Ohio, and at Kansas City, Missouri. These NWS hydrologists provided, in addition to the general guidance information on floods and flash floods, specific flood forecasts to a few dozen locations. The NWS hydrologic system was then largely non-automated; volunteer cooperative observers telephoned rainfall and other data to the Weather Bureau offices whenever heavy rains occurred but not more than once per day in most cases. Long delays at the RFCs in receiving and making data entries manually were commonplace, especially during the floods when the data were most important. Hydrologists used simple manual forecasting techniques. Experience and judgment of the hydrologists were key ingredients of the hydrologic forecasting system of the 1940s. The science of meteorology, which provides major supporting tools and analyses critical to flood forecasting, had not attained the present level of sophistication. Even today, with greater automation, better technology, and modern sophisticated hydrologic forecast numerical models, subjective judgments of experienced hydrologists are still important.

There were some advantages to the old system. It was simple, practical, inexpensive, and perceived adequate. Hydrologists of this era provided useful forecasts without significant special training and improved their skills slowly as their knowledge of local hydrology increased and as modest improvements in technology came along. Furthermore, the system was based on relatively simple "river basin models" as contrasted to the modern highly data-dependent "hydrologic systems models" of today. And, most importantly, the various elements of the forecasting system—volunteer observers, a manual data communications and processing system, simple river basin models, state of the art methodology—seemed able to cope with slowly changing societal needs.

However, pervasive changes in the Nation's development, social structure, and economy inexorably forced the NWS hydrology forecasting services to change. From 1950 to 1980, the population of the United States increased by nearly 50 percent, and, more importantly, the percentage of the total population living in urban areas went from 64 percent in 1950 to 73.5 percent in 1980 (Bureau of the Census, 1981). Much of this development, we have heard, occurred in flood-prone areas. At the same time, public attitudes about protection of the environment became more prevalent, forcing the slowdown and, at times, cessation of construction of dams and levees and other "structural" flood management projects.

Such changes in national demographic patterns, national priorities, and the economy have caused incremental hydrologic changes during the past half century. These have overwhelmed the capabilities of the NWS flood forecasting system in many ways. First, the sheer number of flood-prone communities require NWS resources and capabilities far beyond that of the present semi-automated NWS flood warning systems. Second, urbanization and channelization have caused not only higher flood peaks but also floods that peak faster. Much too often, the flash flood arrives on the scene before the present NWS flood warning systems can react. For example, on a typical day, the volunteer weather observers are expected to telephone data into the NWS office at 7:00 a.m., but only after a significant amount (one-half inch) of rainfall has occurred. But, critical flash floods can and do occur between reporting times and between observing stations.

Cost-Benefit Aspects of Flood Forecasting

The incremental cost to NWS to provide hydrologic services was about $15 million in Fiscal Year (FY) 1982. What are the benefits?

Studies of specific flood damage statistics show that adequate flood warnings can and do save lives and reduce property losses. According to one study, an increase in the warning lead time from a few hours to 14 hours for an "18-hour flood event" (a flood on a river in which the crest of the flood at a point occurs 18 hours following a period of excessive rainfall over that portion of the river basin above that point) and an increase in the lead time for flash floods from a half-hour to 2 hours for a 6-hour flood event would save about $100 million per year in personal property, such as automobiles, appliances, and other removable belongings.

Several elements are important to any assessment of the benefits of flood forecasting (Day, 1973). These include the length of warning time, magnitude of reducible damage, efficiency of response to warning, duration of flood, weather conditions, frequency of flooding, and time of occurrence of flood peak. A mathematical model was used in Day's technical study to simulate the benefits of providing flood forecasting in the Susquehanna River Basin for urban private residences only. The study showed that a flood warning system, coupled with a community preparedness and action program, could reduce urban residential flood damage by 20 to 33 percent, assuming a 100-percent response from the community. The study also projected benefits-to-cost ratios averaging 5:1. Greater savings would have probably been realized if the cost of personal automobiles were included in the model. As noted in the study, these results could not be used solely to estimate the total benefits accruing from the river forecast service, because the study did not include benefits accruing to industrial and commercial properties, which are likely to be substantial.

A later study on the flood damage reduction potential of forecast services in the Connecticut River Basin (Day and Lee, 1976) showed a benefit-to-cost ratio of 10:1. This study did include both residential and commercial properties.

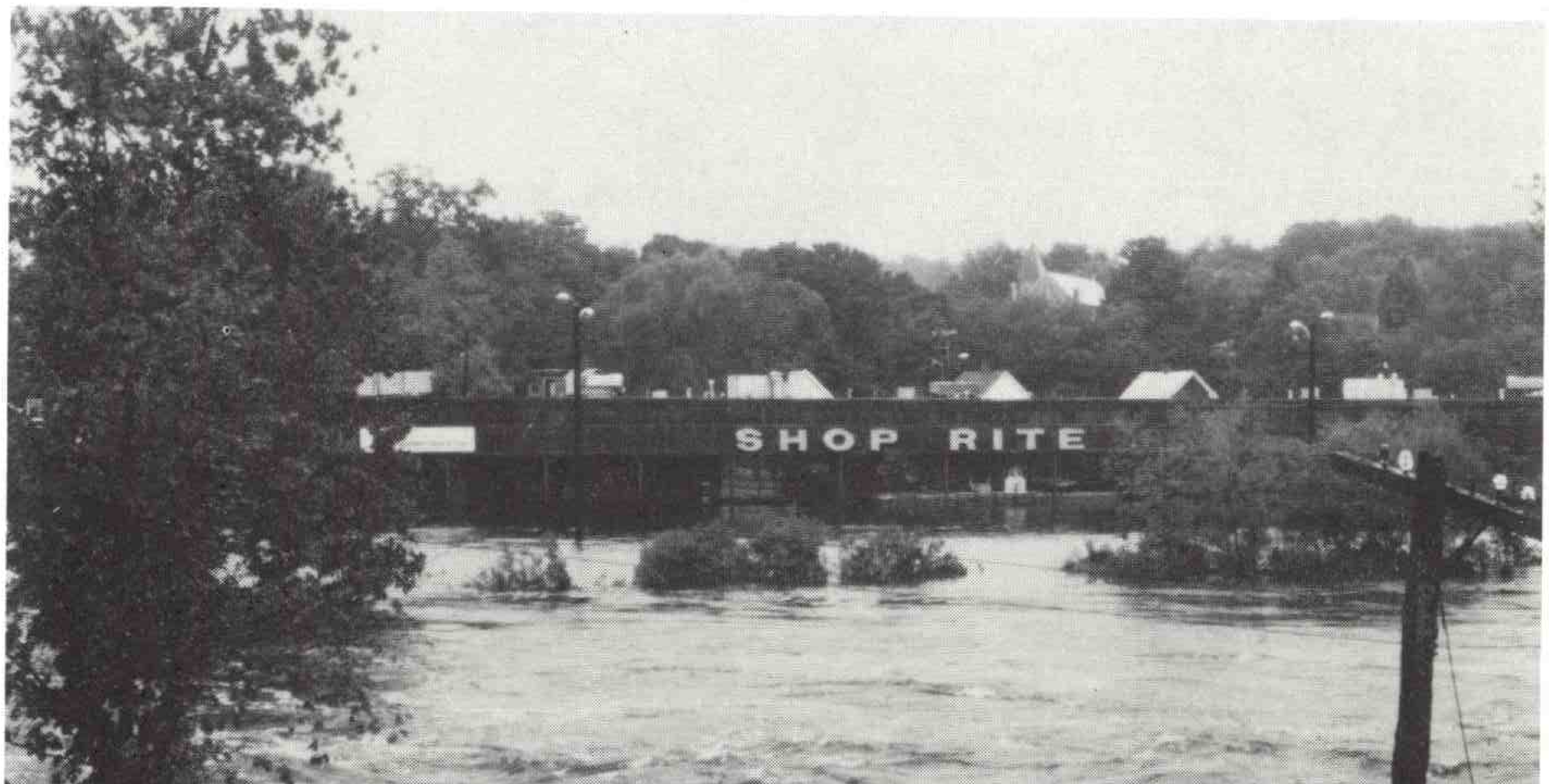
A more recent study of the benefits of flood forecasting with advanced warnings uses probabilities of benefits for several scenarios (GKY and Associates, Inc., 1981). The configurations of the rain gauge network and forecast lead times are coupled, and the analyses are made on a River Forecast Center (RFC) basis—one computation for each RFC. The results of this study are thought to be on the conservative side because, among other factors, the damages are calculated only for urban localities of more than 2,500 inhabitants.

The scenarios used in the GKY study are (1) the status quo, i.e., the systems in existence when the study was being done; (2) computer automation to the RFCs with processing time assumed to drop from 90 minutes to 15 minutes, (3) the availability of "Touch-Tone" telephones for the cooperative observers; (4) the automation of the present observational rain gauge network but with no "Touch-Tone" service for the volunteer observer system; (5) expansion of the cooperative observers network by 50 percent, all with "Touch-Tone" capability; (6) the expansion of cooperative observers network and the automated gauge network; (7) service expansion; and (8) service redeployment. The sum of these estimated benefits above costs calculated for the eight scenarios for 1985 are as follows for all urban sites with a population of over 2,500 people:

Scenario	**Benefits Above Costs**
(1)	$228.2 million
(2)	$231.7 million
(3)	$234.6 million
(4)	$249.6 million
(5)	$251.3 million
(6)	$260.6 million
(7)	$384.7 million
(8)	$298.0 million

The largest benefits are for scenario (7), which assumes a service expansion by 50 percent in sites provided with a forecast. This case stipulates that (1) all catchments over 2,000 square miles are provided flood forecast services; (2) two-thirds of the catchments between 500 square miles and 2,000 square miles are serviced; (3) headwaters of less than 500 square miles that provide the largest incremental benefits are serviced; and (4) the cooperative observer

Flooding along the Yantic River, Connecticut, June 1982.



