Use and Benefits of the National Weather Service River and Flood Forecasts

Photo Courtesy of Tom Dietrich

National Hydrologic Warning Council
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Preface

The National Oceanic Atmospheric Administration (NOAA) recently reported that impacts on the U.S. economy from weather and climate events approach $2.2 trillion dollars annually (NOAA, 2001), according to some estimates. High impact examples include: agriculture, forestry, fishing, energy, transportation, and the construction industry; public utilities; finance and insurance; retail trade; hotels and recreation; and public/private property losses. A high percentage of these impacts result from hydrologic events covering both extremes from flood to drought. Over the past 21 years the United States has sustained 49 weather-related disasters with damage estimates exceeding $1 billion. One recent example is Tropical Storm Allison in June 2001, which caused an estimated $5 billion in damage to the Houston, Texas area before continuing its path of destruction along the Gulf Coast and up the eastern seaboard. In addition to high dollar damages, human tragedy frequently accompanies such disasters with flood events being the most costly in this regard.

The National Weather Service (NWS) Office of Hydrology completed an internal report in October of 1997 entitled: "The Benefits of Hydrologic Forecasting." The report (Stallings, 1997) contained an analysis of benefits based on a 20-year period ending in 1996, focusing on the potential future benefits of implementing a new application and dissemination process known as the AHPS (Advanced Hydrologic Prediction Service). Since completion of that study, the AHPS development has proceeded with modest funding and field evaluations of the prototype were conducted with favorable results.

Advanced Warnings Provide Time to Prepare

Midwest Flood, June 1994 *Photo Courtesy of FEMA*

The report is an update to the 1997 study. Conducted under the auspices of the National Hydrologic Warning Council (NHWC), it reflects more current U.S. disaster statistics and provides a breakdown of these statistics by geographic region, thus giving decision-makers a fiscally-sound basis for setting priorities and proceeding with a planned nationwide implementation of the AHPS.

Acronyms

AHPS	Advanced Hydrologic Prediction Service
ALERT	Automated Local Evaluation in Real-Time
ALERT-FLOWS	East Coast Users Group
AUG	ALERT Users Group
FEMA	Federal Emergency Management Agency
GIS	Geographical Information System
IFLOWS	Integrated Flood Observations and Warning System
LCRA	Lower Colorado River Authority
NHWC	National Hydrologic Warning Council
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
NWSRFS	National Weather Service River Forecast System
QPF	Quantitative Precipitation Forecasts
RFC	River Forecast Center
SAAS	Southwestern Association of ALERT Systems
TVA	Tennessee River Authority
UDFCD	Urban Drainage and Flood Control District
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
WMO	World Meteorological Organization
WFO	Weather Forecast Office

Executive Summary

The National Weather Service (NWS) through its River and Flood Program, maintains an around-the-clock vigil of rivers throughout the country and issues watches and warnings to protect life and property when the threat of flooding does occur. (Stallings and Wenzel, 1995). When sufficient flood warning time is given to the communities, appropriate actions can be taken to reduce losses. Thus, economic benefits occur that are directly attributable to timely hydrologic forecasts. This report amends the 1997 report entitled "The Benefits of Hydrologic Forecasting" (Stallings, 1997). The earlier version provided an analysis of flood damages in the United States for a 20-year period and an estimate of annual benefits derived from reduced flood damages by using NWS hydrologic forecasts. Benefits accruing from improved water use and management practices with better forecasts are also described. All estimates in this report have been updated to reflect the latest data.

This report also differs from the earlier version by quantifying benefits for specific regions of the United States, thus enabling the NWS to establish priorities for improving hydrologic services and implementing the AHPS (Advanced Hydrologic Prediction Service) nationwide. Another major difference between the two reports is the establishment of an independent review team representing the external user community. Formed under the auspices of the National Hydrologic Warning Council, these individuals are known for their extensive involvement with operational hydrology, early flood detection and local flood warning programs. The importance of partnerships with external users and cooperators is vital to the mission of the NWS.

NWS hydrologic forecasts and warnings are extremely effective in reducing flood damages in the United States. Advanced warnings for floods can mean the difference between life and death, as well as curtailing economic losses. Some studies suggest that as little as one hour of lead-time can result in a ten-percent reduction in flood damages. Economic benefits derived from three categories (reservoir optimization, short-term floods, and long-term flood events) show a potential savings of $1.62 billion annually.

Although these flood loss reduction benefits are quite significant, the effects of improvements in long-range hydrologic forecasts are also very substantial with an additional $243 million in annual benefits estimated to result from the AHPS implementation. Considering other water resources activities like hydropower, irrigation, navigation, and water supply conservatively adds another $523 million, bringing the total estimated annual benefits from improved long-range forecasting to $766 million.

While the NWS has the primary responsibility for the issuing river forecasts and flood warnings for the Nation, other entities are seriously involved with river forecasting for their own special purposes. For example, among Federal water agencies, the United States Army Corps of Engineers (USACE) and the United States Bureau of Reclamation (USBR) regularly forecasts river flows for their operational needs. Similarly, private entities like the Lower

Colorado River Authority (LCRA) in Austin, Texas routinely make river forecasts for its needs, as a major supplier of electric power. LCRA also collaborates with the NWS. With many other examples like these, nationwide implementation of the AHPS has tremendous potential for residual benefits not quantified in this report. With the AHPS, new partnerships will form while relationships with existing cooperators are strengthened. The business of hydrologic forecasting can then become more of a communal effort through public private partnerships leading to fewer flood-related deaths, lower disaster costs, increased public awareness, and ultimately proactive actions by individuals.

INTRODUCTION

A Technical Report (Stallings, 1997) on hydrologic forecasting benefits was developed in support of the Advanced Hydrologic Prediction Service (AHPS) and for presentation to the World Meteorological Organization (WMO) Executive Council. It contains detailed information on flood damages in the United States and economic benefits associated with flood damage loss reduction, hydroelectric power generation, navigation, irrigation and water supply by using hydrologic forecasts provided by the NWS. As a result of the AHPS and other economical factors, the Technical Report needed to be updated to reflect current conditions. Following data collection and analysis, the 1997 Technical Report has been updated to determine economic benefits associated with NWS hydrologic forecasts occurring during both normal river levels and under hydrologic extremes, particularly flooding. The report provides total flood-related benefits resulting from preventive actions based on the issuance of timely and accurate NWS hydrologic forecasts throughout the United States. The report also provides regional values for each of the NWS's 13 River Forecasts Centers (RFCs) giving the relative economics from hydrologic forecasts to the various water resource needs within their jurisdictional limits. Appropriate tables are included for each RFC depicting the total flood damages in the United States for each RFC along with annual benefits from multiple purpose implementation of the AHPS. The report contains references to other documents or reports used in the development of the Technical Report on Hydrologic Forecasting Benefits.

The modernized NWS provides hydrologic forecasts for approximately 4,000 locations in the United States, using sophisticated models and large amounts of data. Based on these forecasts, flood-control structures are operated to reduce damage. Then, emergency actions are taken at state and community levels to flood fight, evacuate, or take other measures to lessen the impacts of flooding. The amount of lead-warning time for floods can mean the difference between life and death. The NHWC plays a most important role in reducing flood damage by its flood warning systems located in most states.

