Program Development Plan for Improving Hydrologic Services

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

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FOREWORD

The purpose of the Program Development Plan (PDP) is to identify deficiencies in the National Weather Service's (NWS) river and flood forecast and warning services and to develop a program for taking corrective actions.

This PDP serves several purposes. It establishes the scope of the hydrologic service and discusses service performance. Based on performance, a systematic problem analysis is made and service improvement goals are identified. A schedule of activities and resource requirements to improve the hydrologic service program are presented for an extended period beginning in 1985. While the five major program thrusts can stand alone during development and implementation, they are presented as a total integrated plan. Full benefits cannot be realized without the completion of all program thrusts since they are interdependent.

Since the plan covers a multiyear period, program directions are subject to modification and revision as a result of changing requirements and technology or direction by the Executive and Legislative Branches of the Federal Government. The PDP presents proposed intentions of the NWS to improve hydrologic services. It does not represent a commitment, however, except as all or parts of the program are approved and funded by Congress.

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EXECUTIVE SUMMARY

Objective

The National Weather Service's (NWS) paramount mission is the protection of life and property from the ravages of hazardous weather and flooding. The need for timely forecasts and warnings is the compelling reason for most of the requirements for weather observations, communications, processing, analysis, interpretation, and dissemination capabilities. In pursuit of this mission, NWS has established an operational capability to forecast and warn of various hazardous weather and flood events. Within this capability, NWS has implemented a two-pronged hydrologic service directed toward (1) flood forecasting -- to save lives and prevent property losses and (2) river forecast information -- to support water resources management activities. Although the river and flood forecast program has accomplished a great deal in reducing loss of life and human suffering along major rivers and serving water management needs, there is much room for improving the service in terms of providing longer warning lead times for hazardous flood events and making more accurate long-term forecasts of river flows for improving water resources management. Selected improvements in these two areas will enhance NWS's ability to protect life and property from flood events and will provide opportunities for reaping economic benefits through the better use of water resources. The purpose of this Program Development Plan (PDP) is to identify deficiencies in the NWS hydrologic forecast service and to develop a program for taking corrective actions.

Scope of Hydrologic Service

NWS's hydrologic service is directed toward serving 20,000 flood-prone places located in river basins of various sizes and characteristics. Of these 20,000 places, NWS provides flood warnings for 3,000 designated forecast points. Of the 3,000 points, approximately 1,000 of them are for headwater areas; the remaining 2,000 points are along main stem rivers. Of the remaining 17,000 places, 550 are served by local flood warning systems that are owned, operated, and maintained by the local authorities. The other approximately 16,000 places are served by NWS by issuing warnings on a countywide basis.

For the 1,000 headwater forecast points, most of the rivers can produce a flood wave with a high stage known as a river crest anywhere from 0 to 18 hours following a period of excessive rainfall over the river basins. The rivers served by the 2,000 places not in the headwater areas crest beyond 12 hours after rainfall.

For those headwater areas where the river crest times are between 0 and 6 hours, flash flood watches or warnings are issued. Where the rivers crest between 6 to 18 hours, headwater flood forecasts are issued. For events occurring beyond

18 hours, main stem flood forecasts are issued. All these events endanger both life and property, but the effectivenss of the warnings varies according to the time available for action. River forecasts used for navigation and water management purposes are provided for events with 18-hour or longer lead times. (Lead time is the time between the issuance of the warning and the occurrence of the flood.)

Hydrologic Service Performance

The following information is derived from verification studies:

- More than 70 percent of flash flood warnings have less than 1-hour lead time.
- More than 50 percent of flash flood warnings have no lead time -- flooding has already occurred.
- On the average, for headwater forecast points, only a 4-hour lead time can be provided for an 18-hour flood event and a 1/2-hour lead time for a 6-hour event.

The above statistics indicate that the current capability of the forecast service is to provide forecast lead times from less than 1 hour for flash floods to 4 hours for an 18-hour flood event.

Hydrologic Service Problems

Based on a problem analysis of the hydrologic service, the following major conclusions were reached:

1. Deficiencies in the data collection network, lack of an integrated data system, and inadequate hydrologic forecast techniques collectively contribute to delaying the issuance of flood forecasts, particularly for the head water areas. The manual aspects of data collection, handling, and formatting are the most significant contributors to the delay. Unavailability of important data, lack of sophisticated data analysis techniques, and model complexities impact the forecast analyses and also contribute to the delay.
2. Inadequate of calibration of models used in long-term streamflow prediction and river forecast system techniques impact the quality of river forecast information.
3. The coverage of the community local flood warning program is too limited.

Hydrologic Service Improvements

In light of the above discussions, the following improvement goals were identified:

1. Improve the flood forecast warning lead times, particularly for the headwater areas. This goal constitutes the main thrust of this PDP, because improvements in the capability to increase flood forecast warning lead time for headwater areas will also lead to improvement for the flash flood and river forecast programs. There are three program elements to this goal:

   ° Install automated rain gages in 1,000 headwater areas.

   ° Design, develop, and implement an integrated hydrometeorological data system.

   ° Design, develop, and implement a simplified National Weather Service Forecast Office (WSFO) hydrometeorological prediction system (HPS).

2. Improve the quality of river forecast information:

   ° Complete the calibration based on historical data of the extended streamflow prediction and soil moisture accounting models for use in water supply forecasts.

   ° Install real-time calibration (updating) procedures.

3. Expand the local flood warning network.

Economic Benefits From Improved Warning Lead Times

The achievement of the goal to improve the warning lead time will provide NWS with the capability to increase the warning lead time from 4 hours to 14 hours for an 18-hour flood event and from 1/2 hour to 2 hours for a 6-hour flood event. These figures translate into an estimated potential reduction in damages to highly valued personal properties (e.g., cars, televisions, appliances) of approximately $100M per year.

Economic Benefits from Improved River Forecast Information

The achievement of the goal to improve the quality of river forecast information will provide for better volume forecasts of high elevation snowpack runoff events, especially during drought or flood conditions. Program improvement also will make possible the year-round issuance of long-term streamflow forecasts wherever there is need for more efficient use of surface waters. Improvements in the volume forecasts from snowmelt runoff have been shown to have potential benefits of at least $40M to hydropower and irrigation interests in the western

States. However, by far the most significant potential benefits can be derived from year-round extended streamflow forecasts. It has been estimated for the U.S., and demonstrated in a major metropolitan area, that better long-term river forecasts can lead to a 12 percent improvement in the yield of existing major water resource facilities. The potential benefit from these improvements is calculated at $2.5B per year for the next 20 years.

Program Improvement Costs

Costs of improving NWS hydrologic services were estimated for five major program thrusts: (1) enhanced data collection networks; (2) an integrated NWS-wide hydrometeorological data system; (3) development and implementation of simplified techniques for headwater and flash flood forecasting; (4) application and implementation of long-term streamflow prediction and river forecast system techniques; and (5) expanded implementation of community local flood warning programs with emphasis on automated systems. This plan recommends that beginning in FY 1985 the costs of hydrologic service improvements increase from $800K to a peak of $4.5M in 1991 and 1992 and then (beginning in 1993) drop to $2.7M in recurring costs, mostly to maintain the data collection networks. Potential benefits in current dollars from the improvements are estimated at $2.6B per year, almost 120 times the total cost of the program enhancements.

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1.0 INTRODUCTION

The National Weather Service (NWS) hydrologic service program has two basic goals: (1) to warn people about storms and floods to save lives and property and (2) to report on the Nation's rivers to support water resources management for the benefit of all sectors of the economy. These goals are in accordance with the Congressional Organic Act of 1890, which makes the NWS responsible for "...the forecasting of weather, the issue of storm warnings, the display of weather and flood signals for the benefit of agriculture, commerce, and navigation, the gaging and reporting of rivers...." The pursuit of these mission goals has resulted in the implementation of a two-prong NWS hydrologic forecast service directed toward (1) flood forecasting -- to save lives and prevent property losses and (2) river forecast information -- to support water resources management activities.

Although the river and flood forecast program has accomplished a great deal in reducing loss of life and human suffering along major rivers and serving water management needs, the program has had limited effectiveness in dealing with smaller, rapidly cresting rivers and streams. Also, the present service does not meet the growing needs of river forecasts for extended periods, especially during drought situations.

The purpose of this Program Development Plan (PDP) is to identify deficiencies in the NWS river and flood forecast service and to develop a program for their solution as well as overall improvements in the hydrologic services. In order to provide for a systematic development of the PDP, the basic concept of hydrologic forecasting, the present forecast service, operational problems, improvement goals, and other aspects will be discussed.

2.0 CONCEPT OF HYDROLOGIC FORECASTING

2.1 Typical River Basin

This section highlights the basic concept of hydrologic forecasting to establish a fundamental baseline of understanding and terminology for subsequent discussions.

Figure 1a shows a simplified sketch of a typical river basin. Shown running through the central position of the basin is the main stem river. This main river is fed by tributary rivers in two headwater areas. These headwater source areas can also be referred to as tributary basins. The primary sources of water for the basins are rain or melting snow. However, from the point of view of river flooding, dam breaks or breaks in ice jams can suddenly release vast amounts of water into the river system. Normally, when rain falls into the basin, some of the water is absorbed by the ground and the remainder flows from the high areas down into the rivers. The amount of water absorbed, of course, depends on the dryness of the ground and other more complex factors.

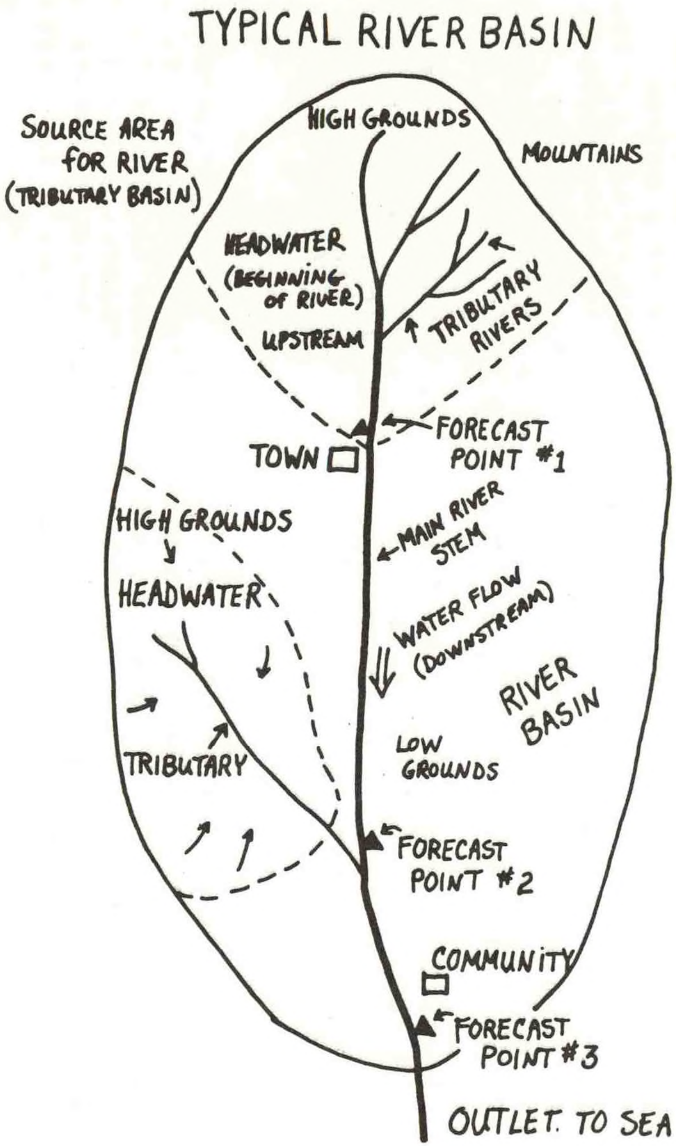
As the rain continues, the river will begin to rise up the river bank as depicted in the cross-sectional view of the main river channel shown in figure 1b. At 10 a.m., the water stage (height) reaches the point where the bank is full. Beyond this point, the water will overflow the bank and flow into the flood plains so that flooding takes place. A river gage of the staff type or other more sophisticated means can be used to measure the stage of the river.

If a plot of the river stage as a function of time is made as shown in figure 1c, the resulting curve is called a hydrograph. This hydrograph is a fundamental hydrologic product. The flood stage of the river, determined by field survey, is shown on the hydrograph. With this information, one can see when the rising river can be expected to flood and when it can be expected to crest (12 noon) and drop below flood stage.

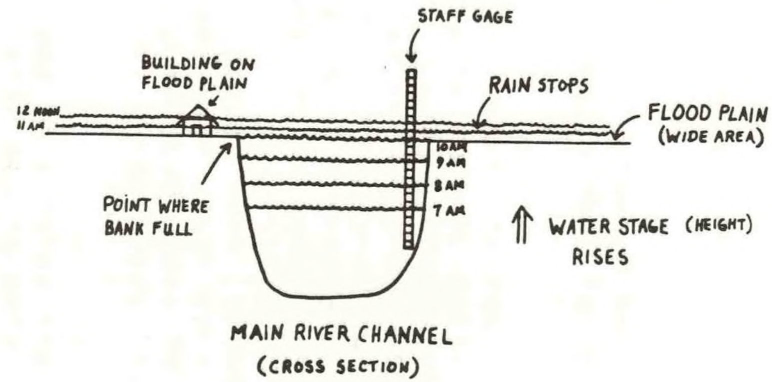
In practice, based on precipitation data and the characteristics and the initial physical state of the basin, forecasts are made on the rise and fall of the river at specific forecast points. Three of these forecast points are shown in figure 1a.

2.2 River Forecasting Concept

A basic output product of a river forecast is a hydrograph. In order to simply illustrate the concept of river forecasting, two hydrologic mathematical models, one designated as the soil moisture accounting model and the other as the channel routing model, will be used. (Other models can be introduced, but they are not pertinent to explaining the concept.) Assume a forecast of the river stage is to be made for forecast point #3.



1a.



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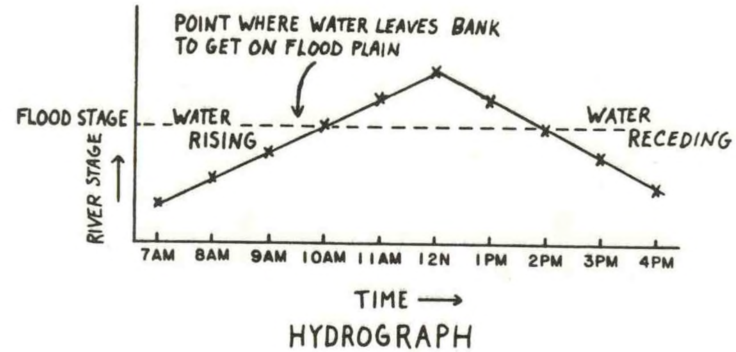


1c.

FIGURE 1

Examination of figure 1a shows that the river stage at forecast point #3 depends on the amount of water flowing through forecast points #1 and #2. Because the basin runoff characteristics and initial ground wetness when rain begins play a critical role in the accuracy of the forecast, these factors must be taken into consideration. Thus, the first step in the analysis is to use the soil moisture accounting model to calculate how much of the measured (or predicted if available) rainfall will be absorbed by the ground and how much water will flow into the river in the tributary basin at the beginning of the main stem river so that a hydrograph can be generated for forecast point #1.

In order to predict how much water will flow through forecast point #2, the water passing through forecast point #1 must be routed through forecast point #2. The second step in the analysis then is to use the channel routing model to mathematically simulate movement of the water down the main river channel to forecast point #2. The output of the channel routing model is a hydrograph resulting only from the water flowing down the river through forecast point #1. The rain that has fallen in the basin between the two forecast points which has not been accounted for must now be entered into the analysis. The third step is to use the soil moisture accounting model again to account for the rain falling down stream of forecast point #1 so that a hydrograph can be made for forecast point #2. The final hydrograph for forecast point #2 will be a combination of the hydrographs from the channel routing model and the second running of the soil moisture accounting model.

In order to get a hydrograph valid for forecast point #3, the process will have to be repeated by channel routing the water and soil moisture accounting the rainfall over the area between points #2 and #3. Thus, the hydrograph at forecast point #3 will include the hydrologic and hydraulic outputs of forecast points #1 and #2.

3.0 SCOPE OF NATIONAL WEATHER SERVICE RIVER FORECASTING

Since people like to establish residences and communities close to the rivers and therefore in the flood plains, the flood warning aspects of NWS's programs are oriented toward making river stage and flood forecasts for various points in the river basins to warn residents of impending flood dangers. The purpose of this section is to delineate the extent of NWS's river forecasting activities prior to discussing the details of the system operations from organizational and procedural points of view.

3.1 Number of Forecast Points

There are literally thousands and thousands of river basins of various sizes, shapes, and characteristics which make up the United States. Some of the basins have flooding problems and others do not. The Federal Emergency Management Agency (FEMA) has identified 20,000 flood prone places. NWS's flood warning program is directed toward serving these 20,000 places.

For various reasons, NWS is provides services to the 20,000 places on a nonuniform basis. Specifically, NWS provides flood warnings for 3,000 designated forecast points. Generally, there is a river gage at these points. The relationship of the forecast point to the potential area of inundation is usually not known, except for those places where NWS, the Corps of Engineers (COE), local authorities, and others have jointly studied the situation and defined where the flood waters might flow.

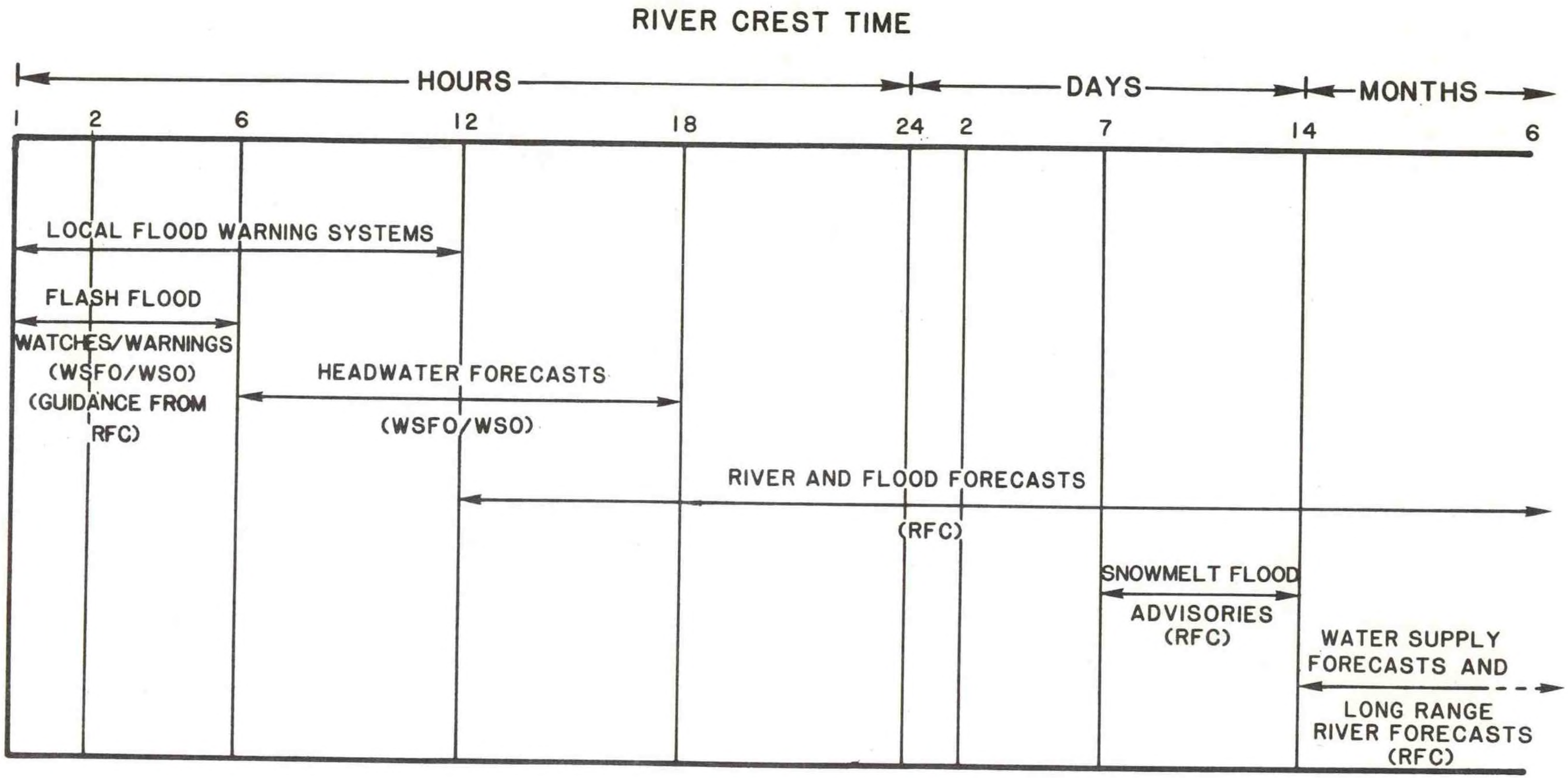
3.2 Distribution of Forecast Points

Of the 3,000 forecast points, approximately 1,000 of them are for headwater areas, and headwater flood forecasts are provided for them. The remaining 2,000 points are along river main stems, and river and flood forecasts are provided for them. The reason for the distinction is the rapidity with which a flood situation (i.e., river flood crests) can develop at the forecast points following a specified amount of rainfall during a given time period over the river basin. For the 1,000 headwater forecast points, most of the rivers can crest and overflow 0 to 18 hours after rainfall begins. The rivers in the 2,000 places not in the headwater areas can crest 12 hours or more after rainfall begins. These hours are referred to as river crest times.

The River Forecast Centers (RFC's) are responsible for providing river and flood forecasts for most of the 3,000 forecast points. These forecasts are sent to the Weather Service Forecast Offices (WSFO's) and Weather Service Offices (WSO's) for dissemination to the public. WSFO's and WSO's, using guidance information from RFC's, generate and disseminate forecasts for the remainder of the 3000 points not covered by the RFC's.

Of the remaining 17,000 flood-prone places, 550 of them are serviced by local flood warning systems that are established with the expertise and guidance of NWS hydrologists, although they are owned, operated, and maintained by the local authorities. The other approximately 16,000 places are served by NWS on a county-wide basis, but the service is limited to generalized flash flood warnings which indicate only that flooding may be expected somewhere in the area.