CREDIT: State of Connecticut, Department of Environmental Protection, Natural Resources Center.

network is expanded by 50 percent. In addition to the above, automatic gauges would replace cooperative observers in many areas, to the extent that (a) there is an average of three automatic gauges for each headwater, and (b) for every automatic gauge in a headwater area there is one in a downstream area.

Several long-term averages of hydrologic service benefits and costs are shown in Table 3. The highest benefit to cost ratio given is 100:1 for the Pittsburgh River District.

Table 3.—Summary of Hydrologic Service Benefit and Cost Relationships

Estimating Source	**Benefit/Cost Ratio*
Weather Bureau flood damage estimates (1951-1965)	15:1
Congressional report (89th Congress, House Document 35)	17:1
**Pittsburgh River District (1947-1966)	100:1
Meadville, Pennsylvania (50 years of record, 22 floods)	30:1

* Ratio of estimated dollar benefits from hydrologic services to cost of providing hydrologic services.

** Compiled by Pittsburgh Weather Bureau Office for the Upper Ohio River Basin.

SOURCE: Environmental Science Services Administration. 1969. A Plan for Improving the National River and Flood Forecast and Warning Service. Office of Hydrology, Silver Spring, Maryland, p.16.

To summarize, floods affect millions of citizens who live in flood-prone places. The average annual flood damage is estimated to be nearly $2 billion dollars, with an average annual loss of life of 185 individuals. These floods occur in a random fashion throughout the year. The importance of proper and effective forecast and warning systems cannot be overemphasized.

The Federal response to flood management has been to build dams and levees, to provide incentives to manage flood plain development, to provide subsidized flood insurance and disaster relief monies, and to provide the Nation with a $15 million NWS river and flood forecasting service staffed by about 300 people of which about 165 are hydrologists. We are aware of no study which has not concluded that the benefits of a flood warning service exceed the cost of providing the flood forecast and warning services. The benefit cost ratios range from better than 2:1 to 100:1; estimates of reduction of flood damages due to flood warning services range from about 10 to 30 percent (Day, 1973). If only a 10-percent reduction in urban damages were realized, it would amount to average annual savings of about $200 million, equivalent to more than 13 times the current NWS budget for hydrologic activities.

CHAPTER 2
The Nation's Hydrologic Services

Federal Role

At least 10 Federal departments, six independent Federal agencies, two offices and a council in the Executive Office of the President, and eight Federal-State commissions are involved in water management activities (Department of Commerce, 1978; National Science Foundation, 1980). Some, such as the quasi-public Tennessee Valley Authority (TVA), carry out related activities for their own enterprises. However, the dominant portion of the national hydrologic services relevant to river and flood forecasting and warnings are provided by four principal agencies.

The U.S. Army Corps of Engineers (COE), through its Civil Works Program covers the entire range of water resource development. Its role involves the planning, design, construction, operation, and maintenance projects for flood protection, navigation, water supply, fish and wildlife enhancement, hydropower, water quality management, and recreation. The Corps' mission also includes general water and related land resources management through planning studies and regulatory functions.

The major part of the hydrologic data required by the Corps are collected by other Federal agencies through reimbursable agreements. About 5,000 stream gauging stations are funded by the Corps, and about one-half of these are operated for the Corps by the U.S. Geological Survey. The Corps and the National Weather Service operate, through cooperative agreements, 39 precipitation networks in dam and reservoir areas. Each agency requires the data obtained from these networks for its own mission needs.

The U.S. Geological Survey (USGS) appraises the quantity, quality, and movement of the Nation's ground and surface water resources. A major USGS hydrologic program is its National Water Data Network which provides for collection of data and the conduct of hydrologic studies in areas of Federal and State interests. In areas of Federal interest, e.g., river basins and aquifiers that transcend State boundaries, and other areas of interstate and international concern, the effort is federally funded. In areas of joint State and Federal interests, the program is funded jointly by USGS and by State agencies on a matching basis. USGS also collects data and performs analyses and studies on a reimbursable basis as may be requested by other Federal agencies.

The data collected by USGS in its National Water Data Network of most significance to NWS river and flood forecasting are streamflow data at about 16,000 stations. Other Network data include lake and reservoir stage, chemical water quality and water temperature, fluvial sediment, and ground water levels.

The Soil Conservation Service (SCS) of the U.S. Department of Agriculture (USDA) plans, designs, and operates small watershed protection structures and provides water supply forecasts for water users in 11 Western States including Alaska. More specifically, the major responsibilities of SCS include:

- Planning upstream flood control measures that may include additional storage for water supply and recreation.
- Planning resource management systems for erosion and water control on non-Federal agricultural lands.
- Data collection of snow and related hydrometeorological data, such as snow water equivalent, total precipitation, and temperature, which the National Weather Service uses for water supply forecasts.

The snow and related hydrometeorological data are collected at 1,600 data collection sites, 500 of which are automated. Prior to 1980, the snow was sampled once a month, January through May, at each of 1,600 sites. However, the automatic snow telemetry system (SNOTEL) provides real-time (current) information once a day.

The National Oceanic and Atmospheric Administration (NOAA), through the hydrologic services program within its National Weather Service (NWS), has the Federal responsibility to provide river and flood forecasts and warning service to the Nation. The official government river and flood forecasts and warnings to the public are issued only by this agency. The NWS hydrologic services program has about 300 employees of whom about 165 are professional hydrologists.

Other types of hydrologic forecasts provided by NOAA include streamflow forecasts used for decisions concerning navigation and for controlling of pollutants and hazardous substances, reservoir operation for hydroelectric power generation, and water supply for irrigation and energy. In addition, its hydrometerological studies are used by other agencies in the planning and designing of dams, highways, and airports, and for flood insurance programs.

Before describing the structure and operations of NOAA's hydrologic service, it is important to keep in mind the role of the other three agencies described—COE, USGS, and SCS. Even though they have no responsibilities for public dissemination of river and flood forecasts and warnings, the data they acquire from systems established for their own purposes and provide to NOAA are of major importance. Without these data, NOAA would be unable to provide an effective flood service.

NOAA's River and Flood Forecasting and Warning System

The "Organic Act" of 1890, as amended (15 USC 313), provided for the transfer of the original Weather Bureau from the Army Signal Service to the Department of Agriculture and thence to the Department of Commerce. As stated in the Act, the Weather Bureau

> . . . shall have charge of the forecasting of the weather, the issue of storm warnings, the display of weather and flood signals for the benefit of agriculture, commerce, and navigation, and the gauging and reporting of rivers . . . .

These responsibilities in river and flood forecasting are now carried out through NOAA's NWS Office of Hydrology and associated components.

NOAA provides service to more than 20,000 flood-prone localities situated in river basins of various sizes. All areas receive general weather forecasts that include the prediction of rain and the issuance of flash flood warnings on a county or zonal basis. Most areas also receive generalized river and flood forecasts for large rivers and tributaries. Site-specific flood forecasts are provided for about 3,000 of these localities.

Figure 2 illustrates the general manner in which the forecast points are distributed in a typical river basin. Following the occurrence of excessive rainfall over the basin, most rivers are capable of producing in their "headwaters" a high crest flood wave from a few minutes to 18 hours after the rainfall. About 1,000 of NOAA's forecast points are located in these "headwaters." These are illustrated by Forecast Point #1 in Figure 2. The Forecast Points labeled #2 and #3 cover regions greater than 1,000 square miles and are located at sites that crest, on the average, more than 12 hours after the rainfall.

In those headwaters areas in which the river crest times are less than 6 hours, NOAA issues flash flood warnings. Headwater flood forecasts are normally issued by the Weather Service Forecast Offices, based on guidance from the RFCs, for streams that crest in 6 to 18 hours. Main stem flood forecasts are issued for floods whose peaks are expected to occur beyond 18 hours. Figure 3 diagrams the relationships between predicted time of flood crest occurrence and various forecasts and warnings.

NOAA Organization

NWS has a central Office of Hydrology, consisting of the Hydrologic Services Division, Water Management Information Division, and the Hydrologic Research Laboratory. The Director of the Office of Hydrology has overall program responsibility for the NWS Hydrologic Service Program and carries out this responsibility through interactions with higher (and lateral) headquarters functions, field components, and through the supporting missions of the divisions and laboratory within the Office of Hydrology. The Hydrologic Services Division works with the field components on day-to-day operational matters. It is responsible for coordinating requirements for new technology and for assisting in implementation and maintenance of equipment and computer systems. The Water Management Information Division carries out hydrometeorological design studies for NOAA and various cooperating water resources agencies. The Hydrologic Research Laboratory is responsible for the research and development in support of field operations.