There are three categories for deriving economic benefits: optimum reservoir operation, short-term forecasts, and long-term forecasts. All benefit analyses in this report are based on the test 20-year period from 1981 through 2000 with dollars indexed to 2000 price levels (American Institute for Economic Research, 2000). The NWS works very closely with operating agencies like the USACE, to provide data forecasts in exchange for reservoir scheduling information to produce hydrologic forecasts at key downstream damage centers. Other operating entities such as the Bureau of Reclamation (USBR) and the Tennessee Valley Authority (TVA) also regularly interact with the NWS during flood potential periods. These agencies develop their own forecasts to meet their operational needs. The NWS field offices and the NHWC members exchange data and information while floods threaten their areas of responsibility. The NWS also regularly interacts with water resources at the federal, local and private level in coordinating forecasts and warnings. Continuing coordination is essential to meet each agency's mission and goals.

BACKGROUND

Water is an essential requirement in sustaining life. From a national perspective, water is abundant in the United States. Unfortunately, precipitation is not distributed uniformly throughout the country. As a result, floods and droughts are common (Stallings, 1988). Floods are a natural and inevitable part of life along the rivers in the United States. In fact, 75 percent of Presidential National Disaster Declarations are due to floods (Rubin et. al., 1986). The NWS, through its River and Flood Program (Fread et al., 1995), maintains an around-the-clock vigil of rivers throughout the country and issues watches and warnings to protect life and property when the threat of flooding does occur (Stallings and Wenzel, 1995). When sufficient warning time is given to the communities that will be impacted by a flood event, appropriate actions are taken and economic benefits occur that are directly attributable to timely NWS hydrologic forecasts.

The NWS's 13 regional River Forecast Centers (RFC) prepare hydrologic forecasts for the time and height of the flood crest, the time when the river is expected to exceed flood stage, and the time when the river is anticipated to return within its banks. When developing the forecasts, every source of data is used. The development and maintenance of a reporting data network for precipitation, river stage, and reservoir data are essential elements in support of river forecasting. The NWS relies on a wide variety of sources and techniques to collect data. Whether flood, drought, or more moderate conditions prevail, the delivery of hydrologic forecasting service begins with data collection. Many of the ground sensors are owned and operated by major NWS cooperators, including the USACE, the U.S. Geological Survey (USGS), USBR, and the TVA.

In addition to real-time hydrometeorological data, historical data are used in conjunction with powerful hydrologic and hydraulic models (Fread et al., 1995). Additionally, the RFC hydrologists must possess extensive knowledge of the river basin to assure that data used in the models are accurate and reliable. Crest-stage forecasts can be made a few hours in advance for cities and communities along streams draining small basins, but they can be made two weeks or more in advance for some cities and communities along rivers draining large basins. Daily forecasts of river-stage discharge are prepared routinely for use by those interested in river-related activities such as navigation and water management. Reservoir-inflow forecasts aid federal, state, and local water-management agencies in the operation of their reservoirs.

Although flood forecasts and warnings are the most dramatic hydrologic products issued by the NWS, interest in long-range water forecasts increases when droughts and/or shortages of water supplies occur. The 1998 drought throughout the Midwest and southeastern United States (Hudlow, 1989) and the 5-year drought over California and other areas of the West (1989-1993) are two of the most severe droughts experienced in the United States since the mid-1930s. In 1992 Ventura County, California had a federally declared disaster on Feb. 12, 1992. That is the time when the Recreation Vehicle Center became

inundated from a very flashy flood on the Ventura River. Flows went from a manageable 6,000-cfs to more than 47,000-cfs in less than 45 minutes. This type of event is not that unusual for flash floods. The use of ALERT systems provided major assistance in providing timely warnings. Even Highway 101 was under water and stopped all commerce going North to the bay area and all other southbound to Los Angeles and San Diego. Several routes were covered with debris from landslides.

The year of 2001 was well above the average annual flood damage experienced in the United States. Almost every state suffered some flood damage during the year. Annual spring flooding across the upper Midwest and northern Plains reached near record heights at a few locations, but with significantly less damages than occurred in 1997. Puerto Rico, West Virginia, Arizona, and Hawaii incurred major flooding. However, the impacts of Tropical Storm Allison are staggering. Estimates of flood damage exceeding $5 billion, more than any other tropical storm in United States history. NOAA published a report on Allison, (Department of Commerce, 2001) which contains additional information on the damages and the 41 deaths that occurred from the flooding. The report was prepared in an effort to continually improve services by evaluating their agency's performance following major weather-related disasters, particularly when events result in significant loss of life. A NOAA service assessment team was activated in the Houston area approximately one week after the storm had caused its damage into the region. The team made concerted efforts to contact and conduct face-to-face interviews with emergency managers, the media, and other local officials affected by NWS operations. The team had prior knowledge of Harris County's ALERT system and was aware of its value to the local NWS forecast office. During the interview process, the ALERT system proved its value once again in Tropical Storm Allison as an effective real-time flood detection system.

AREAS IMPACTED BY FLOODS

In 1978, the USACE made a study to identify the ten highest flood potential areas of the United States (USACE, 1978). The areas were selected based on average annual damages, threat to life, and flood damages associated with a major flood event of a rare magnitude. All ten areas had experienced recent large floods and associated significant damages. In many cases the floods were fast peaking events that occurred in densely populated urban areas. One of these highest flood potential areas was Houston, Texas, which recently suffered catastrophic flood damages during Tropical Storm Allison. Therefore, based upon the USACE flood potential report, the severe flood was not unexpected. Other major metropolitan areas included in the USACE list of top ten flood potential areas are Kansas City, Denver, Phoenix and Los Angeles.

In addition to riverine flooding, the United States is also subject to major flooding along its coasts. When hurricanes threaten the coastal areas, the National media concentrates on the extraordinary winds, coastal erosion and storm surge. The impacts of lowland flooding

is basically ignored. Not only do significant floods result in these coastal areas, but the access routes to safely evacuate are often impacted. The public needs education on this threat to life and property. Each year, the hurricane season begins on June 1 and ends on November 30. Several experts on hurricanes (Gray et al., 2001) indicate that a new era of more active hurricane seasons in the North Atlantic appear to have been ushered in by natural meteorological and oceanic variations. This new era could last until well into the 21st century. Professor Gray states that population increases in hurricane-prone areas of the United States – including southern Florida, the Carolinas, New England, and the Gulf of Mexico – makes society much more vulnerable than before. In addition to the coastal areas, hurricanes have weakened in strength but carried copious rainfall amounts and produced significant flooding well inland. Hurricane Camille in 1969 and Hurricane Agnes in 1972 are prime examples of tropical events whose path of destruction continued for many miles inland.