Figure 2 shows the relationship of hydrologic services to river crest times.



RELATIONSHIP OF HYDROLOGIC SERVICE'S TO RIVER CREST TIME

FIGURE 2

4.0 PRESENT RIVER FORECASTING SYSTEM

The purpose of this section is to highlight the functions of the present river forecasting service in terms of the NWS organization and major elements of the forecast service, e.g., data collection and analysis, forecast preparation, and dissemination.

4.1 National Weather Service Field Organization

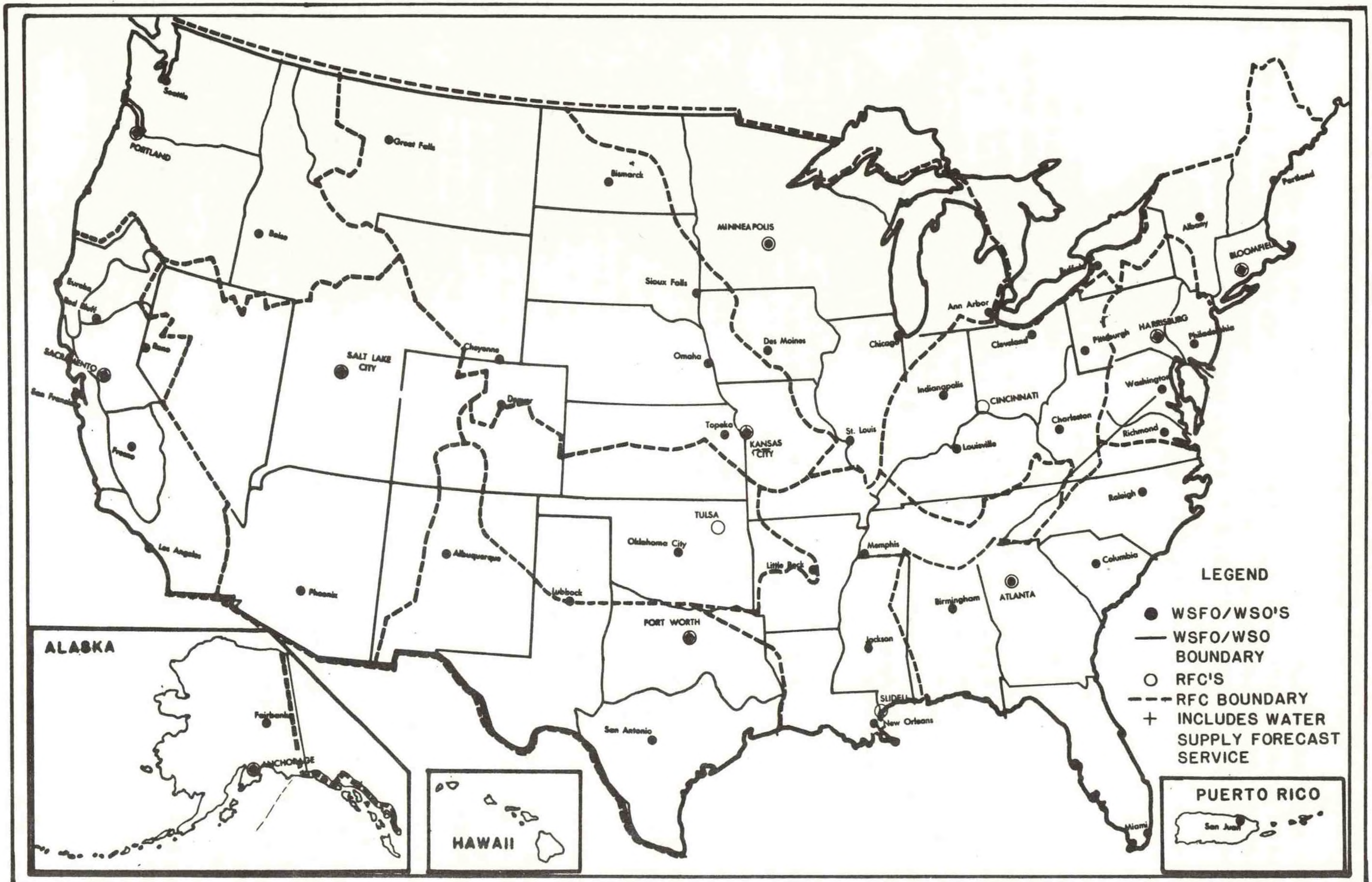
4.1.1 River Forecast Centers (RFC)

There are 13 RFC's that are responsible for the preparation of hydrologic guidance and forecasts. An RFC is staffed with professional hydrologists. For hydrologic reasons, the RFC area of responsibility is organized along river basin boundaries as shown in figure 3. Each RFC serves several WSFO's. The RFC's use hydrologic data received by WSO's, WSFO's, and other agencies and, in some instances, collect data directly from observers. Hydrologic data are analyzed and processed in computers for the preparation of site specific river forecasts, flood forecasts, advisories, and hydrologic guidance. When lead time exceeds 12 hours, time is available to collect data, process data, run hydrologic models, analyze results, and prepare a forecast. Thus, the RFC is able to provide some headwater forecasts and the river forecasts and snowmelt advisories illustrated in figure 2. They also routinely provide flash flood guidance criteria on a county or zone basis to the WFSO's. RFC's are responsible for execution of the technical aspects of the hydrologic field programs and provide technical assistance to the WSFO's. Accordingly, RFC hydrologists have helped develop and are responsible for the forecast procedures in their area. These procedures, which utilize state-of-the-art hydrologic models, must be continually updated to account for natural and man-made changes affecting river basins. Utilizing sophisticated computer resources, RFC hydrologists develop computer software to run hydrologic models and process large quantities of data.

In addition, RFC hydrologists provide technical advice for local flood preparedness planning and water management decisions and develop forecast procedures for the Local Flood Warning Systems for communities. The RFC hydrologists also provide WSFO's and WSO's with headwater flood forecast procedures for those river basins that respond so quickly to rainfall that warning time may be extremely short. The WSFO's and WSO's use these procedures in conjunction with the guidance provided by the RFC's to make the operational forecasts.

4.1.2 National Weather Service Forecast Offices (WSFO)

The WSFO's have the responsibility of delivering the river and flood forecast service to the public. Most WSFO's are assigned a hydrologic service area (HSA) that corresponds to its forecast service area. The HSA normally consists of a state (see



RFC BOUNDARIES AND WSFO/WSO HYDROLOGIC SERVICE AREAS

FIGURE 3

figure 3), although there are exceptions. The WSFO is responsible for issuing to the public various hydrologic products, incuding flash flood watches and warnings, flood warnings, river and flood advisories, and daily river forecasts. The WSFO is also responsible for collecting and relaying river and rainfall observations; adapting to local needs the river and flood forecasts provided by an RFC; preparing river forecasts for rapidly rising headwater rivers; and disseminating to the public all hydrologic forecasts, including flood and flash flood warnings.

As shown in figure 2, the WSFO provides flash flood watches/warnings when lead times are less than 6 hours. Floods which occur in these extremely short time intervals are known as flash floods and require immediate detection and warning. For lead times of 6-18 hours, the WSFO's provide limited headwater flood forecasts. The WSFO's are open around the clock with a staff which consists primarily of meteorologists trained to provide hydrologic program functions and, in most instances, includes a service hydrologist. In addition to performing 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., local chapters of the American Red Cross and the FEMA. The service hydrologist also coordinates the hydrologic program with the local offices of agencies such as the COE, U.S. Geological Survey (USGS), Bureau of Reclamation, and Soil Conservation Service (SCS).

4.1.3 Weather Service Offices (WSO)

The WSO's are smaller offices that also have hydrologic function responsibilities. Many WSO's have county flash flood warning service responsibility (see figure 2), and some collect hydrologic data and disseminate river forecasts and flood warnings to the public. WSO's also provide communities an advisory service that informs community officials of protective measures that can be taken to minimize loss of life and destruction of property caused by floods.

4.1.4 Other Organizational Components

Quantitative Precipitation Forecast (QPF) support for the hydrologic program is provided by the National Meteorological Center (NMC), through its Heavy Precipitation Branch (HPB). QPF's are reviewed and updated by the WSFO's for the RFC's. Accurate and timely prediction of heavy rainfall events is extremely important for hydrologic forecasting.

The National Environmental Satellite Data and Information Service (NESDIS) is involved in hydrologic support via supplying NWS field offices with satellite imagery, relay of data, and special applications of image analysis. The Synoptic Analysis Branch of NESDIS provides satellite estimates of rainfall to NWS field offices.

Management of the hydrologic field operations program is provided by six NWS regional headquarters. The regions supervise the hydrologic service program and provide some technical support. The Regional Hydrologist is the focal point for these activities. The Regional Hydrologists and his staff are actively involved in defining hydrology program requirements and providing solutions to operational problems, and are responsible for coordinating with field offices, NWS Headquarters, and other agencies. A major task involves the development and continuation of cooperative operating agreements with major water resources agencies, such as the COE and USGS.

The Office of Hydrology (O/H) at NWS Headquarters establishes policy for the hydrologic program within NWS and provides a national focus on the NWS's hydrologic services. National interagency coordination and budget management and planning to meet long term needs and international participation in the world's hydrologic community are major functions of O/H. The O/H provides support to the hydrologic field program in the design, deployment, and procurement of computer systems, and technical support of computer and communications systems. Applied research and development of forecast procedures and hydrologic techniques are major technical support activities provided by O/H and are unique in the world.

4.2 Elements of the Forecast System

Conceptually, a hydrologic forecast service should be considered as part of a total flood forecast and response system (Krzysztofowicz and Davis, 1982). The reason for this is simple -- a flood forecast is of value only if it induces a response from a flood plain user which leads to an effective reduction of loss. In this context, the forecast-response system can be viewed as being composed of five elements --(1) the data collection network which records data in the field and sends them to an RFC and/or WSFO and WSO where they are transformed for use in a hydrologic forecasting procedure; (2) the forecasting procedure which includes all the objective and subjective procedures employed by the forecaster in order to compute a forecast of the magnitude and time of occurrence of a flood crest at a specific forecast point on a river or to identify possible areas of inundation; (3) the dissemination channels which communicate the forecasts to the flood plain dwellers via routes such as the NOAA Weather Wire Service (NWWS), NOAA Weather Radio (NWR), telephone, and various public and private organizations; (4) a decision procedure which is used by residents of the flood plain, objectively in the case of preplanned emergency procedures and subjectively otherwise, to determine the degree of response, the type of protective action, and the allocation of resources for various protection activities; and (5) the set of protective actions (such as evacuations, flood proofing, shutdown of facilities) to reduce potential losses, which are taken by the flood plain user in response to a flood warning.

Although all five elements are part of the forecast-response system, it should be noted that NWS is not in control of all these elements. Specifically, NWS can control the forecast system through data collection, hydrologic procedures, and communications systems, but it can only influence the response system through public education and dissemination of contingency information.

Appendix A provides additional details on the five elements of the forecast-response system.

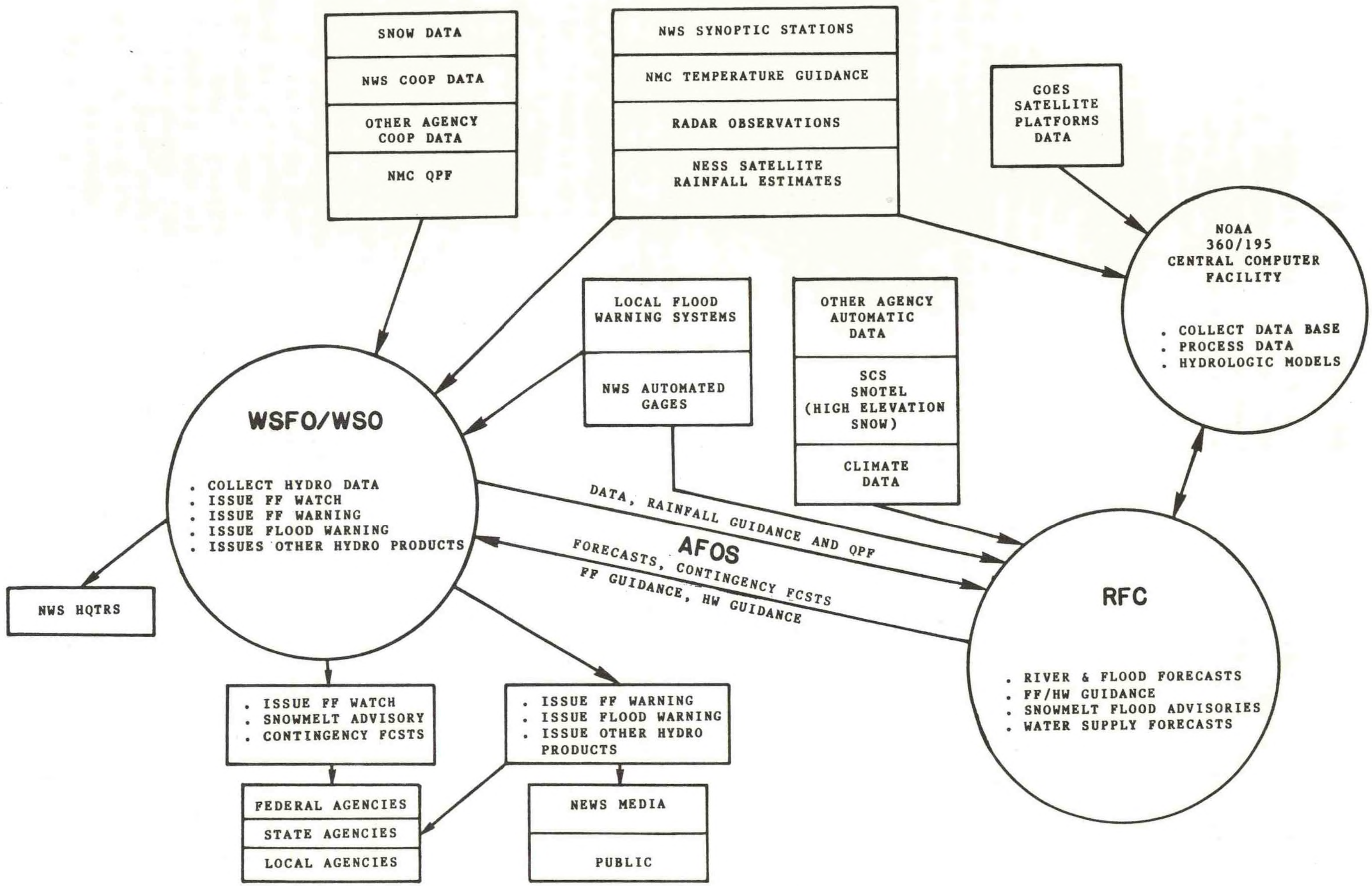
4.3 Functional Flow of Forecast Service

The preceding sections discussed the general operations of the WSFO's/WSO's and RFC's and highlighted the basic elements of a forecast system. The purpose of this section is to illustrate, using the functional flow diagram of figure 4, the general operations of the NWS river forecast service by sequentially tracking, beginning with the inflow of data, the generation and ultimate dissemination of the forecast products. In the process, some of the complexities of the system will surface. The discussion is directed toward providing the background for the subsequent problem analysis and the identification of goals for improving the system.

4.3.1 Flow of Input Data

The data collection network of the NWS river forecast service is composed of a river and rainfall observing system and remote sensing devices which detect precipitation fields (radar, satellite imagery, and aerial gamma detection). The ground truth observation system is composed of manually read and automatically reporting gages, owned, maintained, and operated through a very complex set of relationships among Federal, state, and local authorities.

As can be seen from figure 4, data from the various sources selectively enter directly into the WSFO or WSO, RFC, and National Oceanic and Atmospheric Administration (NOAA) central computer facility (currently the IBM 360/195 system). For example, data from the NWS cooperative observer network, snow data, and other agency data go directly to the WSFO or WSO, whereas the data and forecasts from the local flood warning systems and data from the NWS automated gages go directly to both the WSFO or WSO and RFC. Similarly, data from the NWS synoptic stations, NMC temperature guidance, radar observations, and NESDIS satellite rainfall estimates go directly to the WSFO/WSO and the 360/195 computer system. Note that the RFC needs the data from virtually all the sources in order to carry out its river forecasting function, but it relies on the WSFO or WSO to send certain data (e.g., from the NWS cooperative observer network), and it also must access the 360/195 system to get the synoptic, radar, and satellite data.



FUNCTIONAL FLOW DIAGRAM OF FORECAST SERVICE

FIGURE 4

4.3.2 Product Generation and Dissemination

The basic concept of river forecasting has already been explained in section 2.0. However, before the RFC's can do any analysis, the data have to be subjectively quality controlled (evaluated for errors), reformatted, and sent to the central computer facility to be organized into appropriate data files, and to be processed for use in making the forecasts. River and flood forecasts, flash flood guidance, headwater guidance, snowmelt advisories, and water supply forecasts are principal RFC products. These products are forwarded to the WSFO or WSO for their use in preparing flash flood forecasts or for direct dissemination to the users of river and flood forecasts since the WSFO or WSO has the responsibility for service delivery.

The WSFO or WSO with guidance from the RFC, as required, prepare flash flood watches and/or flash flood warnings for issuance to the public; news media; Federal, state, and local agencies; and NWS Headquarters as indicated in figure 4. NWS Headquarters uses the material to brief national disaster preparedness agencies.

Additional details on the operations of the forecast system can be found in appendix A.

5.0 FORECAST SYSTEM PERFORMANCE

Flash flood watches and warnings, headwater forecasts, river and flood forecasts, snowmelt flood advisories, and water supply forecasts are the major hydrologic services provided by the NWS river forecast services. The rapidity with which such flood events can develop following a specified amount of rain over a given time interval already has been plotted as a function of river crest time in figure 2 (p. 3-3). It is now necessary to look at this figure in more detail.

As indicated in the figure, the shortest fused events are flash floods, which can develop anywhere from 0 to 6 hours from the time rain falls. Floods in the headwater areas can occur any time between 0 and 18 hours, but for those events that occur between 6 and 18 hours, forecasts issued are designated as headwater forecasts. Floods in major rivers, however, can take from 12 hours to several weeks to develop. A word of caution is in order here -- these river crest times are approximate and there certainly are overlaps; they are not as clearly delineated as the figure may indicate. Nevertheless, events that develop within 18 hours are considered as being the upper boundary of rapidly occurring events for purposes of this PDP.

As might be expected, the primary effectiveness of flash flood warnings is in saving lives. There is little time to save personal belongings and property. For the 6- to 18-hour events, however, the effectiveness of the warnings is measured in terms of saving both lives and property. The saving of property in these events is restricted generally to moving highly valued property, such as automobiles, television sets, appliances, etc., to higher ground or otherwise out of the endangered area. Beyond 18 hours, the emphasis is on saving property, since there is ample time to warn people and save lives. The ability to achieve any of the benefits, however, is clearly dependent, as a minimum requirement, upon the amount of warning lead time (time between the issuance of the warning and the occurrence of the flood), that can be provided operationally to the flood plain dwellers.

5.1 Performance Statistics

There is little verification data available for assessing the various aspects of the forecast system. Consequently, in the discussion which follows, the measure of system performance is based strictly on the lead time provided for the flash flood and headwater flood situation, i.e., the 0- to 18-hour events.

The following information is derived from verification studies:

- More than 70 percent of flash flood warnings have less than 1-hour lead time.
- More than 50 percent of flash flood warnings have no lead

time -- flooding has already occurred.

- On the average, for headwater forecast points, only a 4-hour lead time can be provided for an 18-hour flood event and a 1/2-hour lead time for a 6-hour event.

- Longer river flood events have an average lead time of 2 days, and an average error of about 2 feet in forecasting the crest stage.

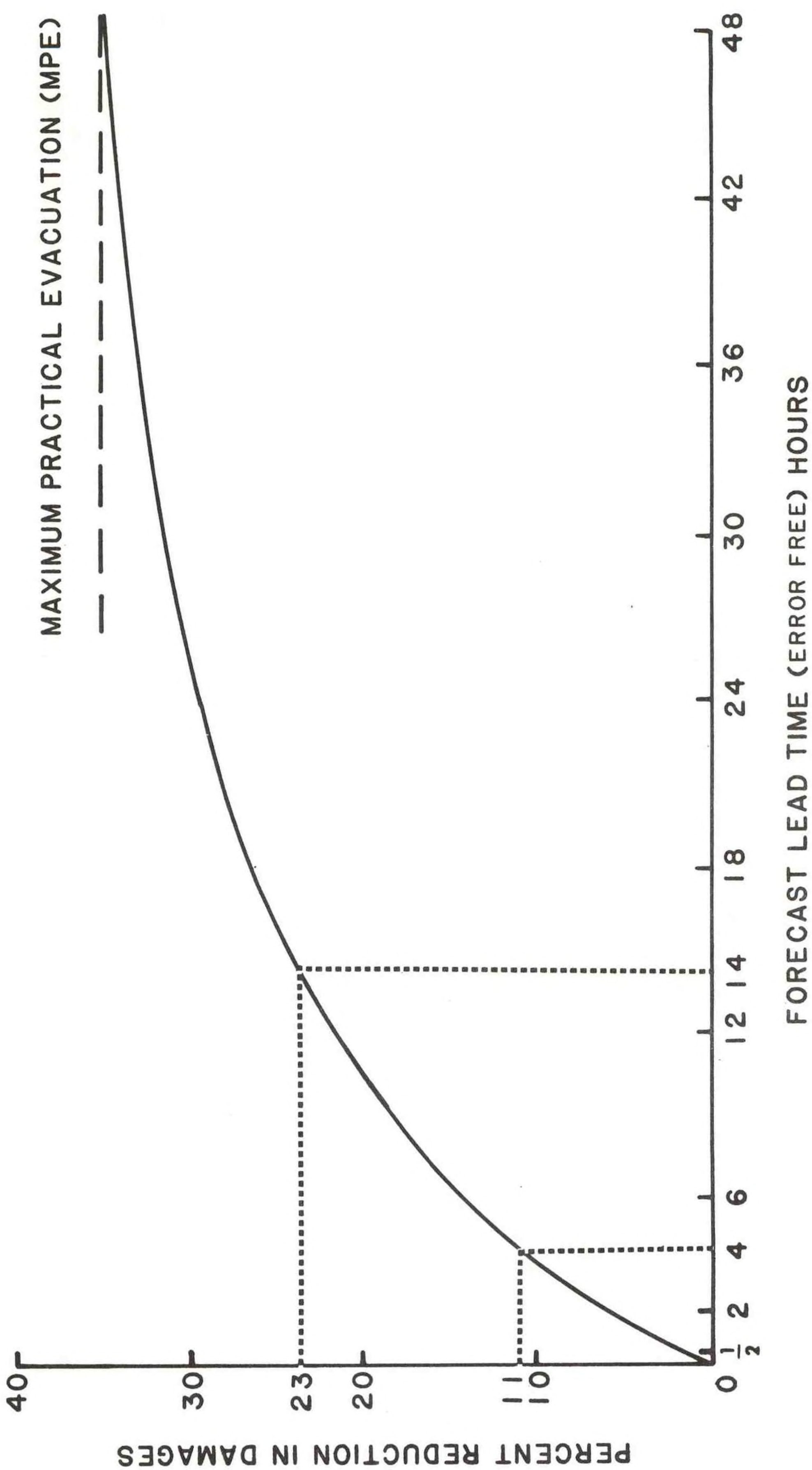
Based on the above statistics, it can be estimated that the current capability of the forecast service is to provide forecast lead times from less than 1 hour for flash floods to 4 hours for an 18-hour event. Longer events have sufficient forecast lead time, but improvement in accuracy of forecast flood stage is needed.