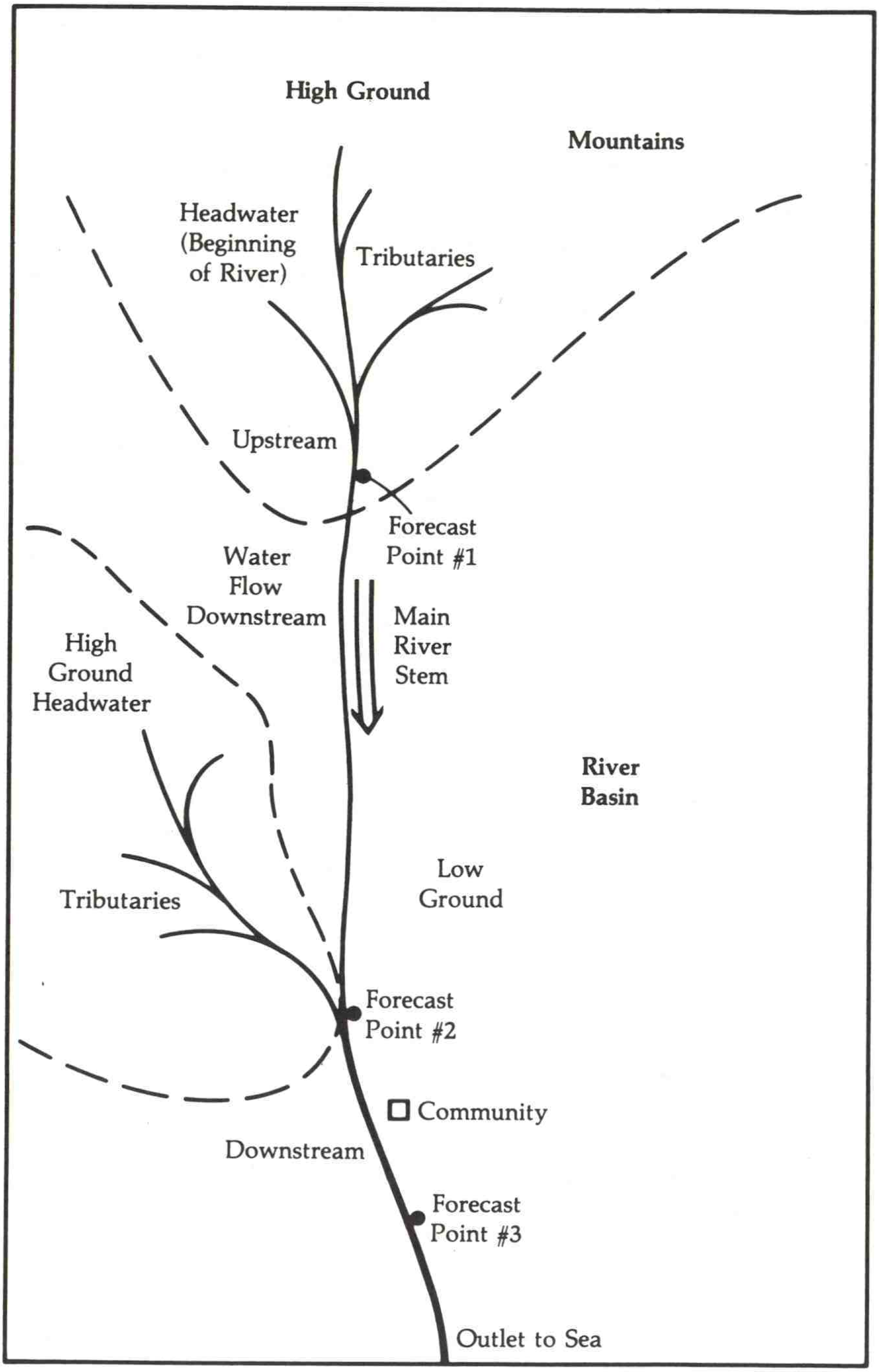


Figure 2.—Typical River Basin.

SOURCE: National Weather Service, National Oceanic and Atmospheric Administration.

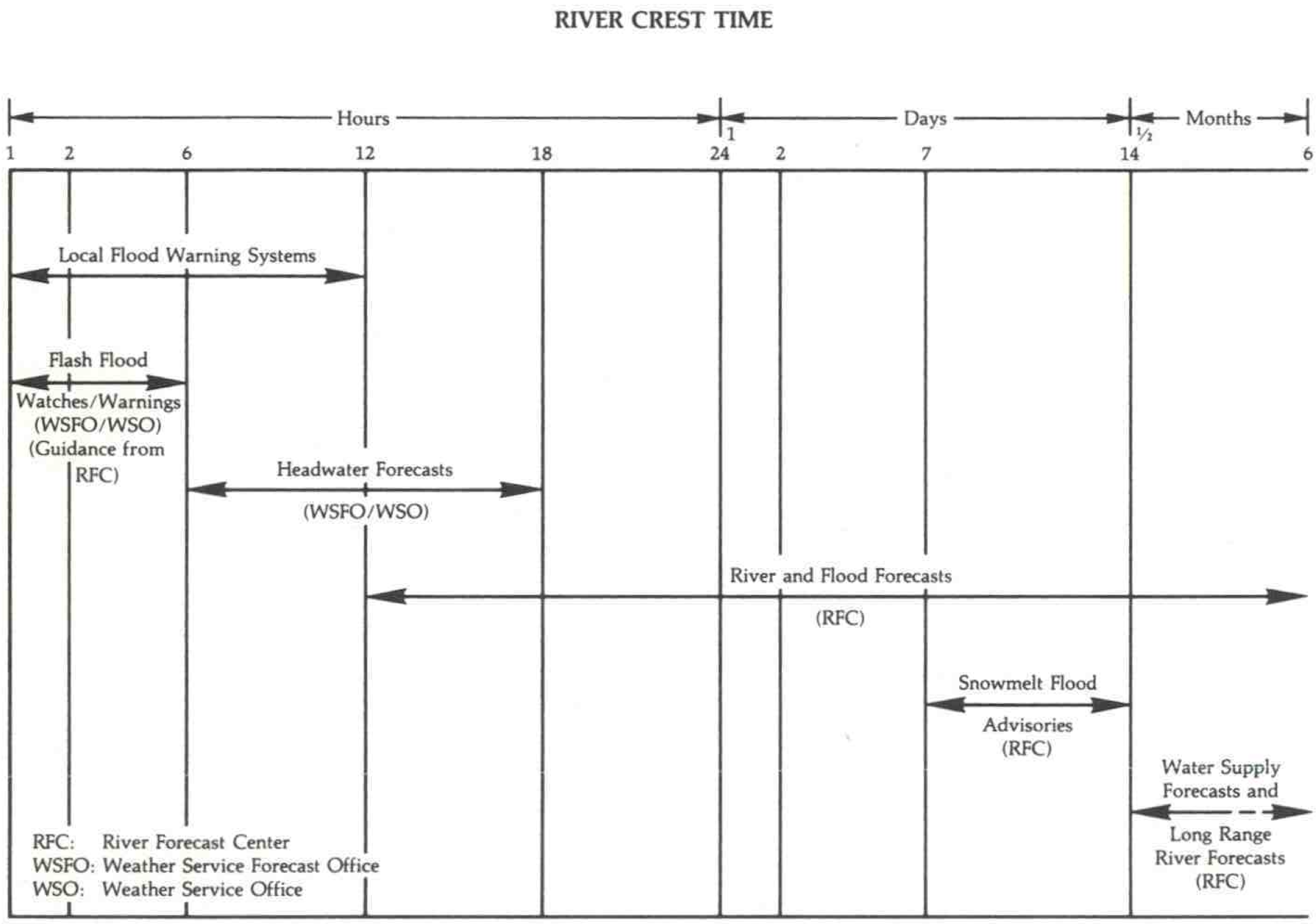


Figure 3.—Relationship of Hydrologic Services to River Crest Time.

SOURCE: National Weather Service, National Oceanic and Atmospheric Administration.

The operational hydrologic field program is performed by the NWS Regional Hydrologists, the River Forecast Centers (RFCs), the Weather Service Forecast Offices (WSFOs), and the Weather Service Offices (WSOs). (See Figure 4.) The Regional Hydrologists are responsible for the overall management of the hydrologic service program within their respective regions. The 13 River Forecast Centers are NWS field offices whose primary responsibility is the preparation of hydrologic guidance, site specific river and flood forecasts and advisories, including snowmelt water supply forecasts. The RFC area of responsibility is organized along river basin boundaries as shown in Figure 4; each RFC serves all the WSFOs and WSOs in its region, using hydrologic data provided by WSOs and WSFOs, other agencies, and in some instances, directly by volunteer observers.

RFCs are also responsible for the technical aspects of the hydrology program. They provide assistance to the WSFOs and WSOs, for example, in headwater flood forecast procedures for those river basins that respond quickly to rainfall and where warning times may be extremely short. RFCs also provide technical advice for local flood preparedness planning and water management decisions, and they develop forecast procedures for those communities that have local flood warning systems.

The WSFO operates around the clock primarily with a staff of meteorologists trained in hydrologic program functions. In most instances, a service hydrologist

Figure 4.—RFC Boundaries and WSFO/WSO Hydrologic Service Areas.