FLOOD LOSSES IN THE UNITED STATES

Floods can occur at any time and at any location. Although the recurrence rate of floods has not changed during the past century, the nature of associated disasters has mutated because of population growth and rapid changes in our society (Institute for Business & Home Safety, 2001). For example, more people live on marginal lands subject to floods and modern economics depend on large-scale infrastructure (networks of roads, pipelines, railroad tracks), which are costly to repair when damaged by natural hazards. Natural disasters cause more than physical damage. They shut down businesses, many of which never re-open. Indirect societal costs associated with loss of jobs and business disruption often exceed the costs of repairing structures. Some floods result from intense rainfall occurring over a short period of time. These flash floods afford little opportunity to flood fight or allow residents to secure valuables and drive vehicles out of the flood-threatened area. Some example of damages and damages prevented is contained in Appendix A. A subsequent loss of life from flooding can be high in some instances.

Another type of flood produces extensive damage and occurs over longer periods of time. These events provide enough time to flood fight by constructing temporary levees or other measures. A heavy snowpack accompanied by above-normal temperature and/or above-normal rainfall can produce major flooding over large areas of United States. Two examples of long-term floods occurred in 1965 over the upper Mississippi and Missouri Rivers, and the Red River of the North with flood damages of approximately $1 billion (adjusted to the 2000 price index) and in the spring of 1973 where flood damages were approximately $730 million. Benefits from these two events are described in the Benefits of Hydrologic Forecasts Section of this report.

It is not enough to provide real-time information. The information must be understood and the necessary steps must be taken. The data and interpretations made possible by today's technologies are only as good the means of communicating them to the emergency

managers, and the public who have to react to the flood events. Unfortunately, for a variety of reasons, deaths do result despite the improvements in providing flood forecasts and warnings. Statistics on deaths from flooding are available for almost 100 years from the NWS. It is extremely difficult to ascertain the impacts of improved technologies in hydrologic forecasting and the emergence of the ALERT systems. However, the following information is presented for consideration. For the 30-year period, 3,829 deaths are directly attributable from all types of flooding with an average of 128 deaths annually. The highest amount of deaths (554) occurred in 1972 and the lowest number of deaths (37) in 1988. The average number of deaths for the ten-year cycle are 175 in 1971-1980; 112 in 1981-1990; and 91 in 1991-2000. The case history on Big Cove given in Appendix A does provide some documentation on the potential of saving lives from flood events with improved forecasts and warnings.

Figure 1 shows flood damages that occurred during the 20-year period from 1981 to 2000 ranging from $0.2 billion in 1981 to $18.4 billion in 1993 (USACE, 2000). The average annual damage is $4.3 billion indexed to 2000 price levels (American Institute for Economic Research, 2000). This represents an increase of $0.7 billion from the report prepared four years earlier, principally due to the major floods in 1997 that occurred over the north-central United and California (Stallings, 1997). Table 1 gives total flood damage in the United States for the period 1955 – 2000.

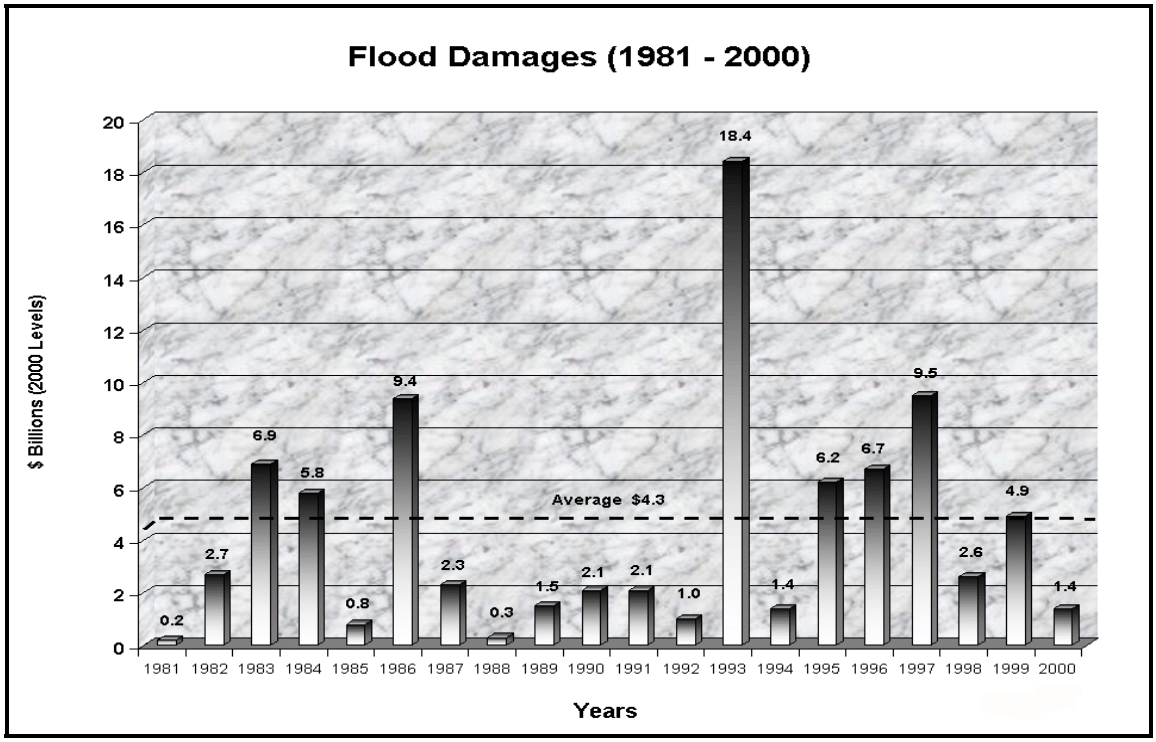

Figure 1. Flood Damage in the United States over a Twenty Year Period
(Dollars in Billions, indexed to 2000 price level)

River Forecast Center	Total Flood Damage ($M) 1955 - 2000
Alaska	708
Arkansas-Red	19,432
California-Nevada	14,157
Colorado	3,434
Lower Mississippi	15,093
Middle Atlantic	19,493
Missouri	21,208
North Central	23,712
Northeast	10,155
Northwest	11,509
Ohio	18,758
Southeast	9,807
West Gulf	13,252
TOTAL	180,718

Table 1. Total Flood Damage in United States (1955 - 2000)
(Dollars in Millions, indexed to 2000 price level)

HYDROLOGIC FORECASTS AND DATA SOURCES

The NWS uses many sources of data in developing its hydrologic forecasts. The USGS is the principal source of data on river depth and flow in the United States (Wahl et. al.,1995). The USGS network currently comprises about 7,300 stations dispersed throughout the Nation. The stream-gaging program provides a continuous, well-documented, well-archived, unbiased,and broad-based source of reliable and consistent water data. During a flood, the USGS and the NWS work together to collect and use the most up-to-date hydrologic data. The USGS collects the streamflow data, and the NWS collects the precipitation data and combines both types of data when making its hydrologic forecasts. The NWS develops and calibrates complex mathematical models of how the Nation's rivers and streams respond to rainfall and snowmelt. The models are developed for preselected forecast service points that are located along major rivers or on small streams near urban areas that have a history of flooding. The paper (Fread et al., 1998) contains additional details on development and calibration of NWS forecasting models.