5.2 Damage Reduction Versus Lead Time

Figure 5 is a plot showing the percent reduction in damages as a function of forecast lead time. This curve is not universally valid for all damages. It was originally developed by the Environmental Science Services Administration but reconfirmed to be valid in 1979 by an NWS contracted study. The curve is applicable to actions an individual can take in protecting personal property. For these actions, reduction in damages generally is limited to saving portable property and does not include items such as flood fighting (e.g., sand bagging) or flood proofing of structures.

Although the curve was designed for individuals, it is believed that the curve is also reflective of opportunities for savings for commercial interests. There probably would be small business enterprises in the flood plains in the headwater areas. Accordingly, the curve is assumed to be valid for the commercial sector. Since individuals in commercial business can probably avoid damages to more expensive portable products, the curve should yield a very conservative estimate of damage reduction.

By plotting the 1/2-hour to 4-hour forecast lead time capability of the current NWS river forecast service for the 0- to 18-hour events (figure 5), a percentage reduction in damages ranging from about 1 percent to 11 percent is indicated.



DAMAGE REDUCTION = F (LEAD TIME)

FIGURE 5

6.0 PROBLEM ANALYSIS AND SERVICE IMPROVEMENT GOALS

Appendix B provides a detailed, systematic problem analysis of the hydrologic service. This section addresses those problem areas in which corrective actions are required to overcome the identified forecast service deficiencies. These problem areas were selected to achieve maximum benefits with minimum changes. For example, it is known that improvements in the capability to increase flood forecast lead time for headwater areas will also lead to improvements for the flash flood and river forecast programs. Benefits will also be realized in the water resources management area because the forecasts for water management use essentially the same data bases and forecasting methods. By using this type of approach in determining where corrective action should be taken, it was concluded that improvements are needed for three areas: (1) flood forecast lead times, (2) water supply and long-term river forecasts, and (3) local flood warning systems. As practicable, the improvements will be quantized in terms of potential economic benefits so that the estimated costs required to effect their achievements can be compared. The activities needed to achieve the improvements, when scheduled and priced, will become the basis for the implementation of this PDP.

6.1 Flood Warning Service Problem Areas

The flood forecast lead time of 1/2 hour to 4 hours for the 0- to 18-hour flood events, as explained earlier, can surely be judged as needing improvement. Before any improvements are made, however, a problem analysis of the flood warning service should be conducted to try to isolate the factors preventing the issuance of more timely flood forecasts so that corrective measures can be meaningfully developed. Such an analysis was made (see appendix B) with the major conclusions that deficiencies in the data collection network, lack of an integrated data system, and inadequate application of forecast models and techniques collectively contribute to delaying the issuance of flood forecasts, particularly for the headwater areas. These findings are highlighted below.

6.1.1 Data Collection Network Deficiencies

- Inadequate precipitation gage density prevents adequate determination of mean areal precipitation (MAP) and degrades forecast accuracy and lead time. Many storms are not detected because of this network deficiency.
- The once-per-day sampling interval of precipitation and streamflow data is not adequate to provide lead time for headwater flood events.
- Use of the criterion reporting procedure by cooperative observers can result in data not reaching the forecast model, representing as much as 70% of total precipitation. (A criteria report is made when rainfall of 0.5

inch or more has occurred.) Forecast accurancy and timeliness is severely limited by this situation.

6.1.2 Lack of an Integrated Data System

- Large delays in data collection, due to manual data handling at the WSFO's reduce warning lead time.
- The WSFO's do not have enough real-time data to make decisions on issuance of flash flood forecasts and warnings.
- Manual data handling at the RFC's results in reduction of lead time.
- The RFC generated forecasts and guidance do not use all available data. This translates into limited accuracy and timeliness.

6.1.3 Inadequate Application of Forecast Models and Techniques

- The RFC's are unable to calibrate completely the hydrologic forecast models because the real-time or historical data bases are inadequate and because simple calibration procedures are not available. At the present rate of calibration using historical data bases, it will take 20 years to calibrate all river basins. There are no operational models which allow recalibration in real time. These conditions degrade accuracy.
- Present forecast procedures used to produce long-term water supply forecasts can be highly inaccurate (average errors of 18 percent) and are severely limited in providing the potential water management services now possible with newer models.
- There is no simple yet comprehensive model available at the WSFO or WSO to give the capability to issue a flash flood warning or headwater flood forecast using all the data available.
- NWS does not provide enough site specific information in flood forecast and warning products for individuals to take action.

6.2 Improvements in Flood Forecast Lead Times

Of the contributors to lead time delays, the cooperative observer network is the most significant primarily because the observations are taken manually. The logical solution to this problem is to automate the precipitation gages. For the delays encountered in data handling and analysis (see figure 4, p. 4-6), the solution is to develop and implement an integrated hydrometeorological data system for use by all concerned. With respect to the forecast models, the solution is to seek less complex functions and different approaches to improve and speed up the calibrations and computational analyses, and to model the interaction of hydrologic and meteorological processes.

Accordingly, the main goal of this PDP is:

> To improve the flood forecast lead times for the 1,000 headwater forecast points where the rivers can crest from between 6 to 18 hours for the primary purpose of reducing property damages.

By collectively taking the corrective measures discussed above, an approximately 4-hour maximum delay time can be attained operationally before a forecast is issued. This delay time is composed of a 3-hour observation of the rainfall to be sure that a problem exists, followed by up to 1 hour to provide the flood forecast and issue the warnings.

Using this 4-hour delay, the flood warning lead time for an 18-hour flood event could be increased to 14 hours instead of 4 hours as indicated by verification studies. Similarily, the lead time for a 6-hour flood event will increase from 1/2 hour to 2 hours. By plotting these new lead times on figure 5 (p. 5-3), an increase in the potential reduction in damages of about 12 percent is indicated for the 18-hour flood event and about 5 percent for the 6-hour flood event.

By going through the above type of analysis for each of the forecast points in the headwater areas for the 6- to 18-hour flood events, a potential additional savings of about $100M per year can be derived from reduction in damages to personal properties. This amount is based on the current estimated annual property loss of about $5B. Appendix C shows how these cost savings were estimated.

Improvements to the service to provide a lead time of 2 hours for a 6-hour flood event also will contribute significant improvements in the 0- to 6-hour flood events, where most benefits can be realized in the saving of human lives.

6.2.1 Automation of Precipitation Gages

In order to provide adequate observations of rainfall in the headwater areas, 5,700 automated precipitation gages are needed. Appendix C gives the details supporting the requirements for these gages. The key points in the determination are listed below:

a. Tables have been developed which show the number of gages (as a function of the square mile area of a basin) required to get adequate rainfall data for 80 percent of the storms with an error of plus or minus 20 percent.

b. One-third of the 3,000 basins currently forecasted have drainage areas 1000 square miles or less.

c. The distribution of the sizes of the headwater areas is known.

d. Use of the tables noted in item (a) leads to a requirement for an additional 5,700 gages in the headwater areas.

e. Gages need to be automated because the sampling intervals must be 4-1/2 hours or less, since the longest river crest time in the headwater areas of concern is 18 hours.

Although 5,700 automatic rain gages are required, it is expected that other cooperative agencies will increase their numbers to over 3,000. Since NWS has about 500 automatic rain gages in the headwater areas, it needs an additional 2,000.

It should also be noted that the automatic rain gages will be used to provide ground truth for digitized weather radar calibration during the rainfall event. Studies have shown that a network of 25 automatic rain gages under each radar umbrella are needed. For those headwater areas covered by the radars, the utilization of these automatic rain gages will enhance the forecasting capability to track storms which can produce flash floods. A network of about 100 next generation weather radars (NEXRAD) is envisioned for NWS late in this decade.

6.2.2 Integrated Hydrometeorological Data System (IHDS)

Various data types from multiple sources with differing times of observation, and quality enter the NWS system. However, neither the RFC's nor the WSFO's or WSO's are currently capable of integrating all of the incoming real-time data for the generation of flood forecasts and warnings. This situation constitutes a critical problem now and will get worse as the NWS and other agencies continue to expand their networks. Thus, a goal of this PDP is:

> To develop and implement an integrated hydrometeorological data system (IHDS) for use by the WSFO's and RFC's. The operational utilization of the IHDS will reduce the delays in data processing from about 4 hours to 1 hour.

6.2.2.1 Concepts of An IHDS

A fundamental step preceding any production of hydrologic forecasts of river stages and floods is the conversion of point data into mean areal values. This conversion is necessary because the hydrologic models require mean areal values as input. Specifically, mean areal precipitation (MAP), mean areal temperature, mean areal potential evapotranspiration, and mean areal water equivalent of snow constitute the family of mean areal values that are required operationally. These values currently are being generated through combinations of manual and automated techniques. There are, however, excessive requirements for manual handling and processing before the mean areal estimates finally can be derived. The concept of the IHDS therefore is to automate the data collection and processing and to provide for whatever other manipulations are required to convert point data into mean areal values for input to the hydrological models. Information in the IHDS will be available automatically to the WSFO's and RFC's through a distributed system of data bases. It is to be emphasized that IHDS is a system of software, hardware, and communications media, and not just a single passive data base. Data bases are part of the system.

6.2.2.2 Major Data Bases

There are several major data bases which need to be included in the IHDS. These data bases are highlighted below in terms of current data collection and processing capabilities. The inclusion of these data bases in the IHDS will eliminate many of the current data handling and processing problems.

The Geostationary Operational Environmental Satellite (GOES) data base is a major source of automatically collected point data. These data are available to the RFC on a delayed basis and are not available to the WSFO's.

The Central Automatic Data Acquisition System (CADAS) collects data via telephone. This is part of the Automatic Hydrologic Observing System (AHOS). The data are available to RFC's and WSFO's through a dial-up capability.

The cooperative observer network consists of rainfall, snow, and river gage observations that must be manually input (at the WSFO) into Automation of Field Operations and Services (AFOS) and then retranscribed and manually input to the RFC forecast system data files.

Data from the NWS/FAA synoptic and aviation observation networks, known as the SA's and SM's, consist of 3-hour and 6-hour observations and are automatically input to the NOAA central computer facility located in Suitland, Maryland. The RFC's reprocess these data and send them to their forecast system data bases. At the WSFO, the data are not available in digitized format for use in generating headwater forecasts.

Digitized radar information is available using two different techniques. The manually digitized radar information is available to the WSFO via AFOS and is available to the RFC's in a data base on the central computer facility. Some RFC's can process the radar data into rainfall estimates and use them with observed precipitation values to produce a MAP. However, most RFC's do not have this capability.

A second type of radar data is more accurate for use in determining rainfall amounts. The hydrologic rainfall analysis project (HRAP) conducted by the Hydrological Research Laboratory (HRL) is now processing high resolution digitized radar data in the Arkansas River Basin. The data are available at the central computer facility but can only be used to provide MAP's for the Tulsa RFC.

Another major data base is composed of QPF's. These values are formulated and issued by the NMC's HPB. The data are relayed to the various Critical Support Forecast Offices which are WSFO's responsible for giving local interpretation to the values and for supplying QPF to the RFC. Final QPF is relayed to the RFC via phone where it is manually transcribed and input to the forecast system by RFC hydrologists.

Digitized rainfall estimates derived from satellite data will be available in the future. An automated data distribution system is being tested now.

6.2.2.3 IHDS Development Approach

As stated in 6.2.2.1, the IHDS will serve as the vehicle for collection and processing of data and analysis of data. The output of the IHDS will be mean areal estimates of various hydrometeorological data. This section describes the two major aspects of the IHDS and the steps leading to implementation of the system. These two major aspects are development and implementation of (1) the WSFO, RFC, and national data bases and their linkages and (2) hydrometeorological data analysis techniques.

6.2.2.3.1 IHDS Data Bases

It is clear that both the RFC's and WSFO's require hydrometeorological data in order to prepare properly their hydrologic forecasts. The objective of the IHDS is to provide the needed data to the users ready to be input into the hydrological models. As part of the IHDS, a national hydrometeorological data base will be established at the central computer facility. This will be the largest and most complete data base in the IHDS, providing a basis for both historical and real-time hydrometeorological data needs and serving as the primary link between the five major data sources identified above and the NWSRFS. The centrally located data base will also be a major contribution to other NOAA activities and offices such as the NOAA Climate Program and NMC's HPB.

WSFO's do not have direct access to the central computer facility, but the RFC's do. Consequently, the RFC's can access the central computer facility for whatever hydrometeorological data are necessary for quality control, analyses, and forecasting. A localized data base (a subset of the national), resident on the minicomputers at the RFC's, could provide the access to data needed by the WSFO's. However, the WSFO's currently do not have such capability of access, and RFC minicomputers have storage capacities too limited to contain the data needed locally.

The developmental approach to IHDS is to create a national hydrometeorological data base at the central computer facility and to augment the RFC's minicomputers for local data handling, processing, and storage. The final step in the development of the IHDS is to introduce a capability for the WSFO's to access the RFC minicomputer data files. The IHDS thus will link the WSFO's, RFC's, and central computer facility together and operate as a distributed system of data bases.

To provide an integrated hydrometeorological data base at the RFC, the following activities are required:

- upgrade RFC minicomputer mass storage capacities;
- design, develop, and implement local RFC data base parallel to design of a national data base for the central computer facility;
- design the input/output software needed to collect, reformat, and quality control data;
- document, test, debug all data base software; and
- implement new data base and data system software at all RFC's.

To provide a national hydrometeorological data base at the central computer facility, the following activities are required:

- design, develop, and implement software routines to receive, format, and distribute data from major data sources;
- design, develop, implement, and maintain an overall data base structure as a national repository for the real-time and historical hydrometeorological data needs of NOAA;
- design, develop, implement, and maintain the necessary linkages of the national data base to the NWSRFS; and
- design, develop, implement, and maintain the necessary linkages from the national data base to the local RFC and WSFO data bases, including product scheduling, formatting, and formulation.

In order to provide data base capability at the WSFO for use in analysis of hydrometeorological data for headwater and flash flood forecasting, the following activities are required:

- develop WSFO data base requirements, including definition of extent of reliance on local RFC data bases, with particular emphasis on handling locally and nationally available digitized radar and satellite data, and capability to run simplified flood forecast models in a standardized software structure;

- design WSFO data base, based on above requirements, and as an operational prelude and necessary step towards System II;

- assess the availability of and procure the most appropriate low cost microcomputer with hardware, software, display, computing, and storage capabilities necessary to satisfy the design requirements;

- develop, document, test, and debug data base software; and

- implement and maintain software.

6.2.2.3.2 Hydrometeorological Analysis Procedures

As discussed above, a major factor related to the improvement of forecast lead times is the acquisition of more frequent and timely hydrometeorological data. However, more complete data coverage will improve forecast lead times only if the data information is properly ingested and used in an objective way to predict future hydrologic conditions. Development of suitable objective data analysis procedures must encompass considerations of both conventional sensors (such as rain gages) and remotely sensed data from radars and satellites. Procedural development also must be applicable to a range of time scales which span from the shorter scales accompanying flash flood occurrences to those relevant to predicting flows on main stem rivers. The HRAP is aimed at designing and implementing such objective rainfall analysis procedures. Rainfall is often the most critical variable affecting hydrologic predictions. The HRAP work is being coordinated with activities underway in NEXRAD, System II, and other NOAA elements. A particularly important activity related to HRAP is the design and implementation of the precipitation processing system necessary for optimum use of NEXRAD data, both for flash flooding and larger scale river forecasting and water management applications.

In order to develop objective analysis techniques for estimating mean areal hydrometeorological values, the following must occur:

- design, develop, and implement the precipitation processing system for NEXRAD which requires the incorporation of information unique to each NEXRAD site;

- design, develop, and implement data collection and quality control procedures to assimilate NEXRAD rainfall estimates into IHDS data bases;

- design, develop, and implement procedures to assimilate, manage, and quality control rain gage data in IHDS data bases for input to multisensor objective analysis routines;

- design, develop, and implement objective analysis procedures for merging multi-radar, rain gage, and satellite rainfall data into optimum estimates for mesoscale rainfall analyses;

- transfer information from national/regional analyses and/or develop procedures for deriving local mesoscale rainfall analyses for input to local WSFO forecast procedures.

6.2.3 WSFO Hydrometeorological Prediction System (HPS)

Two major program thrusts have already been identified to improve forecast lead times. Enhanced data networks will feed into an integrated data system -- the output will be estimates of mean areal hydrometeorological data for input to forecast models.

Translation of hydrometeorological observations and data into hydrologic predictions requires the use of one or more hydrologic prediction procedures. These procedures often take the form of hydrologic models. Types of watershed models range from relatively simple rainfall/runoff models to detailed soil moisture accounting models which are physically based. Types of hydraulic and river mechanics models range from simple routing procedures to the solution of the dynamic equations of motion of water in complex river and water reservoir systems.

As previously described, the WSFO's are responsible for disseminating to the public the river forecasts produced by the RFC's. The RFC's are, in turn, responsible for supporting the WSFO's with as much information as possible to allow the WSFO's to fulfill their service responsibilities pertinent to large scale river forecasting, as well as flash flood predictions. Current procedures used at the WSFO's and WSO's in support of the NWS headwater and flash flood watch and warning services are based on the consideration of information coming from various sources and on observations taken at the local offices or relayed to them on existing communications circuits. Incorporation of this information into modeling procedures at the WSFO's currently is nonexistent or is extremely limited by the nonquantitative nature of the modeling capability.

The current flash flood procedures used by the WSFO/WSO's to provide flash flood watches and warnings are useful to the general public in raising their awareness of impending danger. However, because the current watch/warning procedures are badly lacking in quantitative analysis/prediction capability, they frequently fail to provide sufficient specific and timely information to enable the public to respond to short-fused situations. Thus, of all natural hazards, flash floods remain a major killer in the U.S.

6.2.3.1 Concept of Improved WSFO HPS System

Solutions to the short-fused flood problem will not only depend on use of hydrometeorological information from the NWSRFS to provide the best possible flash flood guidance values to the WSFO's, but also will depend on extensive work to develop an HPS. The HPS will be capable of running in real time on a relatively small mini or microcomputer and of using computational time steps considerably smaller than the hourly time-step limit inherent with RFC forecast system procedures. This HPS, which will be designed with sufficient compactness and efficiency to generate streamflow forecasts for the the most rapid flash flood situations will be analogous in many ways to the NWSRFS. The simplified forecast system will be designed as an integral part of the WSFO automated operational capabilities, making it possible for WSFO forecasters to respond more quickly and accurately to flash flood and headwater situations. The WSFO prediction system will be designed in a modular fashion, incorporating many of the features of the IHDS described in section 6.2.2.

6.2.3.2 Forecast Component of WSFO HPS

The simplified river forecast system at WSFO's will include three major functional components; these being the data entry, data processor, and forecast components; the first two have been described previously.

The forecast component will consist of models similar to, yet smaller in scope, than models used by RFC's. The simplicity and compactness required can be achieved by restricting the number of options and the complexity of the prediction procedures. For example, a less accurate and simpler watershed model than is now used by RFC's would be acceptable in many cases for an event-oriented flash flood prediction system. RFC models have the accuracy and complexity required for continuous long-term soil moisture accounting designed to handle a wide range of forecast situations and conditions. Another example of compactness is in the dam-break flood forecasting area. A simplified dam-break forecasting model is being developed to be adaptable to the simplest possible scenario in which a forecaster wants to produce a flood forecast caused by a dam-break. The possibility of applying a Bayesian statistical approach to the flash flood identification problem also should be considered. This approach would provide useful probabilistic information on the likelihood of flash flooding.

The development of HPS for the WSFO's will be done in conjunction with the Prototype Regional Observing and Forecasting Service, in preparation for System II and NEXRAD. HPS, in its fully developed form, will form a major component of the System II applications software.

Although current QPF products provide general guidance information which is useful in providing an indication of rainfall areas and amounts, they do not provide the detail and accuracy required for assigning QPF values to individual watersheds. There is a need for more direct incorporation of QPF information into the hydrologic models. Incorporation of QPF can be achieved through the development of dynamically coupled hydrologic and meteorological models which include predictive capability for MAP values for individual watersheds and which makes optimum use of meteorological forecast information.

6.2.3.3 Required Activities

In order to meet the goal of improved flood warning lead time through new WSFO forecast procedures the following must take place:

- develop statement of requirements for WSFO hydrologic forecasting directed at solving the short-fused situations not able to be handled by RFC's in real time;
- coordinate requirements with requirements phase of IHDS pertaining to WSFO data base;
- design WSFO HPS to include WSFO data base (data entry, processing, and areal precipitation analysis techniques) as a complete WSFO HPS;
- develop, document, test, and debug software;
- train forecasters on new data base and prediction techniques; and
- implement and maintain software at WSFO's.

6.3 Improved River Forecast Information

The preceding discussions have centered heavily on the first prong of the two-pronged NWS hydrologic forecast service which deals with flood forecasting -- to save lives and prevent property losses. This section addresses a small aspect, one growing in importance, of the second prong of the service which deals with river forecast information -- to support water resources management activities. Specifically, the program aspects to be improved are water supply and long-term river forecasts. As will be explained below, there is a potential for effecting increased economic benefits amounting to $2.5B per year by completing and implementing a sophisticated procedure known as Extended Streamflow Prediction (ESP) and by developing NWSRFS real-time calibration models. It is this potential payoff that led to the setting of the following goal:

To improve the capability to forecast long-term water supply and river flow information through the implementation of ESP and enhanced NWSRFS models for the benefit of water resources management.