SOURCE: National Weather Service, National Oceanic and Atmospheric Administration.

is also available. Aside from the day-to-day operational hydrology functions, the service hydrologist maintains contact with local community officials, the mass media, and various disaster response agencies, e.g., the American Red Cross and the Federal Emergency Management Agency, as well as other government agencies. Most WSFOs are assigned a Hydrologic Service Area that corresponds to its weather forecast service area. The WSFO is responsible for issuing flash flood warnings, flood warnings, river and flood advisories, daily river forecasts, and other hydrologic products to the public. The WSFO is also responsible for collecting and relaying river and rainfall observations to the River Forecast Centers. It also adapts to local needs the river and flood forecasts provided by the RFC, such as river forecasts for rapidly rising headwaters, and disseminates all hydrologic forecasts, flood and flash flood warnings.

Weather Service Offices (WSOs) are smaller offices with hydrologic function responsibilities. WSOs are responsible for county flash flood warnings. They collect hydrologic data and disseminate river forecasts and flood warnings to the public. Similar to the WSFOs, WSOs also provide an advisory service informing community officials of protective measures that can minimize loss of life and destruction of property caused by floods.

Accurate and timely prediction of heavy rainfall events is extremely important for hydrologic forecasting. Forecast estimates of precipitation for the hydrology program are provided by the NWS National Meteorological Center (NMC). These are reviewed, updated, and modified if necessary by the WSFOs for the RFCs. The National Earth Satellite, Data, and Information Service (NESDIS) of NOAA also contributes to the hydrologic service by supplying NWS field offices with satellite imagery and special analyses of these. Included are estimates of rainfall through Satellite Field Service Centers.

About 9,000 non-Federal dams in the United States have been labeled by the U.S. Army Corps of Engineers as "high-hazard"—with potential for loss of human life and property in damage in the event of failure (COE, 1983). The RFCs provide analyses of the flooding that could result from the failure of dams. These analyses are of considerable value to various Federal, State, and local civil defense agencies for advance plans and preparations for quick action in the event of an actual failure.

As stated before, NWS gives flood warnings for about 3,000 specific points throughout the Nation. Communities located at or near one of these forecast points are provided with site-specific flood forecasting service because of their proximity to the forecast point. However, flood forecasts also are provided through the general warnings of river crests between forecast points to alert communities situated between these points.

Daily forecasts of river stage and discharge are routinely issued by the RFCs at many points along some rivers as an aid to navigation and water management. For many of the 3,000 flood forecast points, daily forecasts of river stage at intervals of 6 to 24 hours are made for forecast periods of 1 to 3 days. Similarly, reservoir inflow forecasts assist the Federal, State, and local agencies in the operation of these reservoirs. Forecasts of ice formation and breakup are prepared for a selected number of locations. Forecasts of seasonal snowmelt runoff are prepared on a monthly basis from January through May in the western United States, and from April through September for Alaska. Forecasts of seasonal snowmelt and runoff are prepared monthly for the northeast United States. Water supply forecasts for 600 points, where snow is the principal source of streamflow, are distributed monthly to local communities by local NWS offices. Other contributions to water management information provided by NWS include lake level forecasts and water temperature forecasts.

Present Cost of the NWS River and Flood Forecasting and Warning Service

The marginal costs to the Nation for the hydrologic services provided by the River Forecast Centers, the service hydrologists at the WSFOs, the Hydrologic Research Laboratory, the headquarters components, and the hydrologic data collection and analysis systems was about $15 million in FY 1982. As we noted earlier, it is a marginal cost, because the weather data acquisition system, e.g., radars, satellites, surface and upper air measuring instruments, and the dissemination and meteorological communications systems that support the NWS hydrologic service are established and operated primarily for NOAA's weather forecasting and warning responsibilities.

Table 4 shows the marginal costs for hydrologic services from 1972 to 1982. Although there have been increases in the budget generally associated with inflation, the budget today is nearly identical to the 1973 budget when inflation is taken into account. Yet, demand for services has been increasing steadily. In view of the increasing impacts of flooding on populated areas, service hydrologists have been added to about 40 of the 50 or so WSFOs during the past decade.

Table 4.—Budget for Hydrologic Service of the National Weather Service

Fiscal Year	*Amount (In Thousands of Dollars)*	*Amount* (In Thousands of 1982 Dollars)*
1982	15,287	15,287
1981	14,406	14,706
1980	14,467	16,353
1979	12,089	15,368
1978	11,126	15,921
1977	10,218	15,760
1976	9,264	15,161
1975	9,028	15,460
1974	8,150	15,246
1973	6,828	15,182
1972	4,916	12,362

* Adjusted to 1982 dollars using the Producer's Price Index.

SOURCE: National Weather Service, 1982, National Oceanic and Atmospheric Administration.

Also, in 1981 a new River Forecast Center in Minneapolis, Minnesota, was opened because of the inadequacy of the service for that area emanating from the Kansas City RFC. During this decade, although some technological improvements have been made (e.g., the installation of small computers at the RFCs), software development and maintenance of these computers has been limited because of the higher priority placed on increasing services within the funding resource allocation.

We do not foresee any lessening of demand for these services. On the contrary, recent floods, such as those in the Mississippi River, indicate to us increased demand, which places even greater stress on the existing hydrologic services.

Local Community Flood Warning Systems

Also contributing, and increasingly important elements of the system, are local flood warning systems. These are cooperative ventures among NWS and State and local governments. Although NWS assists the communities through development of procedures and forecasts for local operations, the systems are operated by the local communities. Thus, they have available an enhanced or "specialized" flood forecasting service beyond that which would normally be available from the NWS system.

The major self-help effort is ALERT, the Automatic Local Evaluation in Real Time system. ALERT began in California and has since been expanded to the States of Arizona, Washington, New York, and Connecticut. Presently, over 650 local flood warning systems are operating.

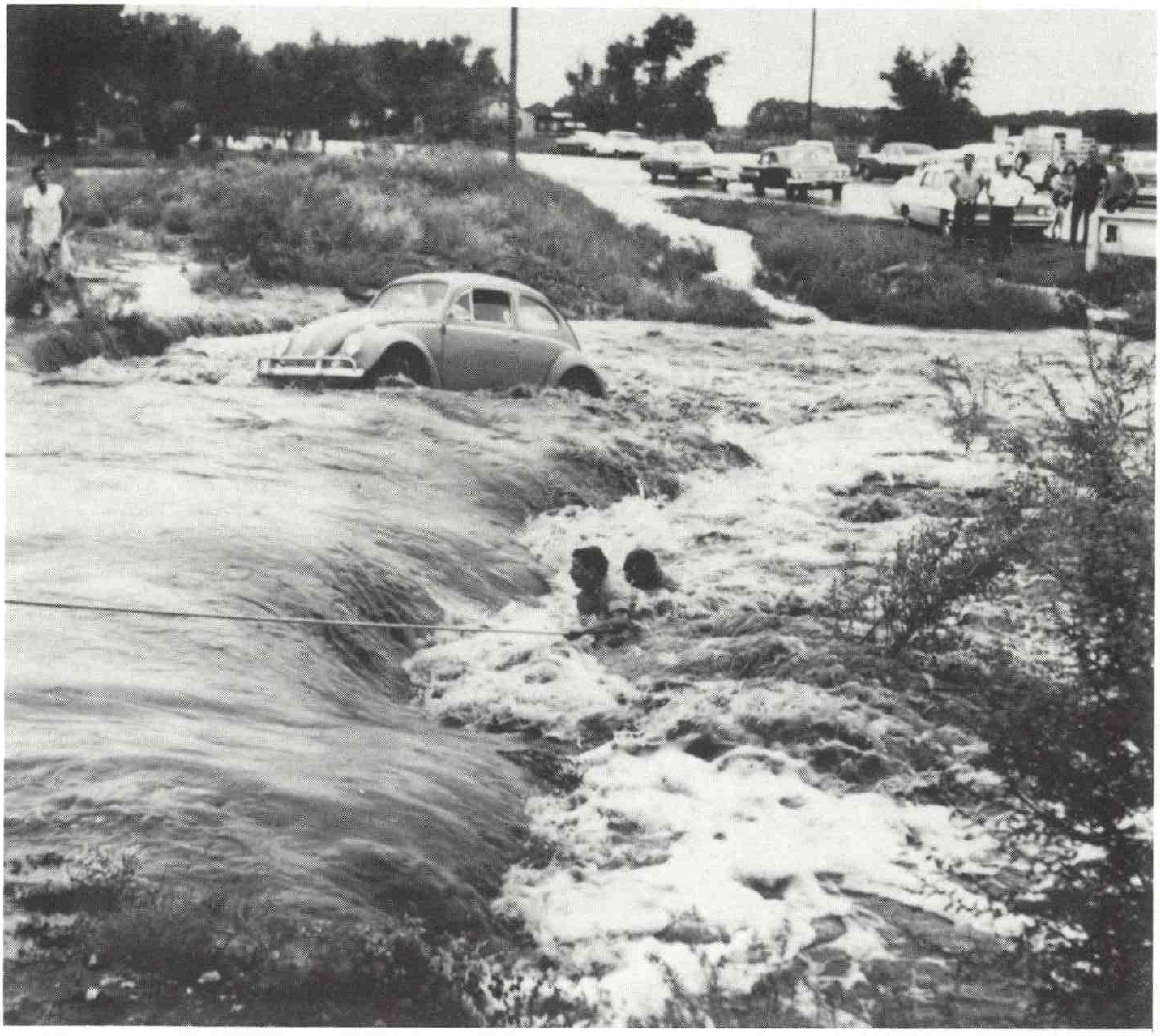
In the ALERT program, NWS provides the community, at nominal charge, with the necessary aids and technical advice on installation and operation of flood warning equipment. Flood forecasting procedures are designed for individual forecast locations, and training is provided to local officials. The local community is responsible for the purchase, operation, and maintenance of the equipment and for making its own special flood forecasts. ALERT is thus a simple, community-initiated, cooperative effort with NWS, that requires an initial community investment of about $50,000. And, although ALERT satisfies community needs, we must note that the system provides warning information only for specific points, is dependent on local non-hydrologists who have other primary duties, and is dependent on the variabilities of community planning programs and budgets. Furthermore, most of the data obtained from ALERT are not available to the national data files, although the data can be transmitted to the local RFC, WSFO, or WSO. Nevertheless, the self-help program has proved effective, especially in flash-flood situations.