The NWS is charged by law with the responsibility of issuing forecasts and warnings of floods to the Nation to help save lives and to reduce flood damages. Through the NWS's River and Flood Forecasting Program, pertinent information on river conditions is disseminated to its cooperators: local, state, and federal decision-makers and the general

public. However, a river forecast is only of value if it induces a response from the residents in the threatened area that leads to an effective action (DOC/NOAA/NWS, 1982). For example, when a flood warning is issued to the general public through appropriate dissemination channels, a benefit can only accrue through evacuations, flood proofing, flood fighting, or the shutdown of facilities to reduce potential flood losses.

Flash-flood watches and warnings, river and flood forecasts and warnings, and water-supply forecasts are the major hydrologic services provided by the NWS. The most rapid flood events are flash floods, which can develop anytime up to approximately 6 hours from the time of heavy rainfall. As might be expected, the primary objective of flash-flood warnings is to save lives since there is so little time to save personal belongings and property. For floods with longer lead times (time between the issuance of the warning and the occurrence of the flood), the effectiveness of the warnings is measured in terms of saving both lives and property. Saving property with less than 18 hours lead time is generally restricted to moving highly valued property, such as automobiles and major appliances, out of harm's way. When lead times are longer than 18 hours, floodplain residents can flood proof and flood fight (construct temporary levees, place sand bags, etc.).

Besides the floodplain resident who uses the hydrologic forecasts, there is another group of users who constantly monitor river and stream levels. The most well-known of these cooperators are the USACE, USGS, USBR, and TVA (WMO, 1989). In the United States, there are thousands of reservoirs, from small to large storage capacity, that are used for flood control, hydroelectric power, water supply, and irrigation. The reservoir may be operated by the federal, state, or local government or the private sector.

BASIS FOR ESTIMATING BENEFITS

Benefits associated with hydrologic forecasts result from a variety of sources. Flood losses can be lessened by upstream reservoirs, emergency actions to flood fight (sand bags, levees, evacuation etc.), and providing warnings to the threatened area. But, in order to compute benefits from hydrologic forecasts, damage estimates under natural conditions must be developed. Additional details on these procedures are contained in the Benefits of Hydrologic Forecasts (Stallings, 1997). It must be recognized that in some instances, timely warnings may be issued but the floodplain residents fail to take the necessary action.

Day (1966) developed and applied a technique to predict annual benefits resulting from the use of NWS hydrologic forecasts. The technique considers the probability of floods at a given depth and the dollar damage associated with the flooding depth. Day applied the technique for Meadville, Pennsylvania because the area had experienced many serious floods during the previous 50 years. Study results reported a total of 650 homes in the flooded area incurred damages totaling $1.43 million with no warning and $1.06 million with warning. These figures indicate a 27 percent reduction in damages due to NWS flood warnings. Four

years later, Day (1970) performed studies on the effectiveness of residential structures for reducing flood damage. Flood damages with no warning were estimated to be $3 million at 1970 price levels while flood loss reduction were estimated at $1 million. Similar studies (White, 1939; Houghton, 1962; Kates, 1965; and Bock and Hendrick, 1966) indicate a 12.5 to 43 percent reduction in flood damage due to short-term hydrologic forecasts. The U.S. Weather Bureau (DOC/USWB, 1959) in its summary report to the select committee on National Water Resources, U.S. Senate, estimated a ten percent reduction of flood damage using hydrologic forecasts for short-term events. In the report, "Benefits of Hydrologic Forecasting," ten percent was selected as the conservative estimate. This still seems to be a viable and conservative estimate.

For long-term events, an analysis was made of the actual economic benefits that ensued by constructing a flood fight to protect structures in harm's way. The cost of moving earth to construct emergency levees and temporary flashboards was subtracted from the benefits estimate. Information on these long-term flood reduction benefits were obtained for the 20-year test period from historical accounts and the USACE Annual Report to the Congress (USACE, 1996 - 2000). All estimates were indexed to 2000 cost levels (American Institute for Economic Research, 2000).

Economic benefits are also attributable from using NWS river and flood forecasts to optimize operations at the numerous reservoirs throughout the United States. The USACE and the USBR rely heavily upon the NWS's hydrologic forecasts to operate their reservoir projects. The flood control projects have been designed to reduce damages downstream and are regulated on a prescribed operational schedule. USACE reservoirs are designed to safely accommodate the maximum possible flood while providing flood protection to areas downstream of that project. The amount of water held out by the reservoir represents the benefit and is compared to the water level that would have occurred under natural or pre-reservoir conditions. Details on obtaining benefits directly attributable to using NWS hydrologic forecasts from a hypothetical USACE flood control reservoir are contained in (Stallings, 1997).

BENEFITS OF HYDROLOGIC FORECASTS

The NWS through its River and Flood Forecast program obtains economic benefits by issuing forecasts that cause a reaction from the pending natural hazard of flooding. There are three categories of obtaining monetary benefits: optimum reservoir operation, short-term forecasts and long-term forecasts. The benefits from short-term forecasts result by using 10 percent of the flood damage that actually occurred during the year and adjusted to 2000 price levels and are described in the previous section. An example is provided by a NHWC member which shows how some areas are trying to reduce flood losses from these short-term events. Several California counties have developed a method of protecting their property from flooding. Much of their problem is steep slopes accelerating water to erosive levels that

bring down mud along with flood water. Filling and placement of sandbags, use of deflection structures made from plywood, and how to analyze the flow paths are clearly demonstrated with drawings and photographs. The counties distribute many copies of this information to fire stations around the county along with lists where more than ten sandbags are available for purchase.

Two examples of benefits based on NWS river forecasts are given. Early in March 1965, the NWS issued an advisory on the flood potential (Nelson, 1965). On the basis of these warnings, the Minnesota Department of Civil Defense began to make plans for protective measures against the major flooding expected in the states within the next 2-3 weeks. Other flood-threatened state agencies took similar actions to lessen the potential flooding. Over the upper Mississippi, Missouri, and Red River of the North, $1.84 billion in flood damage was prevented by flood-fighting measures and subsequent evacuations working in response to the extremely accurate NWS hydrologic forecasts. The second example took place in the spring of 1973. Again, the north-central United States was subjected to snowmelt flooding (Mondschein, 1976). NWS hydrologic forecasts combined with USACE Operation Foresight activities and local government actions were highly successful in reducing flood damage. Although flood damages exceeded $730 million, damages prevented from flood fighting were over twice as great.

The average annual combined economic flood loss reduction benefit from NWS hydrologic forecasts to the United States resulting from the USACE and USBR optimum reservoir operation is $1.022 billion based on the procedures identified in (Stallings, 1997). This estimate is conservative since it does not include numerous other operating agencies that use NWS hydrologic forecasts to regulate their projects with flood-storage capacity to reduce damages. Increased urban and agricultural development occurs downstream from dams which not only accentuates the need for flood prevention but also places more demand on operating the reservoirs to capture as much water as possible for consumption use during extended dry periods. Hydrologic forecasts from NWS RFCs provide a means to obtain both goals. This report has so far addressed only the economic benefits associated with NWS hydrologic forecasts related to flood loss reduction. Table 2 shows the economic benefits from NWS Hydrologic Forecasts. Other agencies flood loss reduction benefits will be described in subsequent paragraphs.