6.3.1 Present Program

Water supply forecasts for 760 points are issued by RFC's to predict streamflow volumes resulting from mountain snowmelt. Computational methods utilize statistical multiple correlation and regression analyses compared to 15-year moving averages. Seasonal snowmelt runoff volumes are forecast based on monthly high altitude snow depth and water equivalent measurements, monthly precipitation for low elevation stations, and streamflow conditions. These forecasts are issued jointly with the SCS. The forecasts of runoff volumes usually are for the April-September runoff period. Forecasts are issued once a month from January 1 through June 1. The forecasts of runoff volume are updated every month to account for actual changes in snow cover conditions which have taken place during the previous month. The forecasts assume that the amount of snow on the ground is known and that normal temperature and precipitation patterns prevail.

Water supply forecasts are prepared mainly to predict the volume inflow of water to the major water storage projects in the western U.S. and New England. The principal users of water supply forecasts are utility companies (which produce and sell hydropower); farmers; municipalities and industries; navigation interests; and recreation, land, and wildlife managers.

Some of the economic considerations for providing water supply forecasts are shown in Appendix D. The main reason for issuing water supply forecasts is that the less perfectly the future supply of water is known (in terms of quantity and timing), the less efficient are the water management activities and the lower the benefits from such activities.

6.3.2 Current Long-Term River and Water Supply Forecasting Capability

The NWS is currently able to predict only the total volume of water expected to runoff from high elevation snowpacks. It has been shown that the standard error of these volumes is about 18 percent, e.g., in two-thirds of the cases, the volume could be ± 18 percent of that forecast. Additionally, the present service does not predict the hydrograph, i.e., the time distribution of the volume forecast for the 760 forecast points.

Since current computations are based on regression models, they tend to predict average and slightly below average inflows well. While the distribution of forecast errors is unknown, it is known that the forecast errors occur primarily in years of extreme high or low flows and when there are large changes from normal precipitation and temperatures. Therefore, accuracy of the forecast suffers. With the forecast limited to volumes, for monthly or seasonal time periods, lead time in its normal sense is not available, i.e., there is no predicted hydrograph. Also, the regression models do not simulate the hydrologic response of the river basin. Finally, regression techniques are not amenable to easy changes; additions of data or changes in desired output require complete recomputation.

Forecasts of long-term river flow and water supply generally are restricted to seasonal forecasts; actually there is a need for year-round forecasts of this type.

6.3.3 Program Improvements

6.3.3.1 Economic Benefits

In light of the above, there is much room for improvement in the present program. The present worth of the water supply forecast service to the Columbia River hydropower generation projects (Bonneville Power Administration) and to the Salt River project (for irrigation) has been estimated at $14M and $11M per year, respectively. However, benefit/cost models applied to the 11 western states show that a 6 percent improvement in forecasts of streamflow volumes resulting from snowmelt runoff alone would be worth $10M per year in added benefits to hydropower interests and $28M more per year to irrigators. Benefits would be much higher if the streamflow hydrograph could be produced, offering daily or weekly forecast lead times, and if variability of meteorological data could be accounted for throughout the year.

In fact, a year-round service leading to improved operation of existing major Federal water resource projects (reservoirs and waterways) can produce additional benefits equal to or greater than the potential benefits from construction of new projects at the current rate of funding. The replacement value of existing Federal water projects is on the order of $170B, that is 60 times the current annual U.S. investment in new construction of water projects and more than 8 times the present value of investments planned over the next 20 years ($2.5B per year for 20 years discounted at 10 percent per year). Assuming that benefits are proportional to replacement value, increasing the productivity of existing projects by only 12 percent is worth as much as new construction over the next 20 years. In one demonstrated case, improved reservoir operations eliminated the need for $250M of additional reservoir construction.

6.3.3.2 Extended Streamflow Prediction (ESP) Model

The NWSRFS presently contains both snowmelt and soil moisture simulation models. The models can be used to compute forecast hydrographs for short-term river events, up to 1 week in advance. These models can be used for even longer term predictions; however, they do not have the capability of accounting for future hydrometeorological variability. That is, the current models can be run with input of long-term average temperature and precipitation, but without knowledge of the day-to-day variations in these data. ESP benefits from the NWSRFS flexible software structure. ESP uses the snowmelt and soil moisture models as its basis and also simulates the random effects of meteorological events based on historical time series. With ESP, changes in input data are easily effected, and a variety of river basin and snowpack conditions can be simulated. ESP's output can be a streamflow hydrograph, volume forecast, or estimates of the most likely streamflows to result from variable temperature and precipitation patterns. These forecasts can be used by water managers to assess the risks involved in alternative decisions. Appendix D explains the concepts of the relationship of improved long term forecasts to benefits from river and reservoir management and gives an example of the use of such information to water management practices during drought.

The operational implementation of ESP will permit NWS to (1) provide forecast hydrographs for the current 760 water supply forecast points, and (2) provide both short-term and long-term streamflow predictions for a wide range of hydrometerological conditions for water managers to investigate various management strategies. ESP, however, is not fully operational. Enhancements and simplified calibration procedures of the NWSRFS models are required.

6.3.3.3 Calibration Procedures Based on Historical Data

A major aspect of hydrologic modeling is calibration. As stated in the problem analysis in appendix B, due to limited personnel resources and other high priority operational commitments at the RFC's, it will take 20 years to calibrate accurately all currently forecasted river basins. Implementation of the models by the RFC's and/or the WSFO's requires calibration of each basin. Calibration consists of selecting the set of model parameter values which most accurately simulate a hydrologic process.

Model calibration using currently available techniques is a time consuming process and requires that the user have a thorough understanding of all of the concepts in the model. The current process basically consists of a trial-and-error calibration step with manual intervention. Calibration involves comparing simulations, based on historical hydrometeorological data inputs, to observed streamflow records. Once this time-consuming process has been completed, the second step consists of the use of an automatic parameter optimization program. However, this second step is currently successful only if the starting values for the parameters of the model are reasonably close to the final values selected in the optimization process. Otherwise, the values may not converge properly, resulting in unsatisfactory parameter estimates. Generally, the problems encountered as a result of erroneous parameter identification increase with the number of parameters which must be estimated for a particular model.

Ways to simplify the model calibration process are needed to accelerate the implementation of ESP. Solutions are required to complete one vital part of the triad of improvements necessary to achieve the objectives of this PDP. Two basic approaches to the simplification of model calibration are possible: (1) develop improved calibration techniques for existing models and/or (2) develop models simpler to calibrate. Potential areas for improvements in the first category include the development of improved automatic parameter optimization schemes and the use of new numerical formulations for the existing models. The thrust in the second category could be to simply modify the current conceptual soil moisture model.

Primary tasks to improve the calibration process will require:

- design new procedures to improve efficiency and accuracy of the calibration process;
- develop procedures or simple models to improve the calibration process;
- debug and test procedures; and
- implement procedures as part of NWSRFS at RFC's.

6.3.3.4 Real Time Model Calibration (Updating)

Hydrologic modeling systems cannot perform at full potential without the incorporation of the capability to update the states of the models with current observations of meteorologic as well as hydrologic conditions. For simplicity, one might think of such model updating provisions as providing the capability to recalibrate the model in real time. Model calibration using historical time series remains a separate and important issue. Fortunately, within the past few years, a new modeling approach has been developed involving applications of advanced estimation theory using a so-called Kalman filter and other estimators. In 1976, the NWS began a limited research effort to apply the Kalman filter theory to one of its river forecasting models. The research to date has produced dramatic results for a relatively simple forecast situation involving a headwater basin without snowmelt complications. The potential benefits of improved accuracy of forecasts for a large river system are far-reaching. (See appendices D and E.) Quite simply, this new adaptive approach for updating model states in real time will optimally adjust and constrain the forecast computations based on available data and forecast information.

Primary tasks to improve real-time calibration are:

- design procedures to provide real-time model calibration (updating procedures) through the best use of available information based on the real-time and predicted hydrometeorological and watershed conditions;

- develop real-time calibration procedures;
- test and debug procedures;
- implement procedures at RFC's.

6.4 Improvements for Local Flood Warning Systems (LFWS)

Although the LFWS program supports NWS's mission of providing flash flood forecasts, they are not under the direct control of NWS. They nevertheless play an important role in bringing flood warning service to flood plain dwellers on a very localized basis. Accordingly, NWS has set the following goals for improving the LFWS program.

1. Provide the help and guidance needed to design, develop, and implement local flood warning systems to as many communities as request it;

2. Encourage the installation of automated local flood warning systems, wherever and whenever possible;

3. Provide training for RFC and WSFO hydrologists and/or disaster preparedness specialists in setting up local flood warning systems, with emphasis on automated systems;

4. Encourage WSFO meteorologists in charge (MIC) to set aside travel funds adequate for the purpose of installing the systems (and for necessary support activities); and

5. Provide links from automated local flood warning systems with the IHDS to improve accuracy and timeliness of forecasts for downstream flood plain dwellers.

6.4.1 Present Program

There are approximately 550 local flood warning systems in communities across the country. These community-owned, operated, and maintained systems provide citizens the means to observe rainfall and streamflow, make a flood forecast for their immediate area, and initiate and implement responses as soon as possible to avoid loss of life and property. Essentially, these forecast systems allow communities to act quickly, independent of the NWS, in situations when even the smallest delay in reaction could make the difference between life and death.

The local flood warning systems are planned in response to requests from town officials, with technical guidance of WSFO service and RFC hydrologists who help plan the community's local data collection network and formulate the rainfall-runoff relationships for the site specific forecasts. All of the actions in the face of a flood are preplanned such that emergency responses can be taken immediately when rainfall occurs. In effect, this method of service offers the optimal response to floods.

Community flood warning systems consist of a variety of equipment, sensors, and technical hydrologic procedures, as well as disaster responses. The major elements of such systems are: (1) rainfall and river stage sensors; (2) communications links to and from an emergency coordination center; (3) a simple method to convert rainfall to a river stage forecast; and (4) disaster response teams assigned to take mitigating actions and to aid citizens.

River and rainfall sensors range from manually read plastic rain gages and staff gages to sophisticated event reporting gages transmitting their readings via radio or satellite relay. Data collection takes place via voice communication and computerized collection. Rainfall-runoff procedures can range from simple "rule-of-thumb" relationships to sophisticated soil moisture accounting models. It is sufficient to say that each local warning system is designed to meet the specific hydrologic needs of the community, constrained by the costs of equipment and maintenance.

6.4.2 LFWS Performance

Little information is available concerning exact benefits and the warning lead times provided by these systems. However, users of this type of warning service have frequently reported on the success of the programs and the savings both in lives and property attributable to their performance.

The more sophisticated systems, known as Automated Local Evaluations in Real Time (ALERT) can provide up to 40-minute lead time for 1-hour flood crest events. The ALERT systems offer improvement over manually generated systems by reducing data errors and allowing for more sophisticated rainfall-runoff computations. River basin areas covered by these warning systems can range from a few square miles to several hundred square miles. The systems are installed to cover a specific river basin or basins.

In Appalachia, the NWS has developed an Integrated Flood Observing and Warning System known as IFLOWS. The national flash flood project is a cooperative venture between the NWS; the states of Virginia, West Virginia, Kentucky, and Pennsylvania; the Appalachia Regional Commission; and the Tennessee Valley Authority (TVA). IFLOWS consists of over a hundred radio reporting rain gages, an automated data collection and processing system, a flash flood and flood forecast system, a communications system capable of receiving both voice and data, and a disaster/response system. At the state Emergency Operations Center, a minicomputer collects data and hydrometeorological information and relays information and forecasts to county minicomputers located in county offices. These state and county minicomputers are linked to the NWS offices responsible for data collection and forecasts. IFLOWS is now operational in the 12-county nucleus area and in 2 years will expand to an 80-county area.

One of the primary objectives of IFLOWS is to evaluate the benefits and costs of automated local flood warning systems.

6.4.3 Service Benefits

The major benefits from the LFWS's are in (1) saving lives and (2) preventing property damage in river basins where river crests occur in the 0- to 6-hour time frame and where the NWS cannot provide site specific forecasts of river stage. LFWS's also provide supplemental data for carrying out other NWS functions. Where the local warning systems exist, they have been extremely effective. There are many communities becoming increasingly interested in this type of service that are turning to NWS for technical guidance.

NWS currently has limited capability to provide assistance to all of the communities requesting help. The sites must be surveyed in the field, the networks planned, the rainfall-runoff relationships calibrated, and links established to the NWS for data input to downstream forecasts. The process can take several weeks involving both WSFO service and RFC hydrologists. The NWS personnel should have knowledge and experience with various ensembles of equipment and algorithms.

Expansion in the number of these highly effective community-contained warning systems is limited by personnel shortages, training deficiencies, and travel fund restrictions at WSFO's and RFC's. LFWS's provide a good way for a community to reduce losses from floods. The NWS should foster and emphasize the installation of the systems wherever possible to ease its own burden of trying to provide real-time flood warning services for the 0- to 6-hour events. The achievement of the stated goals will help improve this preparedness activity.

7.0 SCHEDULES AND RESOURCE REQUIREMENTS

The purpose of this section is to describe the scheduling and resources required to improve the hydrologic service program in the next 10 years. Figure 6 shows the time-phased activities and figure 7 summarizes the resources required to complete these activities.

7.1 Data Networks

To improve the NWS data collection system and dramatically increase lead time in issuing flood forecasts, three basic activities are planned. First, the present manual system of data collection from cooperative observers will be replaced by giving the cooperative observers data encoding capability and by adding nine microprocessors for data collection distributed among three regions. (The Central Region is already implementing use of data entry pads.) This project will begin in FY 1987 and end in FY 1988. Resources required will be $550K for the encoding devices for the eastern and southern portions of the country and $45K for the computers.

The second activity involves changing the 0.5-inch reporting criterion for the cooperative observer network to a required once-a-day report, with the possibility of 6-hour reports if more than 0.5 inches of rain falls. This process will be accomplished in the period FY 1988-1991 at a cost of $350K. The $350K will become a recurring cost after 1991.

The third activity consists of adding 2,000 automated gages to the 1,000 headwater forecast areas to improve lead time for the headwater and flash-flood forecast service. Implementation of the 2,000 gages will be phased in at a rate of 400 gages per year for 5 years with procurement beginning in FY 1988 and installation beginning in FY 1989. The cost is $2,200K for 400 gages per year for 5 years; maintenance costs will be phased in beginning 1 year after the first year of installations. Spares will be purchased at a 20 percent replacement level, i.e., 400 additional gages, 80 purchased per year.

The 2,000 gages will report via satellite relay. While these gages are more expensive to procure initially, their long-term maintenance and operating costs are lower than conventional long distance telephone reporting devices. This is because NWS does not have to pay for use of the satellite.

The regions will need a total of 14 staff-years of effort to implement the network enhancements.

7.2 Integrated Hydrometeorological Data System (IHDS)

To provide an IHDS, design and development work will begin in FY 1985. The initial step will be to design and develop an enhanced RFC minicomputer data base and a national hydrometeoro-

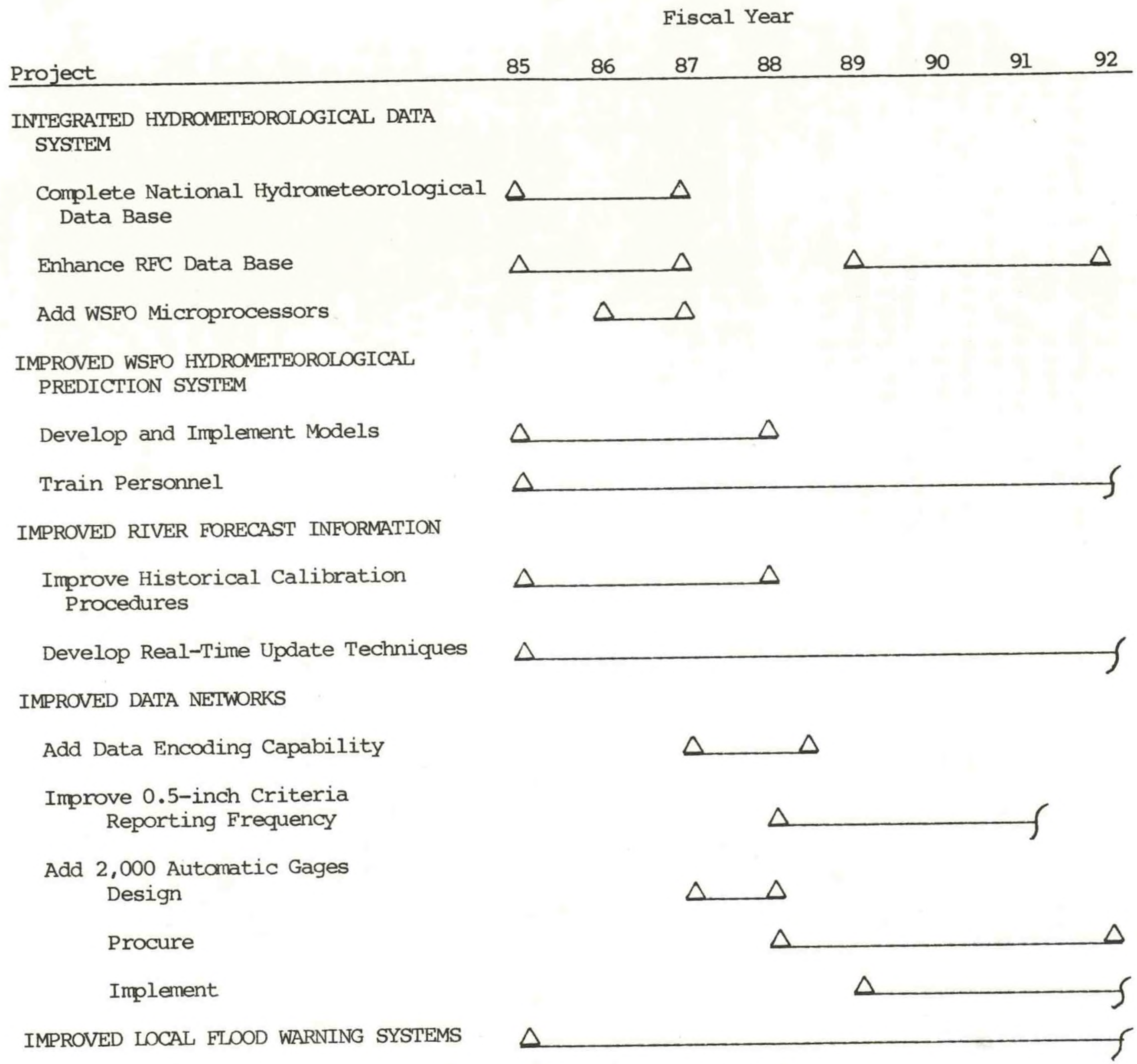


FIGURE 6 - PDP Development Schedule

Resource Summary

Project	85	86	87	88	89	90	91	92
Data Networks	—	—	0/300	2/3200	3/3200	3/3200	3/4200	3/4200
Integrated Hydrometeorological Data System	2/440	1/340	—	—	1/100	1/100	1/100	1/100
WSFO Hydrometeorological Prediction System	0/160	1/160	2/200	0/100	0/100	0/100	0/100	0/100
River Forecast Information	2/100	2/200	2/200	2/100	1/50	1/50	1/50	1/50
Local Flood Warning Systems	2/100	2/100	2/100	2/100	1/50	1/50	1/50	1/50
Total	6/800	6/800	6/800	6/3500	6/3500	6/3500	6/4500	6/4500

Figure 7

logical data base at the NOAA central computer facility which will contain all data required by the RFC's and the WSFO's. In order to meet the design requirements for the enhanced RFC data base (a subset of the national data base), an additional 96 MB of disk storage will be added to each RFC minicomputer. In FY 86, microprocessors will be purchased for 50 WSFO's. These terminals will have dial-up capabilities and will be utilized to collect data from the RFC data bases, process the data and provide processing power for formulation of short fused headwater forecasts and flash flood watch and warning information.

In addition to hardware, two system experts (hydrologists) will be needed to design the system and to develop the data integration techniques (objective analysis for formulation of MAP data). Some contractual work ($100K) will be needed to help with software coding.

The IHDS is envisioned to be on-line in 1987, although some processing software development will be continued while rainfall/runoff models are being adapted for WSFO's (see below) and as System II is being brought on-line.

Accomplishments of these activities will require a total of 3 staff-years of effort and $780K in FY 85 and 86.

7.3 WSFO Hydrometeorological Prediction System (HPS)

In order to improve capabilities of the WSFO, simplified rainfall/runoff and channel routing models in a systems framework must be developed to give service hydrologists and lead forecasters accurate and automated forecasting capability in real time for short fused flood events. Design and development of this system will overlap with the data networks and systems efforts (7.1 and 7.2 above) and will be implemented over a 2-year period beginning in 1987. Costs for the development of the system models will be $220K with 1 staff-year of effort over 3 years. Some of the coding will be done under contract.

A parallel effort aimed at improving WSFO performance in flash flood and headwater forecasting involves training meteorologists and hydrologists in the use of the new data and modeling techniques. Funds ($100K) for a training course given each year and travel and per diem are required for students to attend the class. A teacher for the course is needed; however, funds for this position have already been set aside.

7.4 River Forecast Information

Improvement of river forecast services to support the efficient operation of major water projects and the most beneficial use of the Nation's waterways will be effected through model development and simplified calibration procedures. One staff-year of effort per year for 4 years and $200K in contract funds in FY 86 and FY 87 are needed to improve the complex and time-consuming calibration techniques used to implement the ESP model. Without these techniques, implementation of ESP at the 760 water supply forecast points alone will take 10 to 15 years because of limited resources at RFC's.

A second hydrologist with expertise in hydrologic modeling is needed to develop real-time calibration techniques in soil moisture accounting models. After 1988, a continuing cost of one employee and $50K per year is needed for this effort.

7.5 Local Flood Warning Systems (LFWS)

Implementation of LFWS will be expanded because of a great demand for such services. Many of these systems will be automated. Additional personnel and travel resources are required to respond to these requests. Two additional positions are needed for the period FY 1985 through FY 1988 and one position thereafter for maintenance of the program.