Another similar program is a cooperative arrangement with joint Federal and State funding of about $2 million. IFLOWS, the Integrated Flood Observing and Warning System, is an experimental program conducted by NWS, the Appalachian Regional Commission, and the States of Kentucky, Virginia, and West Virginia to provide an enhanced flood warning service to the Appalachian region. Similar to ALERT, the basic observations and weather forecasting products from NWS are needed to provide a complete forecasting system.

The objective of IFLOWS is to implement a regional flood forecasting system which takes into account flash flood problems extending across geographic and political boundaries and beyond the funding and operational capabilities of any single community. Although still evolving, IFLOWS seems to be meeting the needs of the Appalachian region. The system combines existing sensors, communications, and computer technologies with forecasting techniques and computer model analyses to provide guidance and advice to State and local officials responsible for emergency services. IFLOWS provides for issuance of site-specific warnings of local floods 30 minutes to 3 hours in advance of floods. The observations and warnings also are transmitted to the RFCs, WSFOs, and WSOs. At present, IFLOWS is deployed throughout a 12-county region at the intersection of the three States. There are plans to expand the system to about 75 counties in the States of Pennsylvania and Tennessee.

The Role of the Private Sector

Although private sector direct participation in hydrologic forecasting services is relatively small, that which exists is nevertheless performing an important function. Numerous consulting firms provide hydrologic services for build-



Flash Flood in New Mexico.

CREDIT: Artesia (New Mexico) Daily Press.

ing of dams and similar construction enterprises, and it is not uncommon for a civil engineer to deal with run-off, drainage, and sewer problems of municipalities. However, none of these consulting firms engage in flood forecasting activities, per se. By far, the largest role for the private sector in river and flood forecasting is in the dissemination of flood warnings. The two other functions—data collection and data analyses and forecasting—would be of little benefit without the third function, dissemination. In fact, it is universally recognized that without the participation of commercial television and radio, timely flood warnings to the public would not be possible.

CHAPTER 3
Improving the Service

Present System

From the foregoing, the river and flood forecasting and warning system can be characterized as complex—incorporating the combined efforts and resources of Federal, State, and local governments, as well as important efforts by private citizens who participate in the volunteer observer program conducted by the National Weather Service (NWS).

As we indicated earlier in this report, the statutory authority for flood forecasts and warnings rests with NOAA, and the focus within NOAA is the hydrologic services program of NWS. However, the NWS hydrologic services depend on many Federal and State agencies and others for a major share of the information required to meet river and flood forecasting and warning responsibilities. NWS is the source of basic weather and precipitation information; the U.S. Geological Survey (USGS) provides streamflow data from its water resource investigations effort; the U.S. Army Corps of Engineers (COE) provides stream and reservoir gauge data from its own work on dams and reservoirs; and the Soil Conservation Service (SCS) provides snow survey data necessary for water supply forecasting. Of the 16,000 or so stream gauges installed throughout the country, most are operated by USGS and COE. The bulk of the rainfall data are obtained from some 6,000 volunteer observers, who call in their observations of 1/2 inch or more daily precipitation to the Weather Service Forecast Offices (WSFOs) and the Weather Service Offices (WSOs). And, to ensure the timely dissemination of flood alerts and warnings to the public, there is the critical service provided by the radio, television, and the newspapers.

How much of the flood-prone areas are covered by the present system? A percentage of the Nation's population served would seem to be a reasonable measure. If we counted the number of inhabitants served by a site-specific flood forecast, we would probably find that nearly all of the metropolitan areas with one or more flood-prone sites identified have at least one point that receives a site-specific forecast. This type of measure, however, is misleading with respect to all flood-prone areas where the population and property are considered vulnerable.

As indicated previously, over 20,000 flood-prone sites in the Nation have been identified. Of these, about 3,000 receive site-specific flood forecast service from NOAA. And, beyond site-specific river and flood forecasts and warnings, NOAA's "generalized" forecasts are provided along the major tributaries and large rivers. Thus, most flood-vulnerable areas receive some form of service. Yet, even with all the elements of the current system—Federal, local, and cooperative—operating at maximum effectiveness, NOAA has estimated that data adequate for acceptable service would be available for only one-half of the Nation's required river forecast points. The difficulties lie not merely in the number of gauges but in the overall operating mechanics of the system. Recent studies by NWS have shown the relationship of a river basin geography to the number of rain gauges or measurement points needed to predict flood crests and to the required sampling rate for data flow. The interval between measurements required for reliable service is one which is less than one-fourth the potential flood lead time for the basin. The potential lead time at a flood forecast point is the time lag from the occurrence of rainfall over the basin to the onset of the resulting runoff at that point. According to NOAA, 35 percent of the current forecast points have potential lead times that require sampling intervals of 6 hours or less. And, since the dominant flow of data collection is provided from volunteer observers who provide daily reports, the optimal sampling intervals, considering all sources, are estimated to be available from only 30 to 50 percent of the existing forecast points.

Clearly then, there are deficiencies in the system, its operation, and its coverage. One way to handle most of these would be the infusion of much more money to the central NOAA river and flood forecasting and warning service. We can only guess at the magnitudes. For example, NOAA believes the addition of about 2,000 automated rain gauges by NWS, and the planned network procurement by the other cooperating agencies, are needed to complete even the current 3,000 forecast points to a fully adequate and reliable network. The procurement and maintenance costs for 10 years for these 2,000 NWS gauges, including spares, would be about $15 million. Providing coverage to the more than 20,000 flood-prone sites is not easily extended from this figure, because over 50 percent of the balance of 17,000 sites are located in small areas that would require increased measurement densities for adequate coverage. The costs would certainly be considerable.

It can be argued that the optimum network would be a system independent of reliance on other Federal agencies and on voluntary citizen participation. While we might concur in principle that such an objective is utopian, we do not consider it realistic, necessary, nor appropriate. Certainly the various parts of the complex system do pose problems and require considerable attention by the central core of flood forecast responsibility in NOAA because of the tenuous nature of much of the external capabilities. Yet, the system does provide significant service and is an example of considerable avoidance of duplication in the Federal area.

For these reasons, we have reviewed the system in order to seek and bring to the attention of those responsible the improvements which we believe merit serious consideration on behalf of public safety. Although some of these improvements may require additional funds, we believe the benefits significantly exceed the modest costs.

Public Cooperative Systems

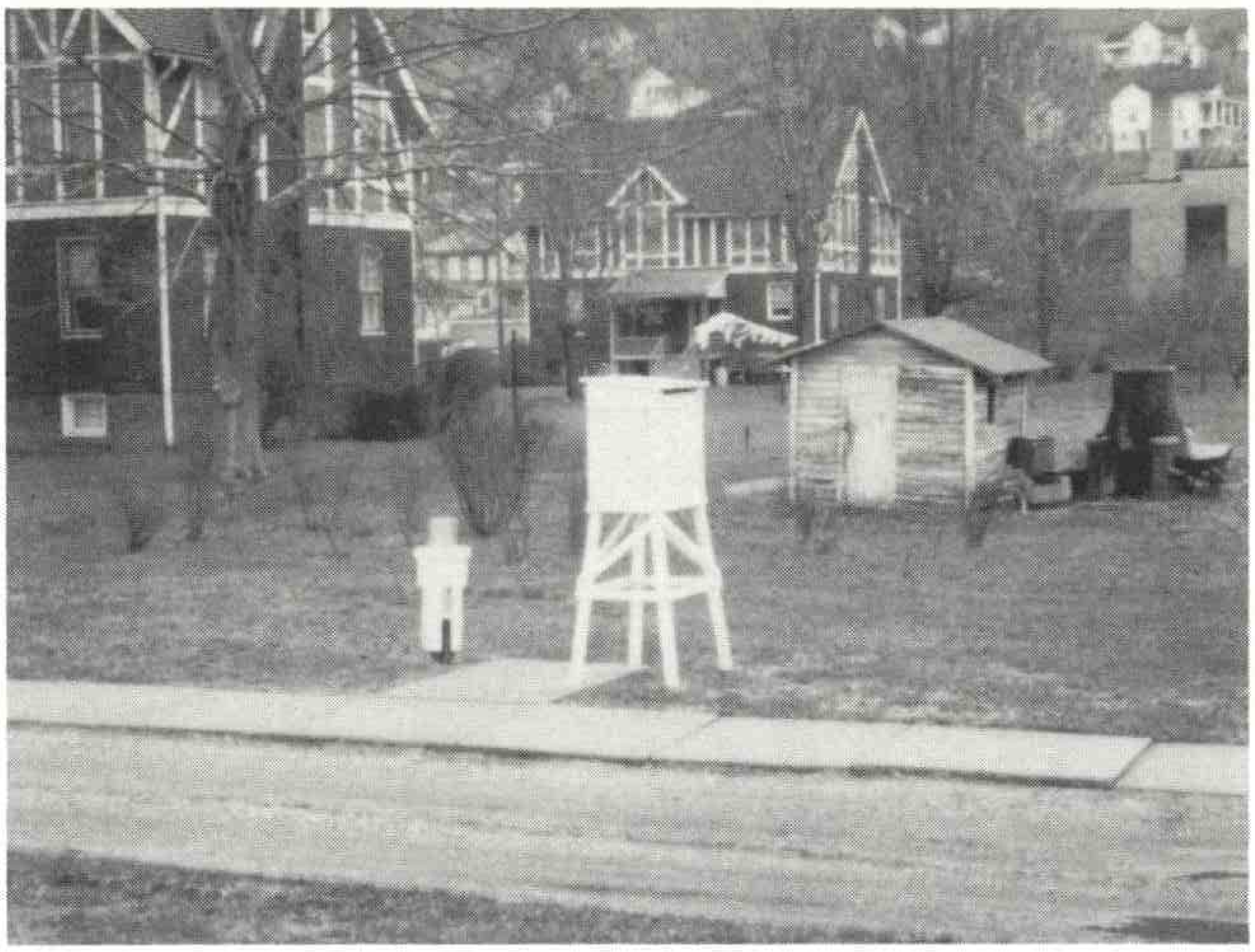
The dominant provider of hydrologic data to the flood forecasting system is the volunteer citizen cooperative observer. The procedures established call for reports every six hours after the first one-half inch of rainfall has fallen. However, in practice, the compliance is in many instances flawed. Reporting is often only twice each day during a rainfall episode, with less than consistent reporting times among individuals, sporadic reporting with some observers omitting some calls during a rain period, calling in randomly, or reporting measurements at times different than the times of observation. Moreover, there is the problem of large sparsely populated areas without volunteer observers, which leaves large gaps in the observational network. The difficulty at the WSFO, WSO, and RFC locations and at the national level in developing a consistent data base from such information is evident.