The NWS is continuing modernization that will produce additional benefits for flood loss reduction in the near future by providing more lead time for flood-threatened people to take the steps necessary to protect life and property (Fread et el., 1995). A major part of the modernization of the National Weather Service hydrology program is the Advanced Hydrologic Prediction Service (AHPS). The AHPS is introducing visually oriented, information rich displays of enhanced river and water resource forecasts. These water related forecasts include the probability of occurrence for large and small areas and for time periods from an hour to a season. This information enables government agencies, private institutions and American citizens to make informed risk based decisions for water resource

management and actions to reduce the dangers posed by floods and droughts. AHPS leverages the existing NWS infrastructure and expertise, and augments NOAA's capacity to work with the research community to quickly apply advances in science to enhance hydrologic predictions. In the 1997 report, it was found the AHPS will produce up to a 15 percent, or approximately $243 million ($1.62 million times 15 percent), improvement in flood loss reduction benefits. The combined economic benefits, when modernization is fully implemented, from the NWS river and flood forecasts is conservatively estimated to be $1.86 billion ($1.62 plus $243 million annually).

Year	Optimum Reservoir Operation	Short-Term Forecasts	Long-Term Forecasts	TOTAL ($B)
2000	0.14	0.14	0.05	0.33
1999	1.09	0.49	0.01	1.59
1998	0.71	0.26	0.02	0.99
1997	2.44	0.95	0.10	3.49
1996	1.22	0.67	0.02	1.91
1995	1.51	0.62	0.02	2.15
1994	0.99	0.14	E	1.13
1993	1.90	1.84	0.24	3.98
1992	0.50	0.10	E	0.60
1991	0.99	0.21	0.21	1.41
1990	1.15	0.21	0.07	1.43
1989	0.57	0.15	0.04	0.76
1988	0.15	0.03	0.01	0.19
1987	0.38	0.23	0.11	0.72
1986	1.97	0.94	1.76	4.67
1985	0.86	0.08	0.03	0.97
1984	1.39	0.58	0.08	2.05
1983	1.97	0.69	0.48	3.14
1982	0.39	0.27	E	0.66
1981	0.12	0.06	E	0.18
Average	1.022	0.433	0.163	1.618

Note: E is for values less than one million

Table 2. Flood Loss Benefits From NWS Hydrologic Forecasts
(Dollars in Billions, indexed to 2000 price level)

So far, this report has focused on the benefits that result from warnings issued by the NWS during flood events and actions taken to reduce flood damages. The forecasting of both high and low flows during non-flood conditions also constitute important input to the efficient operation of any water resources system: hydropower generation, irrigation, and water

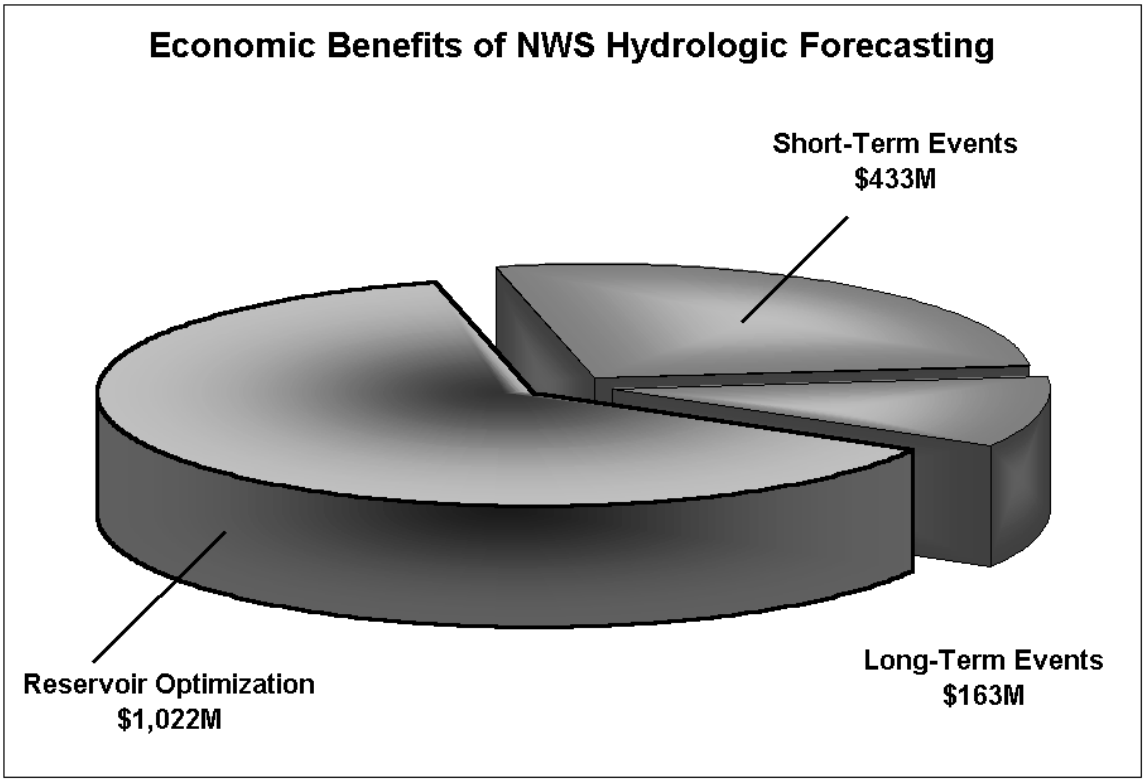

Figure 2. Average Annual Flood Loss Benefits from NWS Hydrologic Forecasts
(Dollars in Millions, indexed to 2000 price level)

supply. In the "Benefits of Hydrologic Forecasting", details are presented on the derivation of national economic benefits associated these non-flood conditions associated with NWS hydrologic forecasts when the AHPS is implemented. An extremely conservative number was selected for hydroelectric power generation. A one percent improvement in hydroelectric power generation operation for the entire United States and through implementation of the AHPS through the entire country would result in an annual benefit of $81 million (2000 cost levels). Economic benefits associated with better hydrologic forecasts through the AHPS implementation for irrigation would realize an estimated $158 million annually (2000).

Stallings (1997) estimated water supply benefits (including irrigation benefits) to be $105 million at 1996 costs levels. Adjusted to 2000 cost levels, the water supply benefits are $115 million. The combined benefits from irrigation/water supply are $273 million ($158 plus $115 million). Navigation benefits, with the AHPS implemented, is expected to significantly increase revenues. The benefits are estimated to be $169 million (2000 cost levels), adjusted from the 1997 Technical Report. Another category of economic benefits associated with improved hydrologic forecasts is recreation. Detailed studies in this category are not readily available and are not included in this report.