8.0 PDP MANAGEMENT

8.1 Program Management Overview

The implementation of this PDP basically involves the completion of the five activities delineated in the schedule and resources charts in section 7.0. Two of these activities require the procurement of hardware, i.e., purchase of computer hardware for the integrated data system and purchase of telemetry equipment and rain gages for the data networks. The development of the WSFO hydrometeorological forecast procedures and development of improved river forecast information, however, involve the generation of hydrologic models and software. Finally, the addition of local flood warning systems requires additional staff and travel funds needed to interact with the local authorities.

Although the five activities must be accomplished collectively in order to increase warning forecast lead times and improve long-term river forecast information for water resources management, they are sufficiently defined so that each activity can be pursued as an individual project. In this respect, each project can be carried out within the existing NWS organization so that a special PDP management hierarchy is not needed.

Several of the projects are planned to be implemented early in the program development to achieve benefits as soon as possible. For example, delay of the development of the IHDS or WSFO procedures will seriously impact plans for bringing new data networks on line and will detract from efficient use and early realization of benefits from major NWS activities planned for the early 1990's, such as System II and NEXRAD.

Planning efforts should begin immediately for program thrusts involving hardware purchases because of the required time for procurement. Procurement and installation of hardware will require close coordination between NWS Headquarters staff in the Office of Technical Services (OTS) and O/H and Regional Directors' staffs.

The most complicated efforts in terms of planning, content, and management will involve design and implementation of new applications software for the WSFO's. Major impetus and encouragement for the new techniques will have to come from field office supervisors with operational support from Regional Hydrologists and RFC's. The new techniques will require some standardization, guidance for which will be developed jointly by the O/H and the Regional Hydrologists. Establishment of a data system requirements group composed of representatives from NWS Headquarters, service hydrologists, and RFC hydrologists could provide the mechanism for determining the data system design and development.

8.2 Program Planning

Each of the five major program thrusts has subtasks for which a comprehensive set of plans must be prepared. The plans will address various aspects of task development, including expenditures and resource scheduling, training, design, development, implementation, and maintenance. The subtask plans will also identify the focal points throughout the organization for each phase of task development and the roles and responsibilities of each office involved. An overall implementation and coordination schedule will be used to track each phase of the subtasks in relation to the PDP and other major NWS initiatives.

8.3 Organization

Overall program direction and management and ultimate responsibility for the PDP will be assigned the Director of the NWS Office of Hydrology.

Subtasks related to network enhancements will be assigned to the OTS under the Director for that office; responsibility for field implementation rests with the NWS Regional Directors. Close coordination with other NWS Headquarters offices will be accomplished through designation of focal points by the respective NWS Office Directors.

IHDS software design and development will be accomplished through establishment of a data systems project group reporting directly to the Director (Hydrology).

° Director, Office of Hydrology:

- provides hydrology program development policy direction;
- reviews and approves subtask plans;
- authorizes establishment of subtask teams and focal points within the O/H;
- coordinates progress reviews and subtask problem resolution with other NWS Office and Regional Directors;
- assumes responsibility for operational hydrology requirements for data networks;
- authorizes PDP expenditures;
- coordinates PDP and represents NWS to other major U.S. water resource agencies.

° Director, Office of Technical Services:

- provides overall direction and guidance to OTS staff for procurement, and for equipment and maintenance standards for data network elements including sensors, electronic reporting mechanisms, and the cooperative observer (substation) network;

- responsible for the distribution and most efficient use of funds authorized by the Director (Hydrology) for the enhancement, operation, and maintenance of data networks;
- responsible for the most efficient introduction of data into NWS data transmission and telecommunications systems;
- responsible for focal points for radar and basic observations programs as related to IHDS.

° Director, Office of Systems Development:

- overall responsibility for potential impacts of the PDP on AFOS;
- assigns focal points for System II development, as related to and impacted by the PDP, especially with regard to WSFO data base design and hydrologic techniques.

° Director, Office of Meteorology:

- assumes responsibility for overall requirements and impacts of PDP on meteorological operations with focal points assigned as necessary for WSFO data base and hydrologic procedures.

° Regional Directors:

- authorize and supervise field implementation of PDP subtasks through MIC's and Regional Hydrologists;
- provide overall regional policy and guidance for regional hydrology program;
- assign focal points and experts to subtask teams;
- provide resources as necessary to aid in design and development of hydrologic techniques and data systems.

° Director, National Meteorological Center:

- overall responsibility for impacts of this plan on NMC operations, especially the data systems;
- assigns focal points as necessary for data system subtasks.

9.0 CONCLUDING REMARKS

A plan to enhance hydrologic services in the next decade has been presented. The five major thrusts of this plan are to (1) enhance data collection networks, (2) provide a national integrated hydrometeorological data system, (3) develop and implement techniques for headwater and flash flood forecasting at the WSFO, (4) enhance, simplify and implement long-term streamflow prediction and river forecast system techniques, and (5) expand the implementation of community local flood warning systems with emphasis on automated systems. Accomplishing these enhancements will result in meeting the major goals of this PDP to (1) increase flood forecast lead time for headwater areas, (2) improve river forecast information services, and (3) expand the use of local flood warning systems.

It should be noted that this PDP is closely interwoven with other major NWS projects, such as System II, NEXRAD, and IFLOWS. It is important that, as work proceeds to accomplish the various objectives of this PDP, a high level of coordination exists between these projects and PDP activities. For example, the timing for implementation of the IHDS is important relative to implementation of System II. The IHDS will be ready for implementation in FY 1987. System II implementation is scheduled for FY 1990.

The IHDS will give the WSFO's basic data handling and analysis capabilities using simplified hydrologic procedures. System II will provide NWS offices with more comprehensive local data bases and computing power to run more complex hydrologic models. The development effort outlined in this PDP will support directly the hydrologic portion of System II.

The NWS views this PDP for improved hydrologic services as a prudent and necessary step to cope with the future. The PDP essentially represents a fundamental change from the approach to hydrologic forecasting systems the NWS has followed for the last 30 years. In the past, each RFC used a different forecast system and was heavily dependent on manual operations. New techniques or procedures developed at one RFC could not be transferred easily to the other RFC's.

New technology in the form of powerful computers and high speed telecommunications systems has paved the way for hydrologic forecasting based on physical concepts of the movement of water through the atmosphere and the soil simulated by complex mathematical models. Introduction of the conceptual mathematical models leads to an ability to imitate events taking place in nature more accurately and with greater frequency than was ever achieved previously. This new era of hydrologic forecasting is possible because the hydrologic models will be linked to each other through a systems framework interfaced to and supported by a national IHDS available to all NOAA elements. The system will be fed by multiple automatically reporting sensors. Such a multiple system structure allows for production of a wide variety of river and flood forecast services, benefiting all sectors of society with forecast products issued in time for the most effective use of the information.

It must be pointed out, however, that this PDP assumes that the present levels of service will be maintained throughout the development and implementation of recommended program improvements. This assumption implies continued support through commitment of resources at least at the same level as are currently available (with adjustments for inflation).

Finally, it must be understood that the PDP is presented as an integrated plan for hydrologic service improvements. While each major program thrust can stand alone during development and implementation, all are interdependent, and all must be completed in order to realize the potential benefits.

Appendix A - FORECAST SYSTEM DETAILS

This appendix presents a more comprehensive discussion of the five elements of the forecast response system conceptualized by Krzysztofowicz and Davis (1982) and the role of NWS in it.

A.1 Data Collection Network

A.1.1 Cooperative Networks

The NWS collects river and rainfall data directly from about 7,000 stations across the country. There are approximately 4,140 stations reporting rainfall only, 1,800 stations reporting river only, and 1,060 stations reporting rainfall and river. Seventy-five percent of the rainfall reports are collected by NWS cooperative observers (private citizens agreeing to read and report on the gage reading for a nominal fee), and the rest are reported by automated systems or other agencies' observers. Of the 2,860 river stations from which data are collected, 68 percent are collected by NWS observers, and the rest, through automated systems or other agencies' observers. Because of the complex cooperative relationships among Federal, state, and local authorities, NWS using its own observers is able to collect data from equipment belonging to other agencies. For example, there are more than 2,800 precipitation stations owned and funded by the COE which are operated and maintained by the NWS. Also, 90 percent of the river gages are owned by the USGS, but NWS has cooperative agreements with the USGS to collect data and to maintain 1,543 of these gages. A major complication with USGS-owned gages is that many of the gages are part of vulnerable cost sharing agreements with the states. Of the approximately 7,000 stations in which the NWS directly collects data, less than 20 percent are automated.

There are an additional 3,000 stations, almost half of them river gages, from which the NWS may receive data through intermediate sources. These are data collection sites that report to another agency which in turn relays the information to the NWS via telephone, TELEX, or satellite communications. The only reports from these which must be made available to the NWS are from satellite (GOES) platforms, because the Department of Commerce owns and operates the satellites.

Of the total 10,000 stations available from which the forecast system can get information, only one third to one-half of them are actually owned or effectively controlled by the NWS. The major contributors of data are the USGS for river stage data, COE for river and precipitation information, SCS for snow depths and water equivalents, TVA for river and precipitation reports, and several major power companies.

A major emphasis is being placed by some of the other agencies on installation of satellite platforms for use in the relay of observed hydrometeorological point data to a central collection point. There are currently 1100 multi-agency GOES platforms now in use in NOAA's hydrologic program. Approximately half of these will be replaced in the near future by random reporting platforms which will provide higher resolution data. It is projected that additional platforms will be installed by NOAA and other agencies within the decade to provide a total of 5,000 platforms.

Rain-gage data reported via satellite data are processed and stored at the NOAA central computer facility.

The data manually collected by the cooperative observers are reported once every 24 hours, usually at 7 a.m. If more than 0.5 inch of rainfall is recorded, then the observer is instructed to report the data every 6 hours until the rain ceases. Automated stations (1) are timed to report at specific time intervals, (2) can be polled (interrogated) at certain times, or (3) can be calibrated to report on a preset criteria (usually 1 mm of rainfall or a variable change in river stage). More than 90 percent of the automated gages are timed, some of these with a facility for special interrogation.

Data from NWS cooperative networks are sent to WSFO's and WSO's via voice telephone. Data collected from noncooperative networks are relayed directly to RFC's via voice telephone and digital communications. Automated stations can report either to RFC's or WSFO's.

A.1.2 Synoptic and Aviation Reports

Important sources of 6 hourly and 3 hourly data to the forecast system are the NWS/FAA synoptic and aviation observation network. These data, known as SA/SM's, are the major source of observed data for input to the NWS's large numerical weather prediction models. Some of the basic observations taken are precipitation and snow depth; and the actual value is always reported, i.e., it is not based on the 0.5-inch criteria. There are 1,649 stations in the basic observation network; NWS owns 437 of them and the rest are collected through contract or cooperative agreements.

The SA/SM data are reported to WSFO's and sent to the central computer facility for processing.

A.1.3 Remotely Sensed Data

Radar and satellite imagery are used extensively, but still mostly subjectively, in the forecast process. There are a few operational objective techniques in use; also, there is much developmental activity currently going on to increase the usefulness of these data. The Southern Region has developed and operationally uses an objective technique to digitize the radar imagery. This manually digitized radar field can be converted into an estimate of rainfall intensities to provide some indication of flash flood potential. MDR values have been expanded to cover all NWS radars. Radar fields are continuously scanned at the radar sites and reported hourly to WSFO's.

Satellite data are received by NESDIS and relayed to SFSS's and WSFO's every 30 minutes. An objective technique is used to convert the imagery into areal rainfall estimates.

The Aerial Gamma Snow Survey program collects snow depth and water equivalent data from more than 300 flight lines in North Dakota, South Dakota, and Minnesota. [The technique employs the fact that natural gamma rays emitted from the earth are attenuated by snow depths.] These data are used by the RFC's in Kansas City and Minneapolis along with ground observations of snow depth, water equivalents, and forecast temperatures to predict snowmelt runoff.

A.2 Forecast Procedures

Most of the processing of hydrologic information and all of the basic procedures leading to the forecasts are executed by the RFC's. After collection by the WSFO's and WSO's and relay via AFOS to the RFC, the data are subjectively evaluated, reformatted, and sent to NOAA's central computer facility via remote terminals. There, they are organized into data files according to their geographic source, location relative to the river point being forecast, and the soil moisture characteristics of the area. The point rainfall observations are distributed into 6-hour rainfall values and then used to estimate mean areal (basin) precipitation values, i.e., a 6-hour linear measure of rainfall over the entire basin. The 6-hourly observations are used to convert the daily (24-hourly) observations to 6-hour values. Once a MAP is produced, it becomes input to a model to convert rainfall to runoff, i.e., excess water that cannot be absorbed by the soil or stored at the surface and which flows overland to the river. Total runoff over an area is converted to the predicted volume of water which will be flowing in the stream at a particular cross section. The discharge is converted to a stage forecast using a relationship known as a rating curve.

Currently, various types of precipitation analysis techniques and hydrologic models are being used by RFC's. MAP can be computed using weighting schemes based on geographical distribution, historical rainfall patterns, and vertical (elevation) distribution. Rainfall runoff models are based on empirically derived coefficients of soil moisture, such as the Antecedent Precipitation Index (API), Streamflow Simulation and Reservoir Regulation (SSARR), or complex mathematical representations of the states of water as it moves through a column of soil (Sacramento Soil Moisture Accounting). Currently, six RFC's use the API model, four use the Sacramento model, and one uses the SSARR model. The other two use variations of these techniques.

Once a stage forecast is produced, it becomes an inflow to the next forecast point downstream. The technique of forecasting the flow of water from point to point is called routing. Many routing techniques based on the storage equation $I - O = \frac{\Delta S}{\Delta t}$, where I represents inflow to a cross section, O represents the outflow from the cross section, ΔS represents the change in channel storage between points, and Δt represents the change in time. All computations are referenced to the travel time of the water from one point to another. These techniques are produced from studies of historical hydrographs. Other techniques are more complex, accounting for changes in channel bottom, side, and surface water slopes; shear stresses; gravity; and inflow or outflow of tributaries.

The most complex method, known as the Dynamic Wave Operational (DWOPER) model, is the most accurate. It should be applied, with improved results over storage routing methods, to any place where backwater, tides, storm surges, and mild channel bottom slopes exist. Currently, the storage routing methods are more widely used. The DWOPER program is being calibrated for or used on a limited basis from the junctions of the Cumberland-Tennessee and Ohio-Mississippi Rivers to the mouth of the Mississippi River; on lower sections of the major western Gulf of Mexico tributaries; on the Columbia River below Bonneville Dam; and on the Illinois River and portions of the Arkansas River. However, it potentially could be applied to many more forecast points.

In headwater areas of less than 1,000 square miles, the forecast procedures are somewhat different from those described above and much less accurate. After determining the MAP and the amount of moisture in the soil the RFC determines the 3-hour amount of precipitation required at each headwater point in order for flooding to occur. These precipitation amounts are called headwater guidance. The guidance is used by WSFO's to make a forecast at a specific point on a river for which a simple forecast technique has been supplied by RFC's. Flash flood guidance (similar to headwater guidance, except the precipitation criterion values pertain to counties or zones) is used to produce flash flood watches and warnings. Headwater guidance is normally issued twice a week, while flash flood guidance is updated once a day.

A.3 Dissemination System

The information distribution systems for hydrologic products are the same as for all NWS products. These include NWR, NWWS, National Warning System, telephone, and special low-speed circuits. The RFC sends its products to WSFO's and WSO's via AFOS.

A.4 Decision Procedure

The NWS has no direct control over the decision procedures employed by flood plain users. The factors which lead to a specific response strategy may vary from one flood to another. These factors may include psychological variables, such as the subjective belief in the danger of being flooded and suffering a loss. However, NWS can influence the degree of response, types of protective actions, and amounts of resources allocated to these actions by aiding in preparedness planning. First, by promoting the use of NWS dissemination systems, like NWR, NWS forecasts enhance the information available to the decision maker. Second, good forecasts influence strategy for the future, although this certainty or perception decays between events. A third way of influencing decision-makers is through use of public education via the media (radio, television, and public flyers) to explain how to deal with floods. A fourth, more direct, approach is to help tailor a strategy to the community's particular flood problem.

A.5 Set of Protective Actions

The set of protective actions consists typically of several short-term protective actions (such as evacuation, flood proofing, shutdown of a facility) which the flood plain user can take in response to a flood warning in order to reduce the potential loss. The NWS is not directly involved in this phase of response.

A.6 Flood Warning Services

The flood warning service program elements, listed in order of importance, are described below.

- Flood warnings for 3,000 forecast points
  - River and flood forecasts
  - Headwater flood forecasts
- Flash flood watches and warnings
- Snowmelt flood advisories
- Local flood warning systems for 550 communities
  - Automated systems
  - Manual self-help systems
  - Flash flood alarm gages
- Dam break analysis
- Ice jam formation and breakup

Flood Warnings are supplied for about 3,000 specific forecast points around the Nation. Most of these forecast points are located on major rivers and larger tributaries, where river and flood forecasts provide lead times of 12 hours to 7 days. Headwater flood forecasts are issued for about 1,000 forecast points where lead time ranges from 6-18 hours. Flood warnings provide community residents with vital time to evacuate flood prone areas and save valuable possessions. In many instances, NWS field offices can provide site specific quantitative forecasts for short fused flood events.

Communities having flash flood problems have two types of services from the NWS available to them:

- Flash flood watch/warning services
- Local flood warning systems

A flash flood watch is issued for a large area, usually concerning several counties, wherever meteorological conditions are developing which could cause flash flooding somewhere in the area. Flash flood warnings are issued, usually for county-size areas, wherever flash flooding is imminent or has been reported to have occurred.

Local flood warning systems (LFWS) are cooperative ventures between the NWS and state and local government. These systems are operated by local communities. NWS develops the procedures and provides forecasts to aid local operations. There are about 650 local flood warning systems. Most of these rely on manual, people-intensive technology. Recently, cost-effective technology has been developed to collect and process data automatically for local warning systems. This technology is being used in the IFLOWS demonstration project in Appalachia and in the ALERT systems begun in California and now being used in Arizona, Washington, New York, and Connecticut.

In late winter and early spring, snowmelt flood advisories are issued for those parts of the county where snowmelt flooding is anticipated. Early alert of potential snowmelt flooding allows for effective preparation by Federal, state, and local disaster agencies to mitigate flood damage.

The NWS provides analysis of potential dam break floods to various Federal, state, and local civil defense agencies. More than 10,000 dams in the U.S. have been labeled as either unsafe or capable of producing devastating losses of human lives and property in the event of a dam breach.

Appendix B - FORECAST SERVICE PROBLEM ANALYSIS DETAILS

B.1 Data Collection

In order to provide river and flood forecast services, hydrologic data must be collected, processed, and input to the hydrologic forecast models resident on the NOAA central computer facility. The output resulting from hydrologic forecast models must be analyzed before a forecast can be prepared and disseminated to the responsible NWS office. The key ingredient to timely and accurate hydrologic forecasts is data. Expensive, sophisticated models, computer systems, and experienced hydrologists are of little use unless there is adequate data available at the required sampling frequency. Hydrologic data primarily consists of precipitation and river streamflow data. Other types of hydrologic data, such as air and water temperature, QPF, evapotranspiration data, streamflow discharge measurements, and reservoir data are required to produce river and flood forecasts.

B.1.1 Precipitation Data

Precipitation data consists of 3-, 6-, 12-, and 24-hour precipitation amounts, snow depth, and snow water equivalents.

B.1.1.1 Cooperative Observer Network

The primary source of precipitation data is a network of dedicated cooperative observers. Most observers are given a standard NWS precipitation gage with instructions to report precipitation amounts every 24 hours or to report rainfall after 0.5-inches of rainfall has occurred. The stations reporting under the 0.5-inch criterion are expected to report rainfall amounts every 6 hours after the first 0.5 inches until the rainfall ends. However, observers almost never report precipitation amounts every 6 hours. Expecting the observers to meet this requirement is asking too much, since they are volunteers, paid very little, and cannot be expected to function like machines. As a result, most observers will report precipitation twice a day (7 a.m. and 7 p.m.) with some observers reporting at 1 p.m. Frequently observers will read their gages at times other than the specified observation time and call in the report as a valid observation time. This type of reporting, of course, introduces errors in the precipitation analysis.

Although this system of observing rainfall was adequate many years ago when simple, less accurate hydrologic models were being used to forecast large river basins with crest times greater than 24 hours, current hydrologic models require precipitation data continually if sufficient accuracy is to be achieved. This requirement is especially critical for smaller river basins. As much as 70 percent of the total rainfall can be missed because of the 0.5-inch reporting criterion. The result is a poor simulation of flood forecasts, soil moisture, and substantial errors. Not only will short-term flood forecasts be inaccurate but lack of adequate accounting of soil moisture propagates with time due to the memory of the model.

Another problem associated with using cooperative observers as a primary source of precipitation data is that observers are not always available to make observations when heavy rainfall occurs. For example, frequently heavy downpours occur late at night while observers are sleeping. This situation can lead to a catastrophic flood event occurring without early warning.

Many cooperative observers also take snow depth measurements and measure water equivalent of the snowpack. These precipitation data are important in determining of the average water equivalent in a river basin. Average water equivalent data are input to update the NWS snow accumulation and ablation model which provides snowmelt estimates. The variability of snow depth and density from point to point within a basin is quite high. For instance, for 10 inches of snow, the water content can vary from 1 to 7 inches. Such a difference can lead to a forecast of no flood when in fact there is enough water in the snow to cause a flood during the spring snowmelt season. Unfortunately, the present snow water equivalent observation network is too sparse to allow accurate determination of average river basin water equivalent.

B.1.1.2 Precipitation Data From Other Agencies

Cooperative agreements between the NWS and other water resource agencies has provided benefits to the NWS river and flood forecast service. Sharing of precipitation data helps eliminate a duplication of effort. However, relying on other agencies for critical data needs can be a liability to the NWS. This is because the other agencies have different missions and may not have the requirement for real-time data collection that is essential to the NWS. An example of this dilemma is the TVA precipitation network in the Tennessee River Basin. Ninety percent of the precipitation data utilized by the NWS are from gages owned by TVA. One to two inches of rainfall falling over the basin during a weekend may not be obtained by the NWS until Monday morning. By then it is too late.

Also a cooperating agency may remove a gage after its data needs are met, leaving the NWS minus a gage. Such actions reduce the stability of the overall hydrologic network which NWS depends upon for data and leads to network shrinkage. The problem is especially prevalent during government budgetary cutbacks.