The local volunteer observer program has strengths and weaknesses. There are problems of reliable implementation. Yet, it is inherently cost-effective. We believe additional small resource increments to expand the network and to provide some observer reporting redundancies would pay off immeasurably in broadening service and in covering some of the uncertainties and unreliabilities that inevitably occur when no real-time data are available. But we do see the need for NWS installing some automated gauges where critical unmet needs exist.

Thus, we do not suggest abolishing the cooperative volunteer efforts nor other systems, such as ALERT and IFLOWS. In fact, we recommend their strengthening. The potential or lessening losses from floods should provide considerable self-interest and motivation for local participation. Such efforts, however, are as effective as the management attention and continuity of interaction with the public provided. For ALERT and IFLOWS, cooperating local and State management programs have been assembled to provide the necessary participating and continuing leadership. In general, it seems the effectiveness and growth of self-help programs, the volunteer observer program in particular, have been limited by the availability of NOAA hydrologists to participate in such public education and technology transfer efforts. It is our view, that while an increase in NOAA's field hydrology strength may be needed to provide increased interaction and management attention to the individual cooperative observers, any increase could be incremental and should be directed toward developing and sustaining the necessary local efforts to maintain the systems. Moreover, there exist advisory agents in the field operating through such programs as Land Grant and Sea Grant that might well be recruited to motivate and train effective volunteer observers.

We recommend, therefore, that the National Oceanic and Atmospheric Administration place high priority on:

(a) Providing additional hydrologists to improve the effectiveness of the volunteer cooperative observer program, and on



A typical official volunteer cooperative station. In the foreground are a bucket-type rain guage (left) and a shelter that contains the thermometer for temperature measurements.

CREDIT: National Weather Service/National Oceanic and Atmospheric Administration.

This automatic radio-reporting gauge is used in the IFLOWS and ALERT programs.

CREDIT: National Weather Service/National Oceanic and Atmospheric Administration.

Automated rain and stream gauges operated by the U.S. Army Corps of Engineers. The rain gauge and radio equipment are mounted on the tower. The stream gauge is inside the housing shown in the lower left corner. Data are transmitted by NOAA satellite to the National Weather Service Offices.

CREDIT: U.S. Army Corps of Engineers.

Gauge at a U.S. Geological Survey stream gauging station. The measuring device is located in the river at the bottom of the gauge house; recording equipment is located at the upper level.

CREDIT: U.S. Geological Survey, U.S. Department of the Interior.

(b) Extending community self-help programs, such as the Automatic Local Evaluation in Real Time (ALERT) system and the Integrated Flood Observing and Warning System (IFLOWS).

We estimate that these actions will require the addition of one or two hydrologists at each of the River Forecast Centers or at selected Weather Service Forecast Offices, depending on the local situation.

The Federal Complex

It bears repeating that NOAA's river and flood forecasting and warning performance effectiveness is heavily dependent on others. At the Federal level, the system could not work without the NWS hydrometeorological data and other data and information systems provided by USGS, COE, and SCS, which are acquired for their own purposes and with their own resources at no cost to NOAA.

The question here is of coordination and network design. Although the gauges of these other contributing agencies do provide necessary data, their placement coincides primarily with the agency's mission needs, and not necessarily with those of NOAA for flood analyses. Although NOAA's needs are considered, we see potential problems. Movement or discontinuance of gauges operated by these agencies can and does impact the data flow to NOAA. Removal of existing gauges by these agencies, either from lack of need or from lack of adequate resources to maintain their own systems—an increasing problem—could at some future time critically impair the NOAA service. Because all agencies involved are aware of their interrelationships in flood forecasting, some measure of positive interagency coordination should be evident in view of the seriousness and frequency of flooding events.

Circular A-67 of the Office of Management and Budget (OMB), issued August 25, 1964, prescribes guidelines for "coordination of Federal activities in acquiring water data from streams, lakes, rivers, estuaries, and ground water.... excluded are activities concerned with research plots and experimental watersheds, and data on precipitation, evaporation, snow accumulation and soil erosions." It also provides that "The Department of the Interior (DOI) is responsible for exercising leadership in achieving coordination of national networks and specialized water data activities." In essence, A-67 affirms DOI leadership, which is delegated to USGS, and the central Federal coordinating role in the acquisition of certain water data but is silent on river and flood forecast and warning services. Similarly, OMB Circular A-62, issued in 1963, affirms the central role of the Department of Commerce for basic meteorological services but also is silent on river, flood, or any other hydrological service.

The Water Resources Council created in the 1965 Water Resources Planning Act (P.L. 89-80) was provided a charter which, while not specifically directed at flood situations, could be interpreted to provide needed coordination. The Council membership includes the Secretary of the Interior as Chairman; the

Secretaries of Agriculture, Army, Commerce, Energy, Housing and Urban Development, and Transportation; and the Administrator of the Environmental Protection Agency. Its legislated responsibilities include oversight of regional or river basin plans and programs in relation to the adequacy of coordination of the water and related land resources policies and programs of the several Federal agencies. It includes establishment of principles, standards, and procedures for Federal participants in the preparation of comprehensive regional or river basin plans and for the formulation and evaluation of Federal water and related land resource projects. We are not aware that the Council's activities in the past have considered policies concerning public flood warnings. At this time, however, its relevance to the coordination issues under discussion is moot. The Council was not funded for Fiscal Year 1982, and its staff has been dispersed. Thus, while it remains in the law, it is not now a functioning entity.

Our review has found two other coordinating mechanisms that should be noted. Under the auspices of A-67, the U.S. Geological Survey's Office of Water Data Coordination (OWDC) has organized a Federal Advisory Committee on Water Data. This Committee provides coordinated interagency advice to OWDC to meet that Office's needs. The Director of NOAA's Office of Hydrology serves as the Department of Commerce (DOC) member. Thus, while serving a purpose not specifically flood system related, the Committee provides at least a meeting ground for information exchange from the appropriate agencies at working levels.

The Committee on Atmosphere and Oceans (CAO), under the Federal Coordinating Council for Science, Engineering and Technology, is the other coordinating body. This Committee, however, has not met in the past several years. The Subcommittee on Atmospheric Research of CAO is an active group that meets regularly, but its interests are primarily research oriented and do not include hydrologic matters.

In summary, we find that there has not been in the past, nor is there now, an adequate arrangement for coordinating and considering the relationships of the critical contributions of several Federal agencies to the operational effectiveness of the government's river and flood forecasts and warnings provided to the public by DOC through NOAA and its NWS hydrologic service.

Therefore, we recommend that the National Oceanic and Atmospheric Administration (NOAA), as the agency responsible for flood forecasting, take the initiative, in association with the U.S. Geological Survey, the U.S. Army Corps of Engineers, the Soil Conservation Service, and others, to establish a policy-level interagency coordination mechanism necessary to ensure appropriate consideration and necessary remedial action whenever changes to the hydrologic data network not under NOAA control are contemplated.

Such means can ensure that the impact of changes on the data network on the quality and effectiveness of flood forecasting and warning and their effect on public safety will be understood, will be brought to the attention of the appropriate forums, and will be dealt with adequately. Moreover, effective coordination could eliminate some other basic operational problems. We understand, for example, that the Tennessee Valley Authority (TVA) provides about 90 percent of the rain gauge data within its region. Yet, when TVA's needs for real-time data are not critical, the information,which is important to NWS, is often delayed—such as weekend information not reported until Monday. Additionally, with TVA and other agencies in the field, further standardization of data formatting and handling is needed. These are important considerations and susceptible to resolution, we believe, by the improved communications high-level coordination would foster.