River Forecast Center	Flood Reduction Benefits ($M)	Water Resource Benefits ($M)			
		Navigation	Hydroelectric	Irrigation/ Water	TOTAL
Alaska	1.0	0	0.2	0	1.2
Arkansas-Red	27.6	16.5	3.1	28.3	75.5
California-Nevada	18.9	0	13.6	49.3	81.8
Colorado	4.6	0	0.7	19.9	25.2
Lower Mississippi	20.3	41.5	2.0	9.0	72.8
Middle Atlantic	25.6	0	1.7	1.3	28.6
Missouri	29.0	15.1	5.5	66.7	116.3
North Central	31.7	23.6	1.5	9.9	66.7
Northeast	14.0	0	8.8	0.7	23.5
Northwest	16.0	10.9	35.7	40.1	102.7
Ohio	25.2	40.9	2.6	1.1	69.8
Southeast	11.4	20.5	5.4	19.3	56.6
West Gulf	17.7	0	0.2	27.4	45.3
Subtotal	243	169.0	81.0	273	766
TOTAL	243	523			766

Table 3. Annual Benefits From the AHPS Implementation
(Dollars in Millions, indexed to 2000 price level)

With the AHPS, flood damage reduction benefits are $243 million annually and water resource benefits are $523 Million. Table 3 shows the categorical breakdown of the AHPS economic benefits associated with NWS hydrologic forecasts.

In addition to the benefits that result directly to the NWS from hydrologic forecasts, many other entities also derive benefits either directly or indirectly from the NWS river and flood forecasts. These entities may be large with national responsibilities like the USACE, regional like the LCRA, or at county level. The forecasts may be developed in-house for operational needs, or prepared by private sector services for use by the LCRA, USBR and others. The individual needs may be for long–range forecasts of major river systems, or short-range for flash floods. Special requirements for dam safety additionally rely on river and flood forecasts. While details are given on only the USACE and NHWC, similar information is applicable to the other users of the NWS river and flood forecasts.

The USACE prepares their own river and stage forecasts to meet their day to day operational needs. These forecasts are not issued to the public. During extreme river conditions, the NWS and the USACE thoroughly coordinate their forecasting activities.

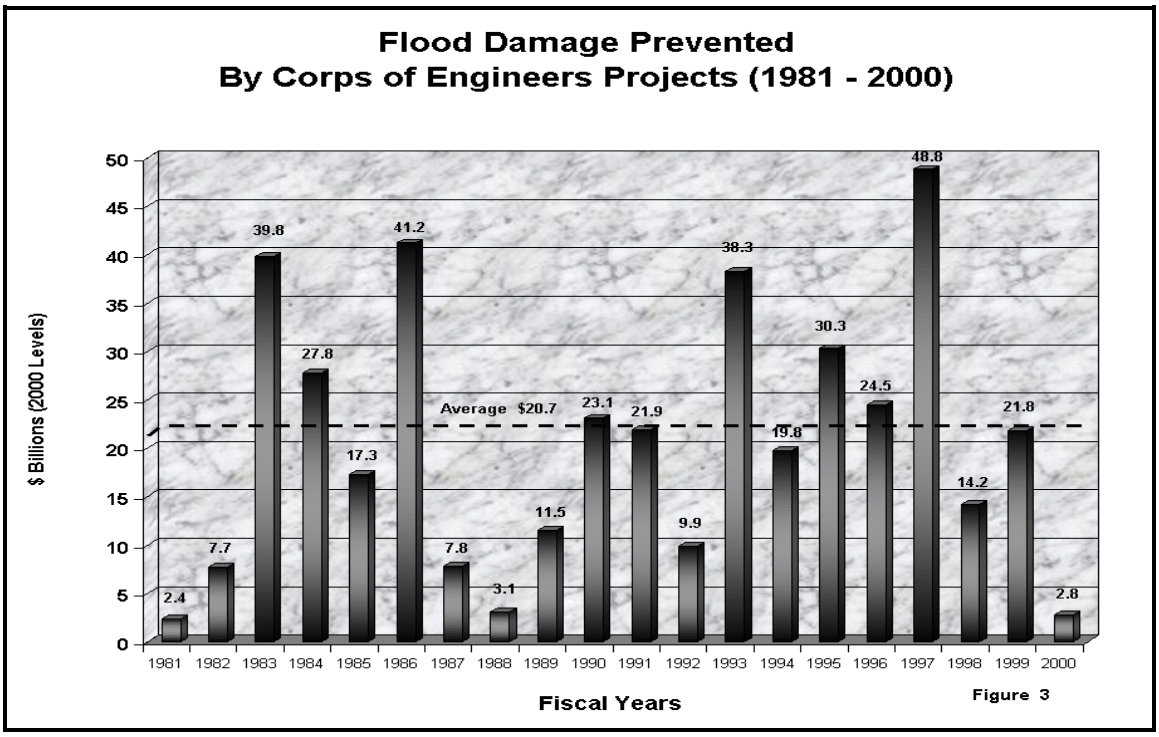

Figure 3. Flood Damage Prevented by Corps of Engineers Project (1981 - 2000)
(Dollars in Billions, indexed to 2000 price level)

Communications are extremely frequent during flood events. This statement also is applicable to the USBR, TVA, USGS and NHWC member agencies among countless other water resource entities in the United States.

Flood damages prevented by USACE during the 20 year period from 1981 to 2000 are shown on Figure 3 and range from a low of $2.4 billion in 1981 to a high of $ 48.8 billion, with an average annual estimate of $20.7 billion (indexed to 2000 price levels). This represents an increase of $3.0 billion from the report prepared four years earlier. In 1997, USACE flood control projects and emergency activities prevented $ 45.5 billion (1997 cost levels), an all-time record high. This record is the result of major storms hitting six areas of the country covering more than half of the nation. The dams and reservoirs on the main stem of the Missouri River stored near-record amounts of water in 1997. The combination of the tremendous amount of snow on the plains and the mountains of Wyoming and Montana in the upper Missouri River basin produced the highest runoff in a century of record-keeping, nearly twice the normal runoff.

The USACE prescribes flood-control regulations for the USBR and includes these dollars in its estimates of flood damages prevented. It may take several years before significant economic benefits occur. This happens when floods do not result upstream of the flood control project or flood warning system. On the other extreme, some flood control

structures or flood warning systems "pay for themselves" in a relatively short period of time. Some examples of successes are contained in the text of this report and in the Case Histories. For the test period, USACE and USBR flood control projects prevented an average of $20.7 billion. Numerous other operating agencies use NWS hydrologic forecasts to regulate their projects with flood- storage capacity to reduce damages. An excellent example of close and constant cooperation between the USBR and NWS is presented in "Benefits of Hydrologic Forecasting" (WMO, 1983). These actions resulted in obtaining maximum flood-control benefits.

Increased urban and agricultural development occurs downstream from dams which not only accentuates the need for flood prevention but also places more demand on operating the reservoirs to capture as much as water as possible for consumptive use during periods. Hydrologic forecasts from NWS RFCs provide a means to obtain both goals.