B.1.1.3 Data Handling and Transmission Delays

The majority of the data collected by NWS cooperative observers and other agency observers must be reported to NWS offices with eventual distribution to the RFC's. Precipitation observers make an observation and call the report into their local NWS office. The precipitation report is then tabulated by an NWS technician. After a substantial group of reports has been collected, the reports must be formatted into a hydrologic data product on AFOS and sent to the RFC for processing. On a heavy rainfall day, as much as 3 hours are required to collect data and relay the data to an RFC. At the RFC, the data must then be punched on cards and input to the computerized hydrologic models. Thus, on days when forecast lead time is of critical importance, severe delays in forecast preparation occur due to manual data handling procedures.

B.1.1.4 Precipitation Gage Density

Based on the sizes of the river basins for which NWS makes forecasts, the present precipitation gage network is inadequate to meet the operational needs of NWS (see appendix C). There are too few precipitation gages to allow for the accurate determination of where the rainfall is occurring and how much rainfall has been observed. Extensive studies have been conducted to determine the number of precipitation gages required to produce adequate simulation in streamflow models. The number of rain gages depends primarily on river basin area and the type of precipitation event experienced.

B.1.1.5 Data Sampling Requirements

The data from these gages must be available at a sampling time interval not greater than 1/4 of the potential forecast lead time of the basin. This potential lead time depends on the time lag between the occurrence of rainfall over the basin and the occurrence of the resulting runoff at the forecast point. About 1/3 (35 percent) of the current forecast points (1,000 headwater areas) have potential lead times shorter than 24 hours and thus require precipitation sampling intervals less than 6 hours. Thus the five precipitation gages required for the median headwater basin (400 square miles) must report precipitation at a 6-hour sampling interval if adequate lead time can be realized. Currently, only one gage out of every six gages reports 6-hour precipitation amounts.

The existing precipitation network consists of about 6,000 precipitation gages. Less than 20 percent of the rain gages are now automated. Although limited data are available at shorter time intervals than 24 hours from the automated gages, the first order NWS stations, and the special reports from cooperative observers, these data are not dense enough to make reliable forecasts for most small basins. Analysis shows that about 3/4 (76 percent) of the existing forecast points require data sampling more often than once per 24 hours. The present NWS river and flood forecast system has the capability to utilize 6-hour precipitation data. The primary source of 6-hour precipitation data is the NWS synoptic reporting network. This sparse network and the few automated precipitation gages are used to distribute basin rainfall into 6-hour time steps. This estimation process can lead to large errors in forecasting when the rainfall is nonuniform.

In the spring and summer months, when there is large spatial variation in precipitation due to the occurrence of heavy isolated thunderstorms, accurate determination of how much rainfall has occurred at various times of the day is virtually impossible.

B.1.1.6 Summary of Problems: Precipitation Network

To summarize, the following are inadequacies of the NWS precipitation data network.

1. The one-half inch criterion reporting of precipitation causes significant deterioration of forecast accuracy.

2. There is a lack of dependable 6-hour observations from the cooperative observers.

3. The present snow water equivalent network is too sparse to allow for the adequate determination of the snow water equivalent for the river basins.

4. The dependency of NWS on the precipitation gages owned by other agencies results in (a) the frequent loss of real-time data and (b) the loss of gages during agency budget cutbacks.

5. The manual data handling of reports from the cooperative observers adversely impacts the timely issuances of flood warnings.

6. The number of precipitation gages in the present network is too sparse to permit the accurate determination of precipitation over small river basins.

7. Sampling frequency of data is too low to forecast adequately at least 1/3 of the 3,000 river forecast points.

B.1.2 Radar Data

NWS radars operate 24 hours a day and can provide valuable information concerning the location of storms and estimates of rainfall generated from these storms. Although the NWS radar units can scan up to 250 miles from the station, the effective hydrologic range is limited to 125 miles from the radar site. Within this effective range, the radar accurately can (1) determine the zero precipitation line, i.e., the areas of a river basin that are receiving rain and (2) isolate where heavy precipitation amounts are occurring. Quantitative estimates of rainfall can be derived from radar echo intensity, but the relationship between the reflectivity measured by the radar (Z) and the rainfall rate (r) is variable. The Z-r relationship varies from radar to radar and storm to storm and can produce large errors in determining storm precipitation amounts. The accuracy of rainfall measurement by radar also in dependent on adequate calibration of the radar hardware. Because of these sources of error it is necessary to derive an overall calibration of the radar data using independent observations from rain gages. In order to provide an adequate calibration of the radar data, a network of 25 precipitation gages under each radar umbrella is necessary. The data from these precipitation gages must be available at any time. This capability for random gage interrogation does not currently exist.

Tests in NWS's Southern Region led to creation of an empirical relationship between the sums of hourly observations of manually digitized radar (MDR) data and rainfall rates. For instance in a 3-hour period, if three 1-hourly MDR values are summed, the derived rainfall may range from roughly 2 inches to 6 inches, depending on the storm characteristics. Currently, an experimental radar project called Digitized Radar Experiment has shown that higher accuracy in determining rainfall rates from radar can be achieved with proper calibration and the use of higher resolution data.

Despite the uncertainties, radar is an extremely valuable tool in detecting probable short fused flood situations in the 0- to 6-hour range. Radar data are also useful when integrated with observed rainfall data in determining mean areal precipitation for 12-hour and greater flood events. Hourly MDR data are available on the central computer facility for RFC use and are transmitted on AFOS for use by the WSFO's and WSO's. Since the observed precipitation gage network is so sparse, radar often becomes the primary tool used in issuing warnings for flash flood/headwater flood events. Most of the NWS radar units are located east of the Rocky Mountains. Limited radar coverage is available in the western states.

B.1.3 Satellite Data

The NESDIS is involved in hydrologic support by supplying NWS field offices with satellite imagery, relay of data, and special applications of image analysis. NESDIS's support to the hydrology program is limited because (1) manually oriented techniques are used which limit the area of coverage in determining rainfall rates, (2) there are uncertainties in the derived rainfall estimates, and (3) the success of estimating rainfall rates is restricted to certain meteorological conditions (rainfall triggered by atmospheric convection). Heavy rainfall produced by thunderstorms can be detected via satellite estimation techniques and if these estimates can be relayed immediately to NWS field offices, flash flood warnings and headwater flood warnings can be issued to threatened communities.

NESDIS is developing an Interactive Flash Flood Analyzer which will provide hourly estimates of rainfall from satellite imagery. A large amount of high resolution (6 square mile gird cells) rainfall data will be available in 1983, which when integrated with radar derived precipitation estimates and observed rainfall data will improve MAP's.

B.1.4 Stream Gage Network

NWS requires stream gage data in order to provide river and flood forecast service for the present 3,000 forecast points. Since most river gages are owned by USGS, NWS is highly dependent on the USGS for data. Recently, budget cutbacks being suffered by the USGS have resulted in the removal of about 20 river gages per year. This alarming deterioration of the stream gage network will certainly lead to degraded services unless these gages are replaced. Even now the NWS forecasts for 3,000 forecast points are based on real-time data from only 2,860 river gages. Thus, some river and flood forecasts are already being issued for forecast points where no observed stream data are available.

Stream gage data collected by observers are relayed to the WSFO or WSO in the identical manner as precipitation data. The lack of reliability of the manual observations (same problems as in reporting precipitation data), dependency of NWS on the USGS for river gages, and manual handling of cooperative observer reports at the WSFO's are all critical problems that limit forecast service.

B.1.5 Hydrometeorological Data

Although precipitation and stream gage data are the essential ingredients for providing flood and water management forecasts, other types of data are also necessary. Since NWS provides inflow forecasts to reservoirs and many forecast points are located downstream of reservoirs, reservoir information must be relayed to the WSFO or RFC from the operating agency. Hydrologic data, such as pool elevation, gate settings, and reservoir outflows, are important for the RFC to generate timely and accurate forecasts. Frequently on weekends and at nights, reservoir data are not available.

B.1.5.1 Air Temperature Data

Air temperature data are important for the computation of snowmelt and evapotranspiration. The primary source of temperature data is the NWS basic observation station network. Currently, 6-hourly and maximum and minimum daily temperatures are required inputs to the snowmelt model. These data are available to the RFC's on the NOAA central computers. In the early spring when snowmelt begins, 3- to 7-day temperature forecasts are needed by the RFC to predict snowmelt runoff. Air temperature forecasts are provided by NMC's Forecast Division to the RFC via the central computer facility.

B.1.5.2 Quantitative Precipitation Forecasts (QPF)

An important input to the flood forecast system is the estimate of future precipitation. QPF products are provided to the WSFO's, WSO's, and RFC's by the HPB of NMC. The WSFO's utilize the QPF's as guidance for determining flash flood watches.

The RFC's use the guidance to determine staffing needs for generation of contingency forecasts and will frequently include the QPF in flood forecasts if there is sufficient confidence in the predicted amounts. Currently, QPF must be input manually as point data into the RFC forecast system. This manual data handling can take an excessive amount of time. Because current QPF products do not sufficiently resolve the mesoscale structure of precipitation, they are most accurate when applied to large river basins (>5,000 square miles).

B.1.5.3 Other Data Needs

Meteorological data such as wind speed, dew point, wind velocity, and cloud cover are used by many RFC's to calculate potential evapotranspiration for hydrologic models. These data are normally available in the synoptic files on the NOAA central computer facility.

River discharge measurements are important data that must be received and processed by the RFC in real time. These measurements are normally made by the USGS or the COE and are used to determine the position of the rating curve at forecast points. (The rating curve is the relationship between river stage and discharge at a stream gage.) The accuracy of river and flood forecasts is directly proportional to the accuracy with which this stage-discharge relationship is determined.

High elevation snow data are needed by the RFC so that water supply forecasts can be produced. All high elevation snow data are collected by other agencies, such as the SCS and the Bureau of Reclamation. SCS data must be relayed to the COE's computer in Portland, Oregon, before NWS can obtain the data. It is important for the NWS to have real-time access to this data for its flood and river forecast information system.

B.2 Hydrometeorological Analysis

In order to predict streamflow, river stages, and other hydrologic forecasts, the various hydrometeorological point observations, such as point precipitation and point temperature observations, must be integrated into a MAP. Steps leading to formation of MAP's include taking various data types for various times of observation from various sources of data, and quality controlling, reformatting, and placing these data into a data base before computing MAP.

B.2.1 Data Processing Capabilities

In terms of problem analysis, the RFC's do not have adequate system software and peripheral hardware capabilities to handle data loading. The acquisition of the minicomputers for the RFC's has off loaded some of the difficulties in automating data collection and processing; however, mass storage is too restricted to be able to handle the data volume. Also, a comprehensive set of data entry processing software is not available in order to provide the necessary processing functions of quality control, reformatting, and data distribution.

At the WSFO, all data handling is done manually. The WSFO has virtually no computer capabilities to process data.

Once hydrologic data have been collected and input to the RFC hydrologic data base located on the NOAA central computer, further processing is required to translate point observation data to mean areal data. All precipitation, temperature, and evapotranspiration data must be analyzed, meshed, and represented as mean river basin values. The present river forecast systems utilized by RFC's have capabilities to convert point hydrologic data into MAP. However, other sources of precipitation data cannot be utilized in determining areal estimates and distribution of rainfall. Digital radar estimates of rainfall and satellite estimates of rainfall currently can only be used subjectively in the analysis of precipitation.

B.2.2 Integrated Data System

The lack of a nationwide integrated data system affects more than just the RFC's. The NMC HPB requires real-time precipitation observations to update issuance of QPF products. NESDIS requires real-time precipitation data to verify satellite rainfall estimates and calibration procedures. Also other agencies, such as the COE, TVA, SCS, USGS, require real-time hydrologic data.

QPF data are now manually input to the present hydrologic models. These data need to be available in a machine-readable form in real time if the RFC's are to respond to rapidly changing meteorological conditions.

B.3 Hydrologic Models

Presently, various hydrologic models are being used by the RFC's to produce hydrologic forecasts. Hydrologic models can be classified as (1) rainfall/runoff models, (2) channel routing models, (3) snow models, (4) reservoir routing models, (5) extended streamflow prediction models, and (6) dam break models.

B.3.1 Rainfall/Runoff Models

Rainfall/runoff models are models which utilize as input MAP and produce basin runoff as output. Commonly used rainfall/runoff models are the API, SSARR, and the Sacramento soil moisture accounting models. In the mid-1970's, the NWS made the decision to utilize the Sacramento model in its forecast system based on test results of the various models conducted by the World Meteorological Organization. With adequate data input, the Sacramento model provided increased accuracy in streamflow simulation, especially during extended dry periods. Since then, evidence suggests that without proper data input, these streamflow simulations are only marginally better than those obtained with other models such as the API model.

In order to run the Sacramento model on any given river basin, it must be calibrated. Using historical precipitation, meteorological, and streamflow data, model parameters are defined via an iterative process of trial and error. The calibration process for one basin can take anywhere from 3-6 weeks depending on the quality of data, skill of the hydrologist in calibration, and operational workload of the RFC. Approximately 15 percent of all the river basins for which RFC's issue forecasts have been calibrated for the Sacramento model. Because of limited personnel resources, operational workload, and the time required to calibrate a river basin, there will not be a substantial increase in calibrations over the next few years using the current calibration techniques. It is also important to note that many river basins already calibrated will have to be recalibrated in the next several years due to land use changes in the watershed.

Since the Sacramento model is not a perfect model, bad data can cause the model to drift even if the calibrated parameter set for a given basin seems to be optimum. Real-time adjustment or updating of the model variables (i.e., soil moisture variable states) is a lengthy trial-and-error process that contributes to decreased lead time of a flood forecast.

B.3.2 Channel Routing Models

Channel routing models are mathematical expressions of varying complexity and accuracy which describe the attenuation or flattening of a flood wave as it moves downstream. However, in many instances, along streams with mild slopes and where backwater effects occur (where water can be forced to back upstream), simpler channel routing models are inadequate. The NWS DWOPER model is the most accurate channel routing model currently used since the model simulates flood wave attenuation using a complex set of hydrologic equations. The entire lower portion of the Mississippi River is now being forecast by DWOPER. Because of the large amounts of data required for calibration and the technical nature of the calibration process, implementation of the model will be slow for the many other rivers where it could be used.

B.3.3 Snow Models

Snow models keep track of the liquid water content (water equivalent) and melt characteristics of the snowpack, and (using snow depth or water equivalent and air temperature as input) simulate snowmelt runoff as output. The snow accumulation and ablation model developed by the NWS HRL is the most accurate snowmelt runoff forecast model currently used and is being utilized by many RFC's. The primary drawbacks in implementation of the snow model are difficulties in calibration and lack of quality data.

B.3.4 Reservoir Routing Models

Reservoir routing models are models which route or move streamflow through a reservoir based on a complicated set of algorithms. Reservoir regulation is usually based on a complex set of factors. The reservoir "rule curve" is the basis from which most flood control reservoirs operate. Simplified, the rule curve describes the reservoir outflow that should be allowed based on the pool elevation throughout the year. However, most reservoirs are multipurpose and must base regulation policy on municipal, power, flood control, pollution, and water supply needs. Prediction of reservoir operation can be exceedingly complex. All RFC's have reservoir routing techniques. The HRL is now developing a comprehensive reservoir routing model which will provide simulation of complex reservoir operations.

B.3.5 Extended Streamflow Prediction (ESP) Models

The ESP model is discussed in sufficient detail in section 6.3 in the main text and appendices D and E and needs no elaboration in this appendix.

B.3.6 Dam Break Models

In the event of a possible dam failure, NWS must be prepared to issue a flood forecast and warning immediately to threatened residents. The HRL has provided an accurate dambreak model; however, this model must be run on the central computer facility to which only the RFC's have access. Simplified dambreak flood wave simulation techniques will be available in the near future to WSFO's for use during emergencies.

B.3.7 National Weather Service River Forecast System (NWSRFS)

The NWSRFS, Version 5.0, is a collection of all the hydrologic models described previously, plus an assortment of precipitation processing routines and utility programs to display and manipulate data, as well as software to provide efficiency in execution of the system routines. A Hydrologic Command Language will provide flexibility in selecting a few or all of the modules in the system depending on the requirements of the RFC. Also, the flexible design structure will allow for immediate introduction of new technology to the system as it becomes available. Version 5.0 is now in the development phase and will be released in the fall of 1983. Version 5.0 provides the basic structure needed for a major change in the way the NWS provides its hydrologic services; however, much work is necessary to bring the total NWSRFS system to completion.

B.4 Service Delivery

B.4.1 User Response to Warnings

For flash flood and flood warnings to be effective, i.e., to motivate an appropriate response by individuals, the warning message must contain detailed specific information so that an individual feels at risk. According to sociological studies conducted after recent flood disasters, people require this specific flood information in order to take action. A warning aimed at a county area does not provide specific information on areas of possible inundation nor does it give flood forecasts for specific gages. Also, most people cannot relate a flood forecast for a forecast point to the areas which may be inundated or even to the possibility of their property being flooded. The better the information NWS can give people, the more likely it is they will make efficient responses in the face of a flood.

The perfect flood forecast is of no value if communities do not take appropriate actions to save lives and property. Although it may not be the direct responsibility of the NWS to make sure that community disaster agencies take appropriate response to flood warnings, it is NWS's responsibility to assure that NWS's services are well understood and how to use them best. Many county and local communities are simply unprepared when a flood event is forecast.

B.4.2 Hydrology Training Programs

A problem which continues to surface frequently is the lack of hydrology training for meteorologists, service hydrologists, hydrologic technicians, and new RFC hydrologists. The only formal training mechanisms for hydrology are (1) a 2-week flash-flood forecast course taught at the NWS Training Center, (2) an out-of-date hydrologic services correspondence course, and (3) formal university training. New forecasters simply do not gain the forecasting insight necessary to deliver properly hydrologic services to the public from these mechanisms.

Appendix C - RAIN GAGE NETWORK REQUIRMENTS AND BENEFITS ANALYSIS FOR HEADWATER FORECAST POINTS

This appendix summarizes the results of an NWS study to:

- Determine the required number of rain gages in the headwater areas;
- Assess the adequacy of the existing rain gage network; and
- Estimate the potential benefits of improving the rain gage network in headwater areas.

This appendix concludes:

- 5,700 automated rain gages are needed to serve fully the existing headwater forecast points; and
- Potential additional benefits from the increased warning lead time that would result are about $100 million annually.

The approach taken is as follows:

- Establish the number of rain gages required in a given headwater basin depending on the area of the river basin;
- Determine the number of headwater forecast points and the river basin area for each;
- For each basin determine the number of gages required and determine the total number required (5,700) as the sum of the requirements for each basin;
- Establish a general relationship of flood warning benefits to headwater areas in terms of the percentage reduction in flood damages, depending on the lead time for response to the warning;
- Determine for each forecast point the potential lead time that could be attained, the required data sampling interval to achieve this lead time, and the actual lead time now achieved;
- Determine for each forecast point the mean annual flood damage; and
- Estimate for each forecast point the potential flood warning benefits that could result from existing services and from future services if potential forecast lead times were achieved.

Because every item of information required by this approach was not readily available at each of the NWS forecast points, a statistical sampling approach was used to extend results from representative samples to the full population.

The results obtained and the assumptions made are described below for each step of the approach. A summary of assumptions follows the step-by-step explanation.

C.1 Number of Rain Gages Required in a Given Headwater Basin

Extensive studies have been made at the Massachusetts Institute of Technology, the NWS O/H, Illinois State Water Survey, and Stanford University of the spatial variability of precipitation, the number of rain gages needed to predict flood crests, and the required data sampling interval. For planning purposes the number of rain gages required to make a flood forecast depends primarily on river basin area. Table C.1 gives the number of gages required for different size areas.

TABLE C.1: Rain Gage Requirement as a Function of River Basin Area

Required Number of Rain Gages	River Basin Area (Square Miles)
3	<40
4	100
6	400
8	1000

The number of gages in Table C.1 is adequate to determine the MAP over the given size area with an accuracy of ±20 percent during 80 percent of the storms occurring over that area and for the data sampling interval appropriate for the river basin area. This is sufficiently accurate knowledge of precipitation to make reliable forecasts.

C.2 Number of Headwater Forecast Points and River Basin Areas

There are 3,000 flood forecast points served by the NWS. Figure C.1 shows the distribution of river basin areas upstream from the forecast points. The headwater areas are those having river basin areas less than 1,000 square miles. Figure C.1 shows that about 1/3 of the existing forecast points (i.e., 1,000 of them) have river basin areas of 1,000 square miles or less.

Also shown in Figure C.1 is the distribution of river basin areas upstream from the 20,000 communities with flood problems according to the U.S. Water Resources Council. This distribution was used as explained below in the process of estimating mean annual flood damages at the existing headwater forecast points.