Therefore, we recommend that the Office of Management and Budget (OMB) establish appropriate guidelines and criteria for the planning and operations of the flood forecasting and warning services through an OMB circular similar to that provided weather services under OMB Circular A-62, or that OMB revise A-62 to include hydrological flood forecasting services under the Federal Coordinator for Meteorological Services and Supporting Research provided in that Circular.

Other Arrangements

In describing the Nation's Hydrologic Services in Chapter 2, we made only brief reference to TVA and the Bonneville Power Authority. These authorities have staff hydrologists who provide their organizations with river and flood forecasts for their own management purposes. Coordination with NOAA hydrologists is close and useful. Thus, there is no question that the forecast skills are available, and we see a possible benefit to the entire system if these. capabilities could be used by the National Weather Service during critical times.

Under current laws, however, official government flood forecasts and warnings can only be issued to the public by NOAA's National Weather Service. It was suggested to us that "deputizing" TVA personnel to issue flood warnings might solve this problem. However, there are other problems as well, such as forecast liability, time of hydrologist service availability, integration of communications, and other similar problems. Nevertheless, we believe there are sizable capabilities here that compel serious consideration. ***We recommend that the National Oceanic and Atmospheric Administration, working with the Tennessee Valley Authority and Bonneville Power Authority:***

(a) Explore the legal, institutional, hydrologic, and cost-effective feasibilities of using, during critical flood forecast conditions, the hydrologic capabilities that exist in organizations, such as the Tennessee Valley Authority and the Bonneville Power Authority, into its river and flood forecasting and warning system, and, if found practical,

(b) Take whatever actions are required, including recommendations for appropriate changes to legislation, to implement this concept.

Technical Improvements

Earlier, we briefly noted that NOAA's hydrologic services were being provided satellite imagery and estimates of rainfall from NOAA's National Environmental Satellite, Data, and Information Service (NESDIS). Satellite observations do hold considerable potential in increasing the effectiveness of flood forecasting. NESDIS developments underway may lead to enhanced satellite capabilities in estimating heavy rainfall. At present, satellite systems are used in the networks primarily as communications relays and to add mesoscale space-time distribution information to the *in situ* gauge networks. And, while we recognize their essential contributions, present techniques do not offer much prospect in the near term for reducing the network densities of field observations from *in situ* gauges.

In our view, it is in the area of seemingly minor technical improvements that considerable effectiveness can be gained for the river and flood forecasting and warning system. Of those we have studied, we believe the following items are worthy of support:

(a) At present, NWS has evolved distinct data sets for its several weather observation systems (radars, satellites, rain gauges, upper air soundings, etc.). Probably because of the lack of resources and the low priority generally accorded data management in government, these data sets are not integrated. This means, for example, that the technique for verifying rainfall measurements received from radars to the actual measurements of rainfall obtained from rain gauges is not available to the forecaster in "real-time," i.e., current data. Furthermore, because of the lack of integration, all the information on rainfall is not generally available to NMC in developing its precipitation forecasts. We see a major improvement from this integration of meteorological and hydrological data bases to river and flood forecasting, as well as to weather forecasting. Such an effort is solely within the purview of NOAA.

(b) At present, although the rain gauge data network is extensive, there are deficiencies, especially in sparsely populated areas where the volunteer observer effort is inadequate, and in those critical areas where sampling rates are major factors in flood warnings. An increase in the number of automated rain gauges in these areas would have a major positive impact on river and flood forecasting and warning effectiveness.

(c) We have noted that considerable information is provided to the NOAA hydrologic service by other agencies. In some cases, however, significant amounts of data, particularly automated rainfall measurements, such as provided by the U.S. Army Corps of Engineers gauges, cannot be used in a timely way in critical situations, because the data are received in a form not compatible with the NWS data processing system. Standardization of data formats among agencies collecting similar types of hydrological data could significantly improve the effectiveness of even the current forecasting system. A start has been made but presently involves only the Corps of Engineers and NWS.

(d) Research and development are key elements in improving the flood forecasting capabilities of NWS. In the short-term, efforts to calibrate the existing numerical models, tailored to specific river basins, are essential. In the long-term, coupling the models for weather prediction with those for flood forecasting would lead to significant improvements in flood forecasting.

(e) Among the technical support items provided to NOAA's hydrologic services by the NWS National Meteorological Center (NMC) is the "Quantitative Precipitation Forecast" (QPF). NMC produces forecasts of quantitative precipitation through its numerical models. Statistical relationships then provide estimates of probability of occurrence of measurable precipitation and the amount of precipitation. After combining precipitation probabilities with other observed and forecast atmospheric conditions, analysts also prepare centralized QPF guidance products. The RFC hydrologists and the WSFOs receive the QPF products, update or modify them, and use them as input to their flood forecast and prediction procedures. It is generally recognized that QPF model improvement is necessary for improved flood forecasting and is believed possible. A 1980 report of the National Academy of Sciences (NAS, 1980) states that:

> While there has been slow but steady improvement in the accuracy of weather forecasts over the past decade, stubborn problems remain. Precipitation forecasts represent both the most important and the most difficult problem area, but there is considerable evidence that economically significant advances in forecasting accuracy are within reach.

(f) The volunteer cooperative observer and other local and regional programs use telephones for communicating observations. In recent years, the technology of telephone communications has resulted in significant improvements to reliability and rapidity of transmission. In particular, we would highlight the "Touch-Tone" system of contact and coded relay that could not only expedite information relay but also could improve efficiency by incorporating standard digitized reporting at the observing end. Significant benefits are available at relatively small costs by providing the "Touch-Tone" capability to observers.

For these reasons, ***we recommend that the National Oceanic and Atmospheric Administration plan and budget for the necessary technical improvements and research efforts to the Nation's flood forecasting and warning services, including:***

(a) The integration of all meteorological and hydrological data bases in the National Weather Service;

(b) The installation of automated rain gauges in areas of sparse volunteer observer availability and in critical areas requiring high sampling rates;

(c) The development, with other agencies, of a national real-time (current) hydrologic data base with standardized formats;

(d) Efforts to improve the numerical models for flood prediction, including the calibration of models;

(e) Efforts to improve the Quantitative Precipitation Forecast models; and

(f) The introduction of "Touch-Tone" telephone volunteer observer reporting.

The total cost to implement all of the technological improvements has not been determined. Some, such as the computer programs, or "software" development, for the data bases and integration of data sets, will undoubtedly take considerable time and effort. At this time, we can only suggest that the cost for the observer "Touch-Tone" telephone system may be on the order of $150,000 per year, and that the procurement and 10-year maintenance costs for providing 2,000 automated rain gauges, which NOAA has determined are needed for the current 3,000 site-specific forecasting points, would be about $15 million. In view of the current economic situation and considering a reasonable start-up period, we would support a NOAA implementation plan to accomplish the above in 5 years.

Flood Forecasting and Flood Insurance

Finally, we introduce a new concept that could importantly affect local flood forecasting and warning. This new concept holds significant promise, and we believe may increase incentives for local and regional participation and contribute to the Federal resources that are required to implement some of our earlier recommendations.

In 1968, the National Flood Insurance Act was passed to encourage State and local governments to make land use adjustments, to constrict the development of land exposed to flood damage, and to minimize damage caused by floods. Additionally, it established a National Flood Insurance Program allowing homeowners, businesses, and local government facilities to purchase federally subsidized insurance at low cost through local agents when certain flood plain management regulations and ordinance were in place. Up to that time, it was difficult, if not practically impossible, for those living in flood-prone areas to obtain flood insurance at reasonable rates from private companies.

This Federal flood insurance program, managed by the Federal Emergency Management Agency (FEMA) through its Federal Insurance Administration (FIA) was slow in getting started. At the time of Tropical Storm Agnes in 1972, for example, only two flood insurance policies had been sold in the Wilkes-Barre, Pennsylvania, area where devastating floods caused damages over $3 billion. Lack of public awareness of the insurance program was a factor, as was lack of insurance agent motivation and sales effort, failure of local communities to seek eligibility, and general lack of concern about flood insurance (NSF, 1980). By the end of 1981, however, over 17,000 communities and other political subdivisions across the country were participating in the program, with 1.9 million policies in force providing over $99 billion in flood insurance coverage.

From 1968 to the end of 1981, the Federal Government has provided about $1.5 billion in flood insurance program subsidies. The General Accounting Office reports that (GAO, 1982):

> According to unaudited FEMA records about $866 million has been collected in insurance premiums during this period, but $1,249 million has been paid to the insured for flood claims. In addition, over $408 million has been paid to the operating contractor, insurance agents, and claims adjusters; $520 million has been spent to prepare community flood maps; and $174 million has been incurred for interest expense on U.S. Treasury borrowings.

Our primary interest is not with the insurance program, however, but with the possible relationships between that program, with its significant costs to the Federal Government, and flood forecasting services. It is our view that the quality of such forecasting services has a direct relationship on losses suffered and thus on insurance costs. It would follow, therefore, that the relationship could extend to the flood insurance charges and premium schedules.