The USACE manages many water projects across the United States. There are 383 major lakes and reservoirs and another 108 major reservoirs with federal flood control storage capacity nationwide managed by the USACE. Additionally, there are 8,500 miles of federal levees controlled by the USACE. Also, there are 276 navigation projects under its auspices, located in 41 states. Over 2,000 million tons of cargo are handled at U.S. ports and waterways. The USACE owns and operates at its 76 projects, 24% of the Nation's hydropower or 3% of the total electric capacity in the U.S. Besides flood control, navigation and recreation, the USACE has almost 10 million acre-feet of municipal and industrial water supply storage.

Both the USACE and the USBR issue annual documents that provide detailed information on operations on their projects along with their economic benefits for the various project purposes.

The general purpose of the NHWC is to improve the performance and utilization of real-time environmental/hydrological monitoring systems with the ultimate goal being the protection of public health, safety and welfare. NHWC organizations routinely provide both real-time and historic data to many entities and individuals including the news media and the general public. Federal agencies like the NWS, FEMA, and USACE benefit greatly by the availability of these data paid for largely by local governments. Appendix B contains supplemental information on the NHWC.

REGIONAL ANALYSIS

A watch on the nation's river systems is maintained by the NWS's 13 regional River Forecast Centers (RFC) located throughout the United States. The RFCs prepare river and flood forecasts, related products, and services for approximately 3,000 communities. Each

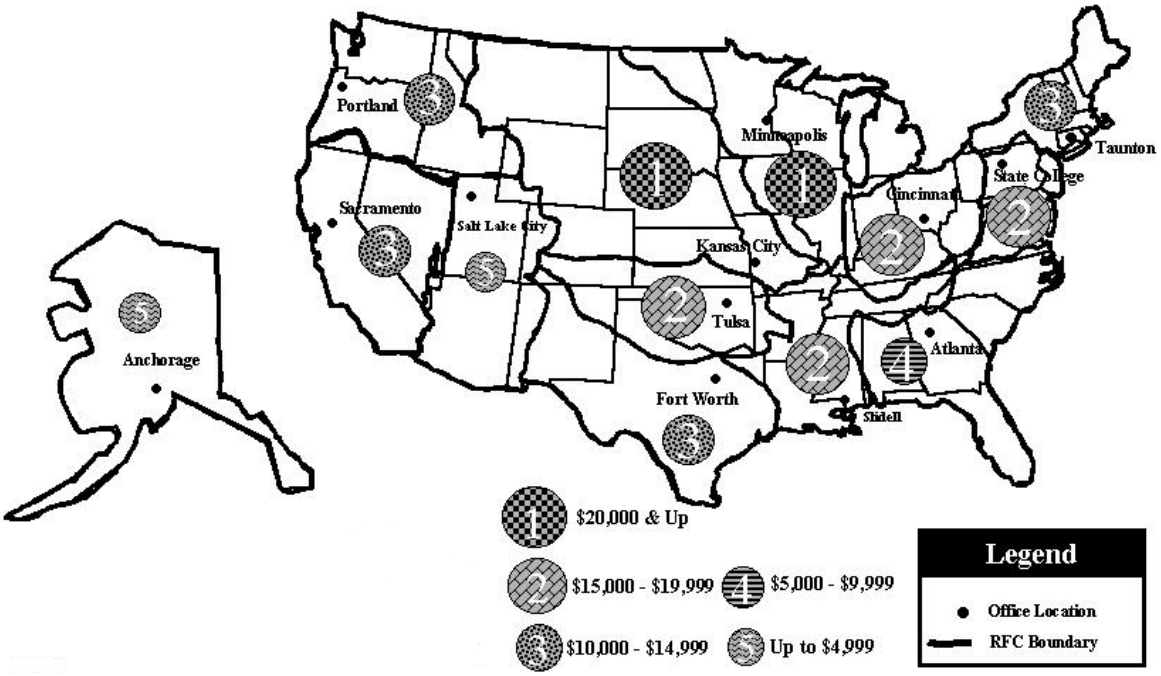

Figure 4. Flood Damage in River Forecast Center Areas (1955 - 2000)
(Dollars in Millions, indexed to 2000 price level)

RFC provides hydrologic guidance and expertise to a network of Weather Forecast Offices (WFOs) located within its area of responsibility. Figure 4 shows flood damage in each RFC area for the period 1955 - 2000.

Hydrologists at the RFCs use NWSRFS (a suite of computer forecast programs) to assist in the hydrologic analysis and forecasting. The National Hydrometeorological Prediction Center provides central support to the RFCs by issuing quantitative precipitation forecasts (QPF's) each day and by forecasting the movement of large storms that are causing significant precipitation. The operation of each of the 13 RFCs is distinctive because of the variation in flood frequency, river basin size and characteristics, population, program requirements, varying climatological differences, and cooperator activities.

Flood damages for each RFC area are based upon a review of damages for each State from 1955 through 2000. Each RFC area of responsibility was divided into the percentage of the State within the RFC boundary and flood damages for 1955 - 2000 were adjusted by the percentage. The flood damage for an RFC area was determined by totaling the damages of these State subareas. Table 1 shows flood damages in the United States total $181 billion for the period 1955 - 2000 at 2000 cost levels.

In addition to flood damage and flood reduction information, the NHWC reviewed data on hydroelectric power, navigation, water supply and irrigation. Hydrologic data on hydroelectric power generated in the United States was investigated by Stallings (1997) from several sources. Using data from Solley et al. (1998) the results for each RFC were determined. The information was available at the state level and subsequently converted over to each RFC area using the same procedures applied to the flooding analyses described above. In this study, the Northwest, California – Nevada and Northeast RFCs ranked at the top of the list. A second "quickee" analyses listing only the number of hydroelectric facilities (ignoring the individual capacity) using the Federal Emergency Regulatory Commission (FERC, 1984) data was developed for each state and converted to each RFC's area of responsibility. These results were basically the same as in the Solley data study. An investigation of the USACE National Program of Inspection of Dams followed. However, the USACE data base was only available by individual project, which proved to be very labor intensive. A decision was made to convert the ratio of capacity in gigawatt hours within each RFC's area of responsibility to the total hydroelectric power capacity for the entire United States. This ratio for each RFC multiplied by the $74 million cited in the "Benefits of Hydrologic Forecasting" represents the annual savings from the AHPS implementation for the RFCs. For this report, the indexed annual economic benefit for hydroelectric power is $81 million (2000 cost levels).

Benefits from irrigation and water supply are combined. The same procedures used for flood loss reduction benefits conversion from national levels to the RFCs area of responsibility was adopted for the combined irrigation/water supply benefits. However, the distribution of benefits from national level to RFCs areas for navigation was computed differently since many RFCs do not have any (or minimal at best) navigation within their boundaries. Therefore, several RFCs will have zero or insignificant economic benefits. Similarly, the decision was made that navigation on both the Great Lakes and Intercoastal Waterways was excluded. Regional navigation benefits based on improved practices from the AHPS were developed using approximate relationships of river miles on navigable waterways. The ratio was applied to the $154 million in benefits from the AHPS from the 1997 report. The indexed benefits from improved navigation practices is estimated to be $169 million annually at 2000 cost levels. Table 4 gives the annual benefits in millions of dollars from flood loss reduction, navigation, hydroelectric power, irrigation/water supply based upon implementation of the AHPS for the NWS's River Forecast Centers at 2000 cost levels. Reference sources are identified for the AHPS benefits associated with each category of water resource.