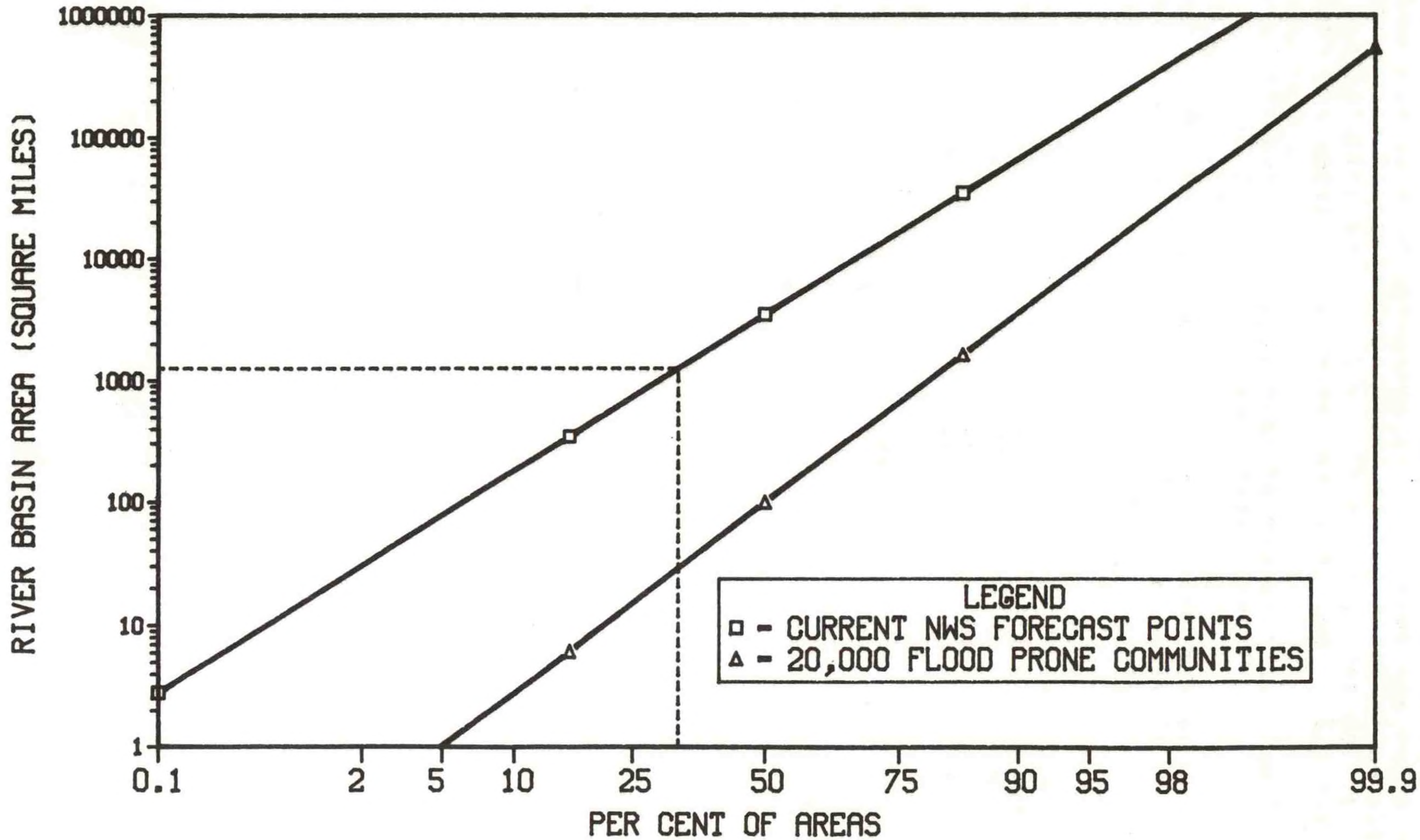


FIGURE C.1 DISTRIBUTION OF RIVER BASIN AREAS ABOVE FORECAST POINTS AND FLOOD PRONE COMMUNITIES

C.3 Total Number of Gages Required in Headwater Areas

The number of gages required for currently forecast headwater areas was determined by applying the required number of gages/area in Table C.1 to the distribution of river basin areas given on the top curve in figure C.1. The calculations are shown in Table C.2. They show that about 5,700 gages are required.

TABLE C.2: Number of Rain Gages Required for Existing Headwater Areas

Area (Sq.Mi)	Cumulative Percent of Areas	Cumulative Number of Areas	Incremental Number of Areas	Required No. of Gages/Area	Incremental Number of Gages	Cumulative Number of Gages
3	.002	6	6	3	18	18
6	.005	15	9	3	27	45
13	.010	30	15	3	45	90
25	.020	60	30	3	90	180
50	.050	150	90	3.2	288	468
126	.100	300	150	4.3	645	1113
200	.150	450	150	4.9	735	1848
398	.200	600	150	6.0	900	2748
631	.250	750	150	6.9	1035	3783
794	.300	900	150	7.4	1110	4893
1000	.333	1000	100	8	800	5693
	Totals		1000		5693	

C.4 General Relationship for Flood Warning Benefits to Headwater Areas

Public and institutional response to warning information improves with increased lead time. This relationship is illustrated by Figure C.2. (Day, 1970) It represents the damage reduction that could be realized through individual actions of residential property owners. It suggests that a forecast lead time of 24 hours could reduce flood damages by nearly 30 percent and that a 12-hour lead time could result in a 20 percent reduction. Such reductions are substantial, but the most dramatic effect is seen with a lead time for only 4 hours, which could produce a nearly 10 percent reduction. This reduction is possible because many valuable items such as cars, televisions, and furniture can be moved readily. The study also concludes that 1/3 of all residential damages in these river basins could be avoided through reliable flood warnings. It is noteworthy that the study did not account for preventive actions taken by industry, agriculture, or businesses nor did it include benefits that could be derived from community actions such as reinforcing threatened levees. Because the benefits to commerce, industry, and from community actions are generally greater than benefits to residential flood plain occupants, Figure C.2 is assumed (conservatively) to apply to all flood damages in the following potential benefit analysis.

C.5 Potential Lead Times, Required Data Sampling Interval, and Actual Existing Lead Times

The potential lead time for a given river basin is the time between the occurrence of the most intense rainfall over the river basin and the occurrence of the flood peak at the forecast point. The potential lead time depends primarily on river basin areas but varies substantially among basins having the same area. A study of lead times for representataive basins was made, producing the conditional distribution of lead times for the current forecast points shown in figure C.3.

Applying basic rules of distribution theory to the distributions shown in figures C.1 and C.3 produced the distribution shown in figure C.4 of potential lead times for the existing forecast points. No additional assumptions or data were introduced to produce the distribution of potential lead times.

In order to achieve the potential lead time for the current forecast points, rainfall observations must be made at sampling intervals much shorter than the potential lead time. As a minimum, this sampling must be no longer than 1/4 of the potential lead time. Accordingly, the distribution of required sampling intervals for the existing forecast points is shown in figure C.4 also.

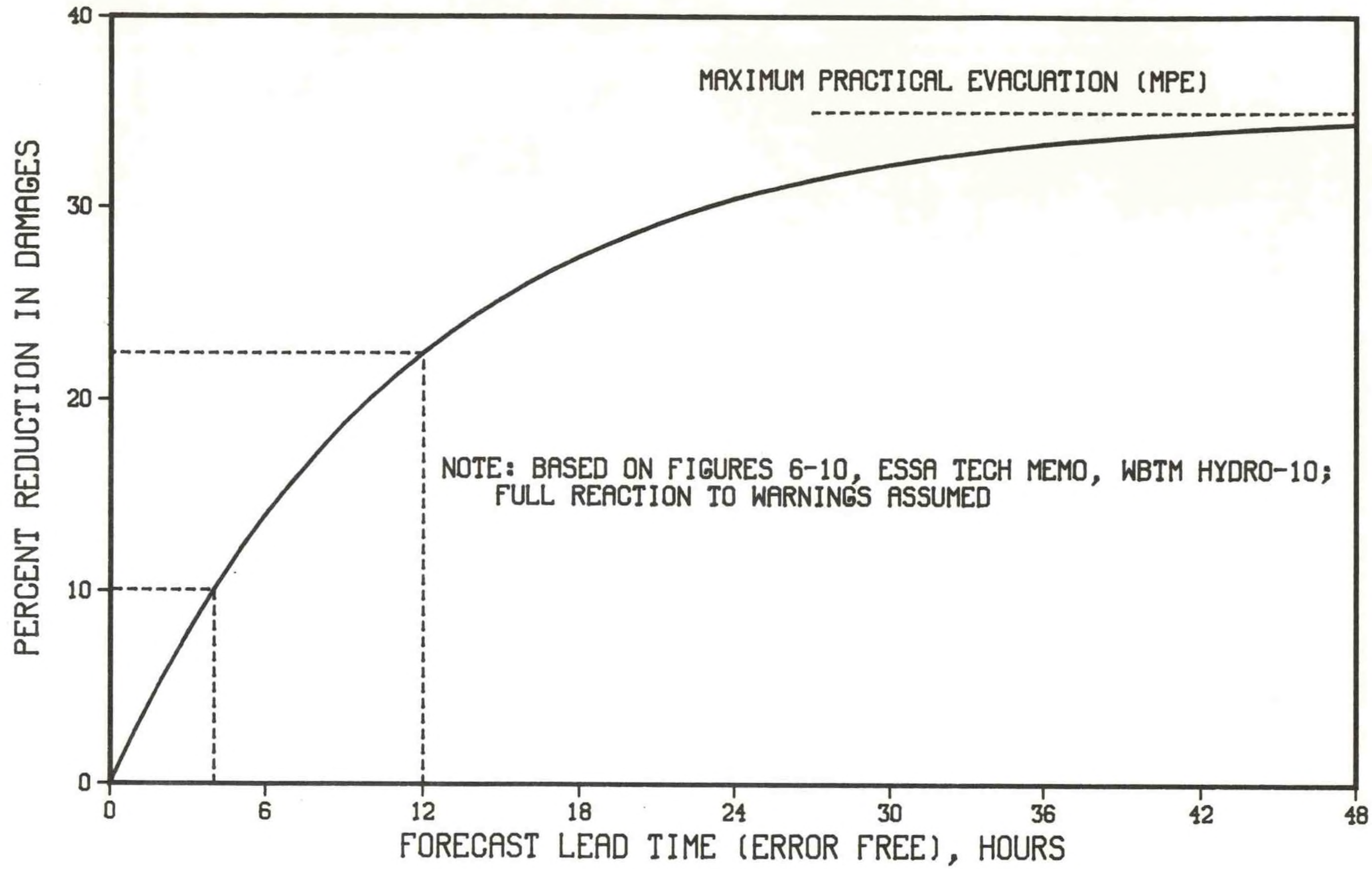


FIGURE C.2 DAMAGE REDUCTION AS A FUNCTION OF LEAD TIME

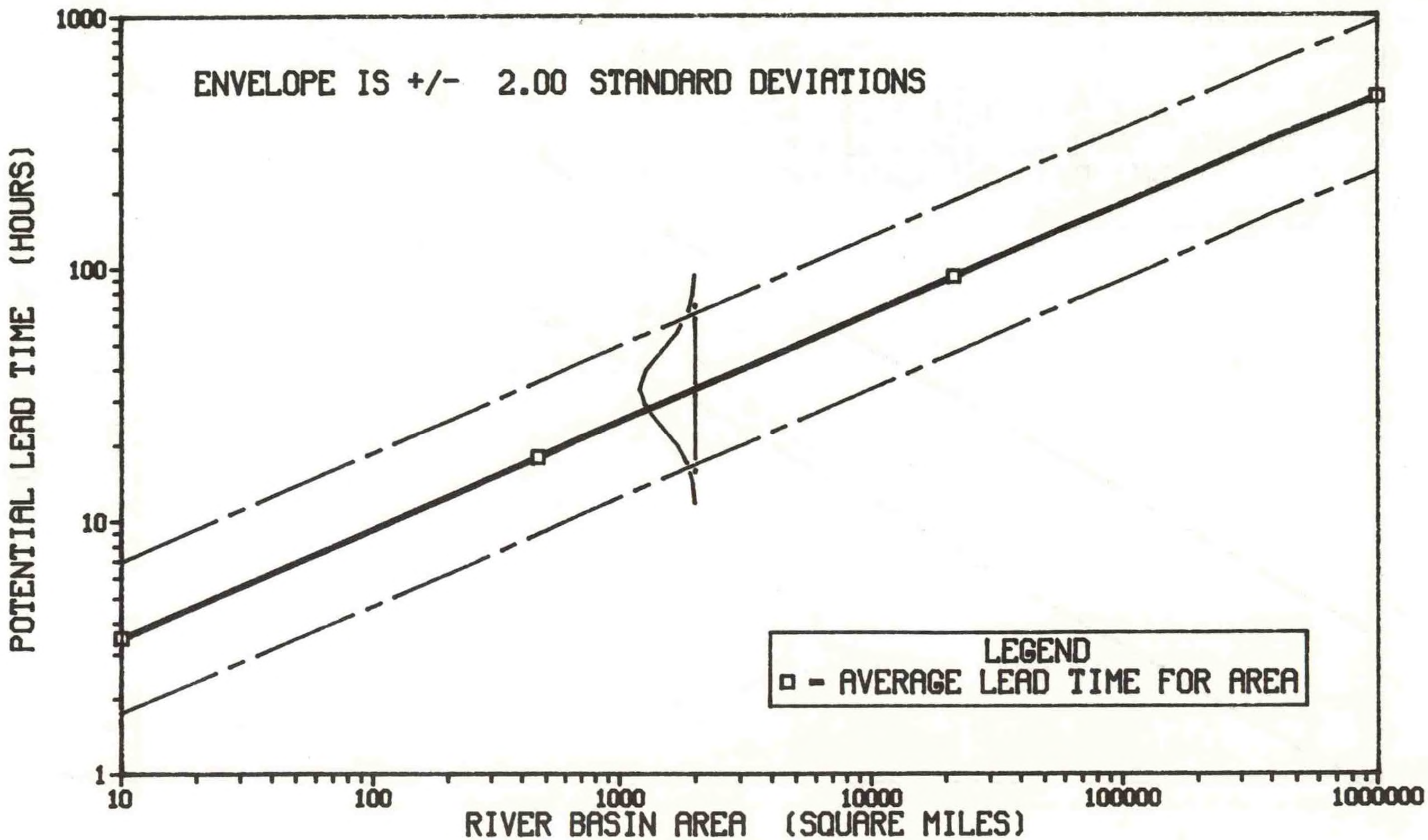


FIGURE C.3 CONDITIONAL DISTRIBUTION OF
POTENTIAL LEAD-TIME FOR A GIVEN RIVER BASIN

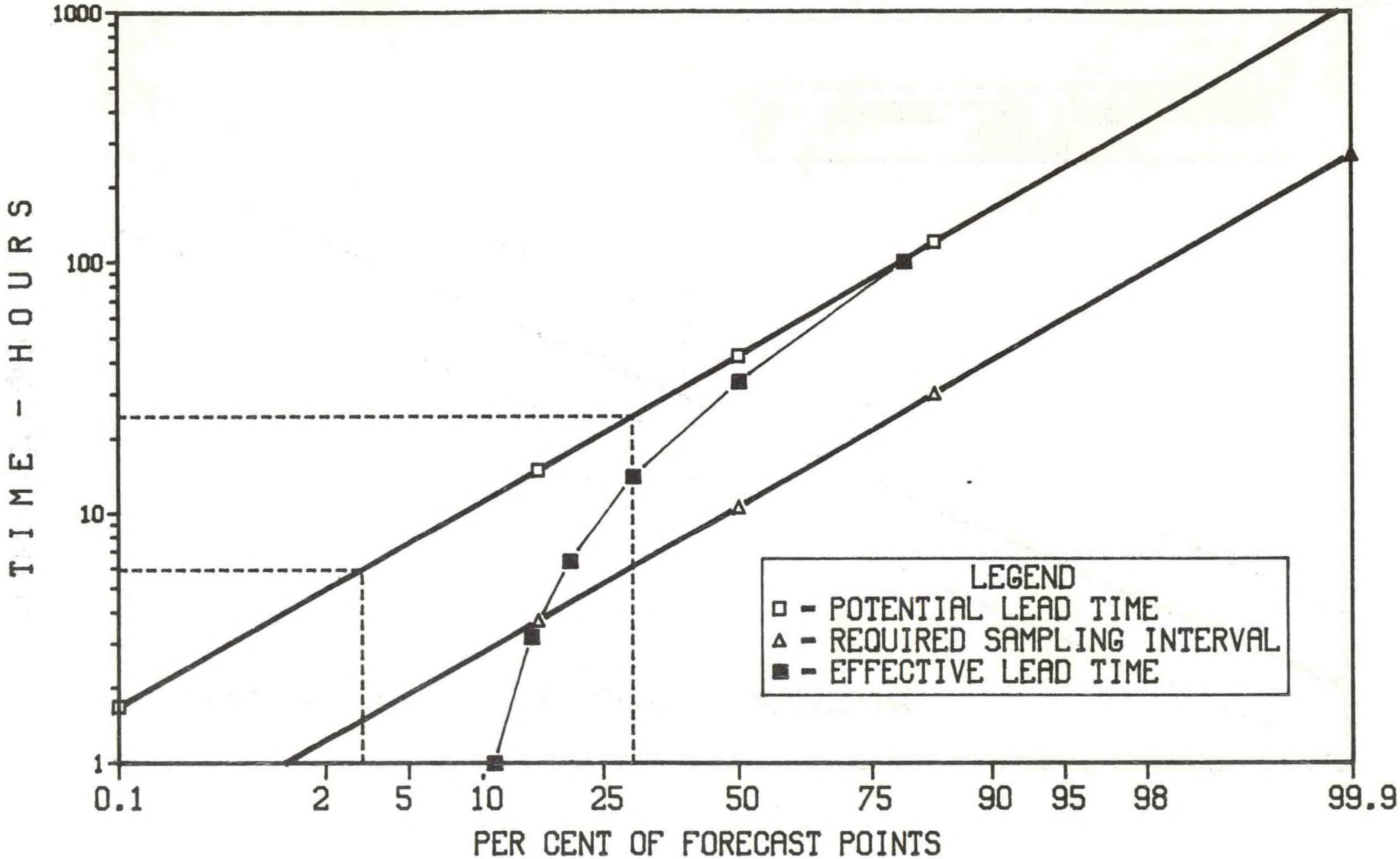


FIGURE C.4 DISTRIBUTION OF POTENTIAL LEAD TIMES
AND REQUIRED DATA SAMPLING INTERVALS FOR 3000 EXISTING NWS FORECAST POINTS

The existing data collection system works best at 24-hour sampling intervals because most data come from cooperative observers who provide daily reports. Although limited data are available at shorter time intervals than 24 hours from automated gages, NWS weather stations, and special reports from cooperative observers, these networks are not dense enough to form the basis of reliable forecasts for most small basins.

Because existing data networks do not operate at the rapid data sampling rates suggested by figure C.4 for rapidly rising rivers, the actual lead time distribution lies below the potential lead time distribution in figure C.4. The actual distribution is unknown but has been estimated to illustrate that substantial amounts of valuable lead time are being lost because of inadequate data network performance.

C.6 Mean Annual Flood Damages for Existing Headwater Forecast Points

Detailed flood damage information for existing headwater forecast points does not exist, but the distribution of damages at these points may be inferred from flood damage estimates for all flood prone places. The procedure used to do this was:

- Estimate the distribution of flood damages among the 20,000 flood prone communities on the basis that the mean annual flood damage for all communities is now about $5 billion and that, according to data taken from a COE study of flood damages prepared for the National Flood Insurance Act of 1968, the coefficient of variation of damages among individual communities is equal to 4.6, a highly variable distribution which was represented in this study by a log-normal distribution.

- Correlate the mean annual damages for a given community with the river basin area above the community so that the distribution of damages between headwater areas and downstream main stem flooding is preserved according to Water Resources Council estimates of upstream and downstream damages. Accordingly, the coefficient of correlation between the logarithms of drainage basin area and mean annual flood damage was estimated to be 0.7.

- Estimate the distribution of potential lead times for 20,000 flood prone places (figure C.5) by combining the distribution of river basin areas as shown in figure C.1 with the distribution of lead times conditional on drainage basin areas from figure C.3.

- Estimate the joint distribution of damages and lead times for all 20,000 communities. With the assumptions introduced above regarding the distribution of damages

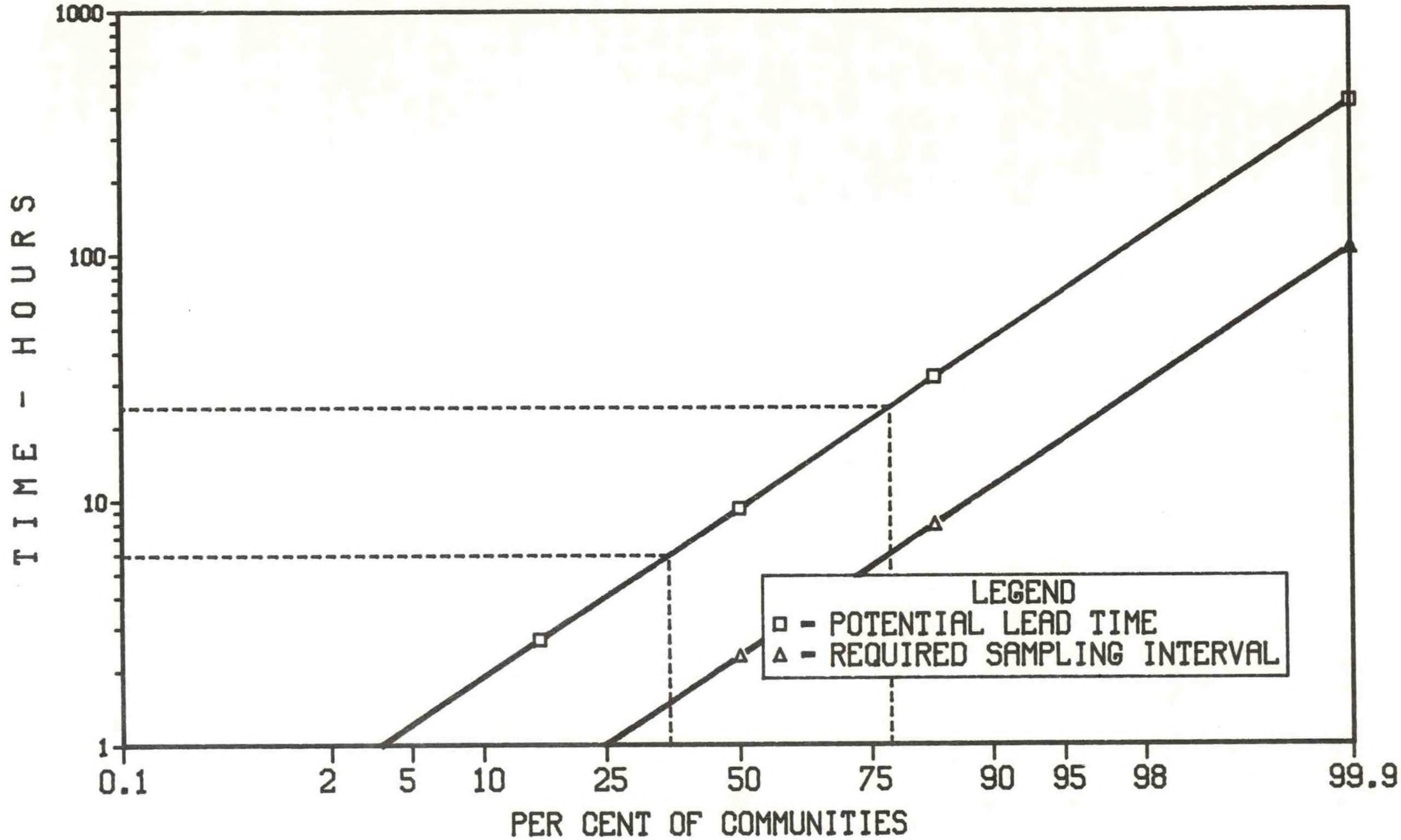


FIGURE C.5 DISTRIBUTION OF POTENTIAL LEAD TIMES AND REQUIRED DATA SAMPLING INTERVALS FOR 20000 FLOOD PRONE COMMUNITIES and the correlation between damage and river basin area, the result is the joint distribution in figure C.6.