We are not aware that this relationship between the costs for flood insurance, both premiums and claims, and the availability and quality of flood forecasting and warning services has ever been quantified. Nevertheless, it would seem reasonable that a flood insurance premium that takes into account the presence and quality flood forecasting and community preparedness programs could result in cost reduction, with larger reductions for those areas with highly integrated and automated systems.

To the degree that this is borne out, an incentive in the form of a reduced flood insurance premiums could encourage a local community to establish or augment a self-help effort for improved flood forecasting and warning systems from its own resources. Moreover, improved local systems could result in reduced Federal flood insurance related costs and possibly in other Federal relief payments. The Federal Government's lower pay outs in these areas could then offset the additional Federal resources necessary to increase Federal assistance to the local communities, to integrate these systems into the regional networks, and to support improved public service from the central Federal service. A potentially sizable reduction in Federal flood management expenditures, together with reduced local flood premiums, seems to be a "business" proposition that cannot be ignored.

We recommend, therefore, that the Federal Emergency Management Agency, in cooperation with the National Oceanic and Atmospheric Administration, undertake take a comprehensive study of a selective region to determine:

(a) The relationships between several levels of river and flood forecasting and warning services and Federal, local, and individual flood insurance costs; and

(b) The feasibility of a flood insurance schedule that incorporates as a factor the degree of flood services and preparedness programs available to a community; and, based on these studies, take whatever actions are required to implement this concept, including recommendations for appropriate changes to legislation.

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APPENDIX A

Summary of Findings and Recommendations from NACOA's Report, "The Future of the Nation's Weather Services"

The Public-Private Mix of Weather Services

1. *We find the present national weather system to be a complex mix of interdependent public and private services that has evolved over the years to provide the United States with effective weather services for protection of the public, for its safety and welfare, and for the efficient operation and planning of economic activities. This kind of mix serves the public interest well.*

The Need for New Technology

2. *We find that the new technology of weather observations, communications, and data processing is indispensible to the advancement of the Nation's weather services. We recommend that policies be adopted which can permit the introduction of this technology without compromising general weather services dependent on more conventional technology.*

We believe that the risk of exposure of citizens of the United States to weather hazards can be significantly decreased by the procurement and installation of new observation, communications, display, and data processing systems. Such procurement will be costly but, in our view, the benefits will far outweigh the costs. We recommend that adequate funding be provided for the new technology.

Effectiveness of the National Weather Service

3. *We are of the opinion that the effectiveness of the National Weather Service in achieving its end objective of protecting the public and serving the economy is enhanced when there is a close relation between community and service. It is important, therefore, that "service" criteria be established to determine which and how many communities shall have local weather service provided by the Federal Government.*

We find that the proposals for changes in the number and distribution of weather stations of the past several years do not conform to well-understood criteria. We do not believe that the almost "hit or miss" approach to weather station closures of the past several years has served the Nation well.

We recommend that criteria be developed for weather station closure and establishment. We also recommend that possible cooperative funding arrangements between the Federal Government, States, and local communities be explored.

The Need for a Strong Central Government Weather Service

4. *We recommend that current policies for operation of Federal meteorological services should continue to be based on the maintenance of a strong central weather service to provide weather warnings and common weather services for all Federal agencies. Steps should be taken to ensure that these policies can be effectively implemented to prevent the establishment of multiple weather services.*

Public-Private Weather Services Responsibilities

5. *The primary responsibility for predicting life-threatening weather events should rest with the Federal Government's National Weather Service. The National Weather Service should issue general forecasts for the public. We recommend that current weather data and forecasts acquired and prepared by the Federal Government should be provided without charge to organizations and institutions that further the objective of the widest possible dissemination of weather warnings.*

We advocate a continuing role for the Federal Government in providing the specialized analyses and forecasts that serve broad economic sectors where there is a high national interest, as defined by Congress, as well as those that are required by other Federal agencies in the conduct of their missions. We see the private sector as providing analyses and forecasts that particularize information to meet the needs of specific clients or constituencies.

The Dissemination of Weather Warnings

In light of the increasing role of the private sector in the dissemination of weather information, we recommend that the Federal Communications Commission take steps to ensure that all weather emergency messages and warnings of the National Weather Service are properly disseminated, identified, and carried in broadcasts.

User Fees

6. *We find the concept of user fees for federally supplied weather information attractive but conclude that the implementation of user fees may be practical only in special cases. Many organizations that now receive weather information and data from the government free of cost to themselves, contribute valuable and otherwise unobtainable weather data, and frequently provide essential dissemination services at no cost to the Federal Government. Services designed to protect life and property should not be withheld from those unable or even just unwilling to pay. Some sectors, such as shipping, agriculture, and aviation, bulk so large in the economy and the national*

interest is so strong that the Federal Government continues to have an important responsibility for providing weather services aimed at increasing their productivity and efficiency. Where the private sector is increasing its provision of weather services, such as is increasingly the case with dissemination, quid pro quo *considerations generally militate against the institution of fees.*

We recommend that any establishment of user fees for private sector users of Federal Government weather data and services should take into account the quid pro quo *contributions of the private sector to the observation, communication, and dissemination functions of the total national weather system. These* quid pro quo *contributions by the private sector provide vital elements of our weather service and are generally provided free of charge to the Federal Government to ensure effective weather service.*

The aviation industry pays special excise taxes into a trust fund set up under the authority of the Airport and Airway Development Act of 1970 to support airport construction and other aspects of the infrastructure of the Nation's airways. We support the use of this fund to provide federally supplied aviation weather services. We see aviation weather services as an integral part of the Nation's airways systems. If other private sector activities, such as shipping, waste disposal at sea, and the like are brought into similar tax arrangements, we recommend that weather services applicable to those activities be funded out of such receipts.

Data Acquisition — A Federal Responsibility

7. *We recommend that the Federal Government retain full responsibility for assuring that the Nation has a data acquisition system capable of acquiring the full set of observations necessary to describe the conditions of the atmosphere and to forecast weather phenomena on all scientifically meaningful time and space scales. We see agencies of the Federal Government as the operators of the bulk of this system with some operations in special circumstances in the private sector. This policy is essential to:*

a) Provide for an integrated data acquisition system whose management can organize, coordinate, and ensure timely transmission of data from many different platforms, collected by many different entities.

b) Provide the international data exchange arranged by governments among all countries of the world to ensure adequate basic weather data necessary for preparation of weather forecasts.

c) Ensure data quality control and a system design for optimal coverage and information integration to serve both civil and national security needs.

Basic Data Analysis and Forecasting — A Federal Responsibility

8. *We recommend that the management and operation of the Nation's basic data analysis and forecasting functions continue as a Federal responsibility.*

This function produces the weather information base common to all weather service products for both public and private use. The discharge of this function requires that computer and communication resources be integrated with the data acquisition system. Only the Federal Government is in a position to discharge this responsibility as long as the data acquisition functions remain a Federal responsibility.

The Private Sector Operation of the National Weather Service

9. *If Federal funding through traditional Congressional appropriations cannot provide for the necessary acquisition of technology for weather observations, and for the basic analysis and forecasting functions, we recommend a study of the establishment of a quasi-government corporation in the private sector to undertake weather data acquisition, and basic analysis and forecasting functions. Under contract, such a corporation would provide those services required by the Federal Government and would have authority to supplement Federal funds from other sources. At this time, we do not find the establishment of a quasi-government corporation to be a desirable course of action, because we do not foresee an increase in efficiency.*

The Interdependence of the Nation's Weather Services

10. *We believe that, in any planning for change in financing and management of weather services, recognition must be given to the fact that the Nation's weather services involve the pooled activities of a number of Federal agencies as well as institutions in the private sector and that all elements need to be considered.*

APPENDIX B

NACOA'S Hydrology Panel Members

Panel Chairman

Paul Bock
Professor
Department of Civil Engineering
University of Connecticut

Panel Members

Jay G. Lanzillo
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APPENDIX C

Session Participants, Individuals and Offices Visited, and Field Sites Visited

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Field Sites Visited

Tulsa River Forecast Center
National Weather Service
Tulsa, Oklahoma

Lower Mississippi River
Forecast Center
National Weather Service
Slidell, Louisiana

APPENDIX D

List of Acronyms

ALERT	—	Automatic Local Evaluation in Real Time System
CAO	—	Committee on Atmosphere and Oceans
COE	—	U.S. Army Corps of Engineers
DOC	—	Department of Commerce
DOI	—	Department of the Interior
FEMA	—	Federal Emergency Management Agency
FIA	—	Federal Insurance Agency
FY	—	Fiscal Year
GAO	—	General Accounting Office
IFLOWS	—	Integrated Flood Observing and Warning System
NACOA	—	National Advisory Committee on Oceans and Atmosphere
NAS	—	National Academy of Sciences
NESDIS	—	National Earth Satellite, Data, and Information Service
NFIP	—	National Flood Insurance Program
NMC	—	National Meteorological Center
NOAA	—	National Oceanic and Atmospheric Administration
NWS	—	National Weather Service
OMB	—	Office of Management and Budget
OWDC	—	Office of Water Data Coordination
QPF	—	Quantitative Precipitation Forecast
RFC	—	River Forecast Center
SCS	—	Soil Conservation Service
SNOTEL	—	Snow Telemetry System
TVA	—	Tennessee Valley Authority
USDA	—	U.S. Department of Agriculture
USGS	—	U.S. Geological Survey
WRC	—	Water Resources Council
WSFO	—	Weather Service Forecast Office
WSO	—	Weather Service Office