- The solid contours represent constant relative occurrence among the 20,000 communities. The highest point on this surface occurs near the point having 10 hours lead time and $50,000 mean annual flood damage. This is the most frequently occurring combination of damage and lead time among the 20,000 communities. The contours toward the edge of the figure represent lower relative occurrence. The contours are spaced so that 10 percent of the communities lie between the contours.

- Assume that the 3,000 existing forecast points were selected for more rigorous forecast service from among the 20,000 in order to serve those with the greatest mean annual flood damage. This is illustrated in figure C.6 where it was found that 3,000 communities have mean annual flood damages in excess of $300,000. The shaded region above $300,000 also implies the distribution of flood damages among existing headwater forecast points.

- Check the consistency of all assumptions by comparing the distribution of potential lead times for existing forecast points as shown in figure C.4 with the distribution implied by the region above $300,000 in figure C.6. The two distributions so derived were approximately the same indicating that all assumptions were mutually consistent.

C.7 Estimation of Flood Warning Benefits for Actual Lead Times and Potential Lead Times for Headwater Areas

If the potential lead time was provided by flood warning, the potential flood warning benefits that would occur were found by:

- Using the generalized benefit curve in figure C.2 to rescale figure C.6 to a distribution of mean annual benefits and potential lead times.

- Adding together the benefits for existing headwater forecast points.

The resulting mean annual flood warning benefit (6 to 18 hour lead-times) for achieving potential lead times in headwater areas was found to be about $170 million.

Part of these benefits are already being achieved because some lead time is now provided to headwater areas. The existing 3,000 forecast points provide lead times estimated to be as shown in figure C.4. These actual lead times are less than the potential lead times, and figure C.4 shows the relationship between actual and potential lead time. The estimate of actual

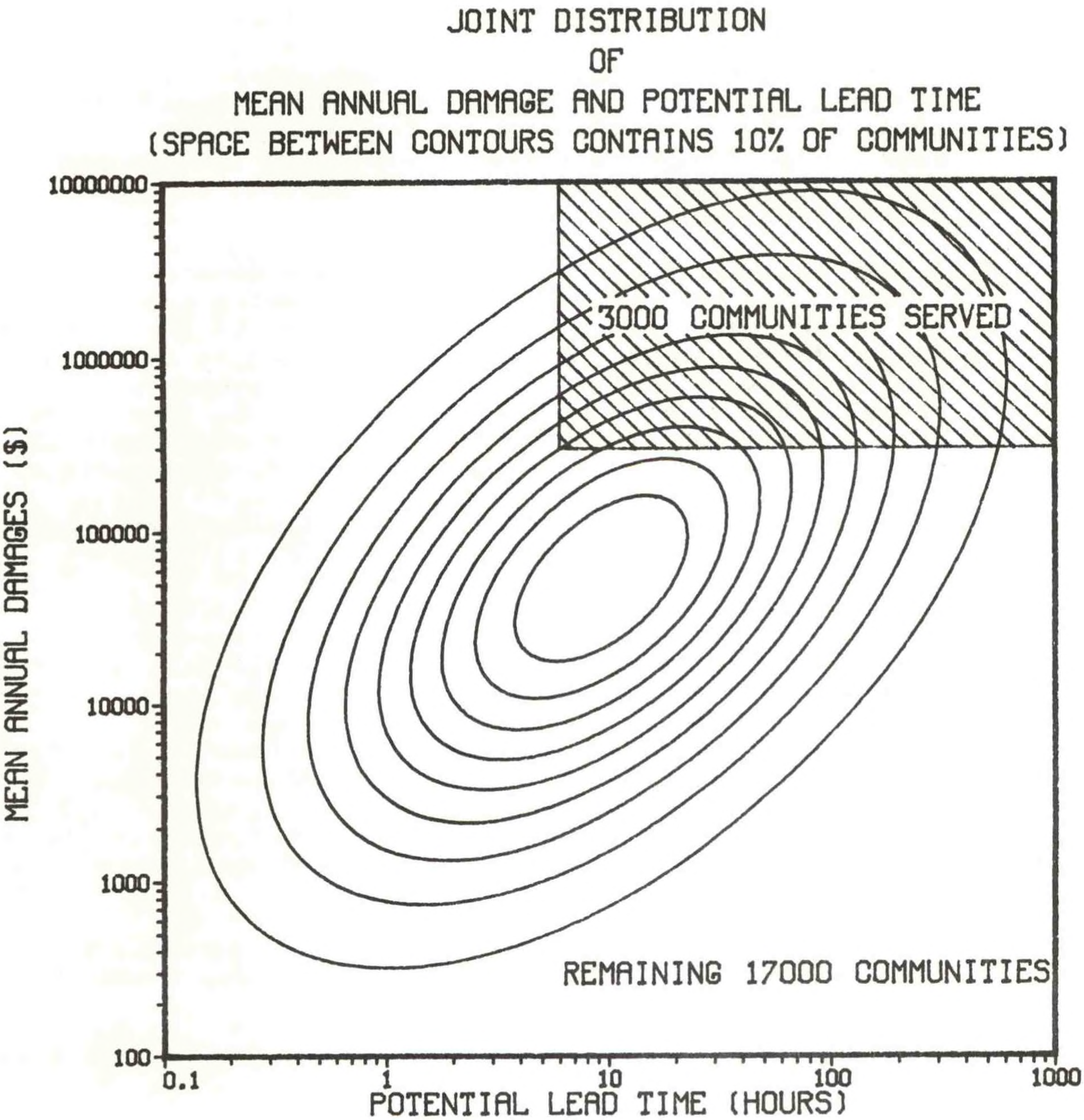


FIGURE C.6 RELATIVE FREQUENCY OF OCCURENCE
OF MEAN ANNUAL FLOOD DAMAGE AND POTENTIAL LEAD TIME
FOR 20,000 FLOOD PRONE COMMUNITIES

benefits from the existing headwater points was found by:

- ° Using the relation between potential and actual lead times implied by figure C.4 to shift the lead time axis of figure C.6 to actual lead time.
- ° Using the benefit curve from figure C.2 to change damages to benefits.
- ° Adding together the benefits for existing forecast points having actual lead times from 30 minutes to 2 hours (potential lead time in the range of 6 to 18 hours).

The resulting mean annual flood warning benefit for existing lead times was found to be $70 million. The incremental potential benefit of improving the lead time for headwater areas was found to be the difference between $170 million and $70 million, i.e., $100 million.

Flood damages and flood warning benefits at existing forecast points were found to be distributed with potential lead time as shown in figure C.7. Also shown in figure C.7 by the same labelled "number of places" is the distribution derived from figure C.6 of the potential lead times at existing forecast points.

These distributions indicate: the most frequently occurring potential lead time at places served is about 30 hours; the greatest propensity for flood damage is at places with potential lead time of about 50 hours; and the greatest opportunity to get flood warning benefits is for places with potential lead time of about 60 hours. The left hand side of the distribution of benefits drops off much more quickly than the distribution of damages mainly because actual lead time are much less than the potential lead times due to delays in data collection and analyses.

C.8 Summary of Assumptions

1. Number of rain gages required to make a reliable flood forecast is given by Table C.1.
2. Distributions of river basin areas for 3,000 existing forecast points and for 20,000 flood prone places are as shown in figure C.1
3. Headwater areas are 1,000 square miles or less.
4. Damage reduction for reliable forecasts in headwater areas depends on lead time according to figure C.2.
5. Conditional distribution of potential lead time for current river forecast points is shown in figure C.3.

RELATIVE FREQUENCY OF OCCURENCE

OF PLACES SERVED, FLOOD DAMAGES, AND POTENTIAL BENEFITS

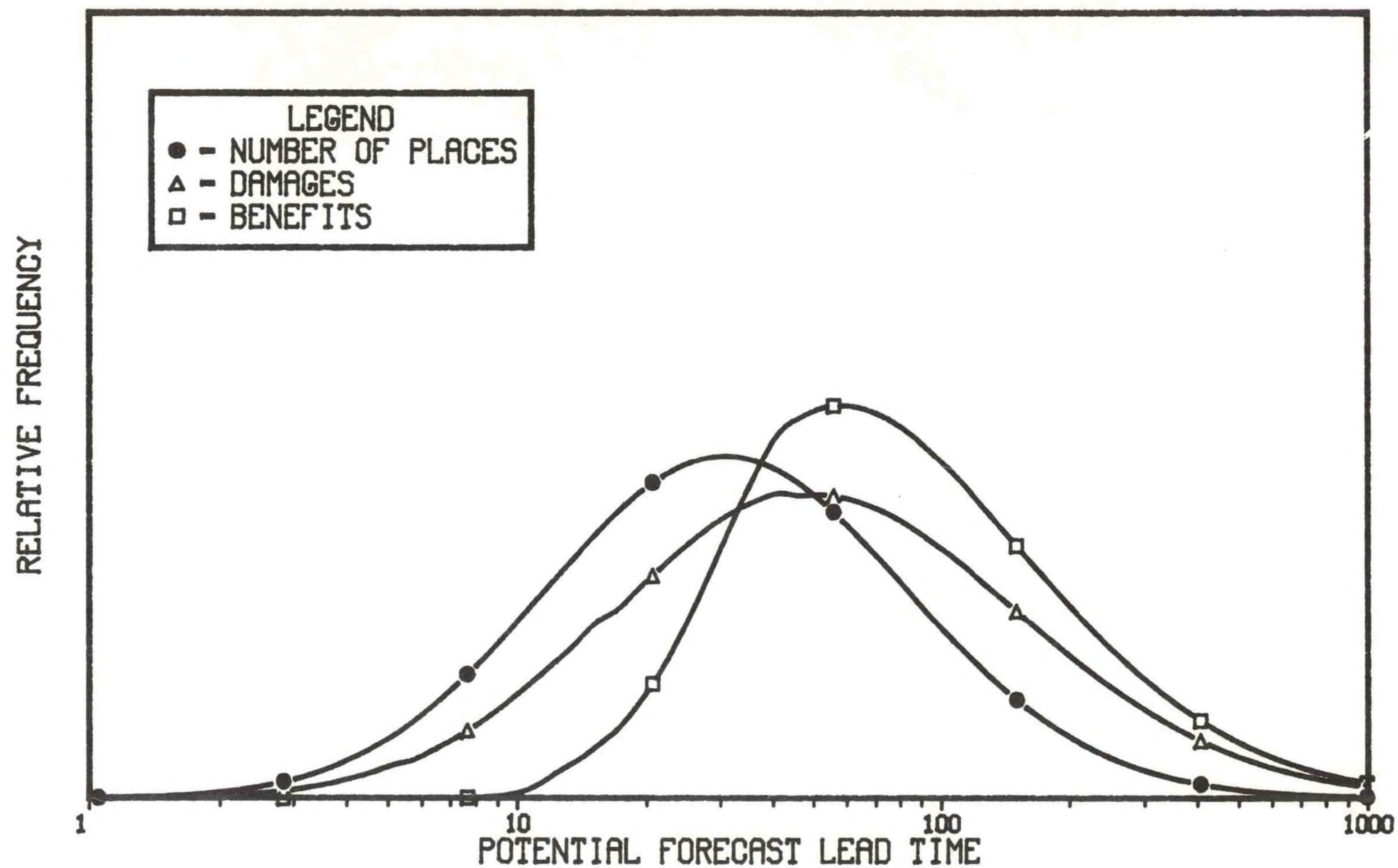


FIGURE C.7 EXISTING 3000 NWS FORECAST POINTS

6. Estimated actual lead times are as shown in figure C.4.

7. Mean annual flood damage for all communities is now about $5 billion.

8. Coefficient of variation among individual community mean annual flood damages is 4.6, and these damages are assumed to be distributed according to a log-normal distribution.

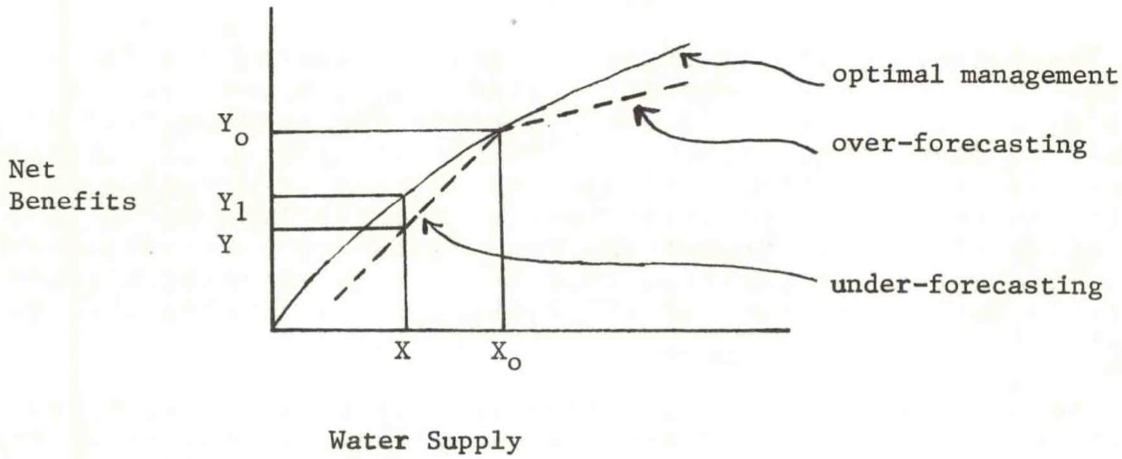
9. Mean annual damages for a given community are correlated with river basin area with a coefficient correlation equal to 0.7, which accounts for a balance of damages between upstream and downstream locations according to the U.S. Water Resources Council.

10. The 3,000 existing forecast points were selected for more rigorous forecast service from among the 20,000 flood prone communities in order to serve those with greatest damage first.

Appendix D - BENEFITS OF WATER MANAGEMENT INFORMATION

D.1 Net Benefits versus Water Supply

Castruccio (1979) described the philosophy of the relationship between river forecasting and water management. The less perfect the future supply of water (in terms of quantity and timing) is known, the less efficient are the water management activities and the lower the benefits from such uses. The figure below illustrates the concept.



A perfectly managed volume of water is represented by X_o with a net benefit of Y_o. However, if this volume is either under or over forecast the net benefits will be derived from the dashed lines. If the volume X_o is forecast and the lesser volume X is obtained, the corresponding benefits will be Y. Had X been forecast correctly, the benefits would have been Y. Therefore, the benefit loss is the difference between Y and Y_1.

This shows that in an attempt to maximize benefits, activities are planned to most efficiently use the water. However, when the actual supply of water differs from that forecast either in terms of volume or timing, efficiency suffers and the water is used less than optimally.

Losses occur from under- and over-forecasting the volume inflow to major water storage projects. For example, for hydropower generation, low forecasts mean sales of excess power at less than the best rate; high forecasts mean contracted sales have to be met by higher cost alternative means of generation.

D.2 Example Application of Water Management Information

Smith et al. (1982) documented the application of the NWS River Forecast System to water management policies during drought in the Washington, D.C., metropolitan area.

Low summer streamflow in the Potomac River is the result of low summer rainfall combined with long-term dry soil moisture conditions. Streamflow forecasting, used as a water management tool during droughts, must consider information concerning soil moisture as well as uncertainty in future precipitation. The Sacramento Soil Moisture Accounting and Extended Streamflow Prediction Models in the framework of the NWSRFS are especially suited to this type of forecasting requirement.

The Potomac Basin is segmented into 24 subregions for which the soil moisture model was calibrated and is operating. A hydrologic routing model is used to route the outflow from one segment to downstream segments. The ESP procedure, as applied to the Potomac River Basin, incorporates current information pertaining to soil moisture conditions as the starting point in a simulation of future streamflows from historical precipitation data. Comparison of the simulated flows with observed historical flows indicates the risks of streamflows falling below a certain amount.

Operating rules for reservoirs are not based directly on probabilistic forecasts of minimum daily flow but rather on the probability of meeting demands and refilling reservoirs. ESP has been linked to a model which simulates the water supply system of the Potomac River to effect this requirement. Twenty-four years (1951 - 1974) of historical precipitation data (restricted to the period May 1 - October 1) were used to simulate 24 streamflow sequences. These 24 sequences (for five sites including Potomac River main stem and reservoir inflow points) were used as input to a water supply (demand) model producing 24 values of computed shortages. The 24 values were then used to produce a probability distribution of shortages for the period May 1 through October 1, 1982. The water supply (demand) model was developed by the Interstate Commission on the Potomac River Basin, Cooperative Water Supply Operations on the Potomac River (CO-OP).

Operations on the Potomac River using the above procedures, developed in a cooperative effort of the members of the CO-OP, the Office of Water Research and Technology, the COE, the NWS, and the states have produced an increase of between 100 and 200 percent in the effective yield of existing reservoirs. In this case alone, improved operations, costing less than one-half of 1 percent of projected construction costs, eliminated the need for up to a quarter billion dollars of additional reservoir construction. The estimate is based on the assumption that benefits are proportional to replacement value of planned construction.

Conservatively, for the Nation, then, increasing the productivity of existing major Federal water resource projects by only 12 percent is worth just as much as new construction over the next 20 years ($2.5B per year for 20 years discounted at 10 percent per year).

Appendix E - FORECASTS FOR WATER MANAGEMENT

E.1 Introduction

The purpose of this appendix is to demonstrate some of the improvements of water management which can be expected by meeting the major goals of this PDP.

The major water management forecast services provided by the NWS are (1) water supply forecasts, (2) extended river forecast for navigation and municipal water supply interests, and (3) reservoir inflow forecasts for use in regulation and management of reservoirs. Services in these three major areas are currently limited. Improvements in river forecast information services will result in substantial benefits to the Nation.

E.2 Water Supply Forecasts

NWS water supply forecasts are an essential service to the Nation. As stated in Chapter 6.3 and appendix D, improvement of services in this area could lead to tremendous economic benefits.

E.3 Examples of the Use of Extended River Forecasts

In addition to water supply forecasts, the NWS provides extended river forecasts for many of the 3,000 forecast points for other purposes. This extended river forecast service is provided for those locations on major main stem rivers where long-range forecasts are required for the operation of river commerce (barge transportation) or water treatment plants. For navigation interests, knowledge of the river stage along navigable rivers is essential to plan loading of commodities onto barges and scheduling of traffic. For example, according to the Sioux City Barge Line, for every 0.1 foot change of river stage that is forecast, an additional $1,500 in commodities can be loaded onto one barge. One tugboat can tow 12 barges, and hundreds of tugboats are traversing the Nation's waterways each day. Increased accuracy in extended river forecasts is thus directly translatable into benefits to the Nation's commerce. As another example, in order to properly load oil tankers in the Middle East, oil companies must know the minimum amount of river stage in the Lower Mississippi River 2 to 3 weeks in advance. The river stage information is critical to the efficient transfer of crude oil destined for the Mississippi River and interior refineries.

The NWS provides 30-day long-range forecasts to meet this critical navigation need. However, accuracy of extended forecasts is limited by many factors. These factors include availability of data, determination of MAP, and model performance as described earlier in the text.

E.4 Reservoir Management Forecasts

A third category of forecasts for water management provided by the NWS is reservoir inflow forecasts. An application of NWSRFS to proper reservoir regulation is discussed in appendix D. The present value of existing major Federal water resource projects alone is $170B. The majority of the construction projects involve building and maintaining reservoirs. Reservoirs provide multipurpose benefits as described in 6.3.

At an American Society of Civil Engineers' Workshop on reservoir system operations in 1979, studies released showed benefits that could be realized by improving management of reservoirs.

1. A 10 percent increase in the value of power from the California Central Valley Project.

2. Up to a 20 percent increase in the value of power from TVA facilities.

3. A 3 to 6 percent increase in flood reduction and navigation benefits in the Arkansas River Basin.

4. A 50 to 60 percent reduction in flood flows while increasing energy production in the Colorado River Basin.

5. A 100 to 200 percent increase of effective yield of existing reservoirs serving the metropolitan Washington, D.C., area, resulting in a saving of $250 million in capital investment (see appendix D).

Preliminary indications are such that improvement of forecasts for water management would produce greater benefits than building additional reservoirs, as indicated by the example given in Appendix D.

The improvements to the hydrologic service program as outlined in this PDP will translate to substantial benefits in the management of reservoirs and reservoir systems. The enhancement of the data network, data systems, and improvements in hydrologic models, all needed for a better flood forecast service will improve accuracy and provide expanded services to the Nation's water users. Without additional costs the release of NWSRFS will provide the capability to handle complex reservoir regulation requirements. As the present models are calibrated, the forecast products will provide valuable information necessary for optimum reservoir management.

Appendix F - ACRONYMS USED IN THIS PUBLICATION

AFOS	Automation of Field Operations and Services
AHOS	Automatic Hydrologic Observing System
ALERT	Automated Local Evaluation in Real Time
API	Antecedent Precipitation Index
CADAS	Central Automatic Data Acquisition System
COE	Corps of Engineers
CO-OP	Interstate Commission on the Potomac River Basin, Cooperative Water Supply Operations on the Potomac River
DWOPER	Dynamic Wave Operational Model
ESP	Extended Streamflow Prediction
FEMA	Federal Emergency Management Agency
GOES	Geostationary Operational Environmental Satellite
HPB	Heavy Precipitation Branch
HPS	Hydrometeorological Prediction System
HRAP	Hydrologic Rainfall Analysis Project
HRL	Hydrologic Research Laboratory
HSA	Hydrologic Service Area
IFLOWS	Integrated Flood Observing and Warning System
IHDS	Integrated Hydrometeorological Data System
LFWS	Local Flood Warning System
MAP	Mean Areal Precipition
MDR	Manually Digitized Radar
MIC	Meteorologist in Charge
NESDIS	National Environmental Satellite Data and Information Service
NEXRAD	Next Generation Weather Radar
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NWR	NOAA Weather Radio
NWS	National Weather Service
NWSRFS	National Weather Service River Forecast System
NWWS	NOAA Weather Wire Service
O/H	Office of Hydrology
OTS	Office of Technical Services
PDP	Program Development Plan
QPF	Quantitative Precipitation Forecast
RFC	River Forecast Center
SA/SM	NWS/FAA Synoptic and Aviation Data Networks
SCS	Soil Conservation Service
SFSS	Satellite Field Service Station
SSARR	Streamflow Simulation and Reservoir Regulation
TVA	Tennessee Valley Authority
USGS	United States Geological Survey
WSFO	National Weather Service Forecast Office
WSO	National Weather Service Office

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