CONCLUSIONS

NWS hydrologic forecasts are extremely effective in reducing flood damage. Advanced warnings for floods can mean the difference between life and death and in reducing property losses. As little as one hour of lead-time can result in a 10-percent reduction on flood damages. Economic benefits are derived from three categories: reservoir optimization, short-term floods, and long-term flood events. First, benefits result by incorporating hydrologic forecasting data and information with operating schedules of cooperators such as the USACE and USBR. NWS benefits from this optimization of reservoir operation are estimated to be $1,022 million annually. During snowmelt runoff and other long-term flood events, forecasts and warnings alert the threatened communities to take action by sandbagging and constructing levees. These benefits amount to $163 million each year. The NWS forecasts for short-term events also are quite effective in reducing flood damages. This report reveals that a safe assumption of average annual flood damage incurred would be 10 percent higher without the NWS hydrologic forecasts, or $433 million annually. These three categories of annual savings due to hydrologic forecasts amount to $1.62 billion annually (Table 2).

Although reduction of flood damages resulting from timely and accurate NWS hydrologic forecasts accounts for $1.62 billion annually under existing conditions, the effects of improvements in long-range hydrologic forecasts are also quite substantial. Another $243 million in benefits is expected to result when the AHPS is implemented, making a total of $1.86 billion annually by using NWS hydrologic forecasts to reduce flood damages.

In addition to flood loss reduction, the AHPS will benefit other water resources activities, e.g., hydropower, irrigation, navigation, and water supply by an extremely conservative estimate of $523 million. This brings the total benefits from NWS hydrologic forecasts, with the AHPS in place, to an estimated $2.4 billion annually.

Although total benefits from NWS hydrologic forecasts, including flood loss reduction and with modernization in place, are estimated at $2.4 billion annually, it is important to point out that the AHPS alone, when implemented, will add $766 million (Table 3) in economic benefits from improved water resources management and long-range forecasts--$243 million in flood damage loss reduction and $523 million for other water resources purposes.

Since people consume water daily for a variety of purposes, such as drinking, washing, hydropower, agricultural, and many others, it is essential to provide the best support for our nation's water resource decision makers. Hydrologic forecasting has proven to be a vital link in providing economic benefits to the Nation and must continue to improve.

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AUTHOR'S NOTE. Over 200 publications were researched for this report, many of which contain valuable background information but were not included.

Appendix A - Case Histories

Benefits related to hydrologic forecasts are very difficult to quantify for a variety of reasons. Similar floods of magnitude and frequency do not necessarily equate to identical benefits. Often, when a second flood strikes in the same place, the residents react more effectively because they have already experienced great loss. They take immediate action to reduce or prevent further flood damage. There are occasions when the heavy rainfall with rising water levels does not occur near flood-control reservoirs and water cannot be captured to reduce flood levels at downstream damage centers. Even when the NWS uses its sophisticated hydrologic models to issue timely hydrologic forecasts, the impacted people cannot always effectively respond and take all necessary steps to reduce property damage and potential loss of life. However, in general, flood-control structures, automated local flood warning systems, and hydrologic forecasts accomplish their intended purpose reduce damage and loss of life from flooding. Following are several case histories that show these successes.

In Pennsylvania, 66 out of 67 counties have implemented manual self-help local flood warning systems. In Lycoming County, the Sprout Waldron Company, in cooperation with county officials and the NWS, has documented substantial savings by implementing flood warnings in tandem with flood-proofing procedures. In the 1975 flood, over $800,000 ($2 million at 2000 price levels) in damages were prevented by operation of a local flood warning system and flood-proofing measures (WMO, 1983).

The city of Milford, Connecticut is vulnerable to inland riverine flooding from the Wepawaug River which flows through the center of town. Milford suffered four major flooding events during the 1990's. However, Milford installed an ALERT system in 1993, which provided the city and its residents with five hours of lead time to make preparations. A newly installed Public Address system was added the following year, complete with evacuation signs. Combined, the ALERT system and the Public Address System have saved the city of Milford four times the cost of their installation in just the past seven years.

Following a flood in Ventura County, California, in February 1980, flood-control district officials (Burnash, 1984) estimated that $500,000 in damages were prevented because of a recently installed $50,000 ALERT flood-warning system. Estimates of the benefit-to-cost ratio for ALERT systems have varied from 50:1 to 10:1. The NWS estimates that the number of automated local flood warning systems nationally is approximately 500, indicating that economic benefits from these systems are in the millions of dollars annually.

The city of Fort Wayne, Indiana, suffered flood damages in excess of $50 million in 1978 and again in 1982. As a result, the city adopted an "18-Month Work Program to minimize the impact of future flooding. An ALERT system and the NWS Airborne Snow Survey (Carroll and Marshall, 1985) were added to the Plan, and flood damages of $24 million were averted in February 1985 when a severe flood event struck Fort Wayne. The

NWS Airborne Snow Survey estimated direct program benefits from $0.7 million to $2.4 million. The cost of conducting the snow survey was $7,700 and thus reaped substantial benefits compared to the projected flood damages that were prevented as a result of the early warnings and flood forecasts based on the airborne snow water equivalent data provided by NWS.

In March 1997, the NWS and the State of Ohio flood-warning programs saved lives and potentially tens of million of dollars in property damage (NWS,1997). With flood forecasts and warnings issued for the main stem of the Ohio River up to four days in advance, residents and businesses had adequate time to prepare for the worst flooding since 1964. Cooperation between state and federal agencies was critical as flood-warning information was developed and disseminated to the public. Almost a half million dollars in flood damage to vehicles, office equipment, and other goods were saved because of a single car dealership having sufficient time to move its inventory to higher ground. Other examples of prompt responses involving vehicles include: (1) a flood event in July 1990 at Las Vegas, Nevada (Sutko,1997), when evacuation of all the automobiles from a hotel garage, with only one hour of advance notice, reduced the loss of cars and (2) a similar success event in Roseville, California, in 1993 (Rutherford, 1993) when numerous automobiles were moved out of danger from a flash flood.

The USACE reported the following economic benefits associated with the AHPS. Retrospective analyses for the Saylorville Reservoir in Iowa indicates the AHPS forecasts would reduce annual flood damages by 35% when compared to non-AHPS forecasts. Similarly in retrospective, operation of the Folsom Reservoir in California would reduce flood damage by 79% using the AHPS forecasts when compared to non-AHPS forecasts. A representative from the Rock Island District, USACE reported that the AHPS saved the navigation industry $300,000 during one event on the Des Moines River in Iowa.

An event occurred as a result of a slow moving thunderstorm along a canyon near Big Cove, North Carolina in September 1990. Although the thunderstorm produced only a quarter of an inch of rainfall in the town of Cherokee, rainfall estimates exceeded 6 inches in less than 2 hours. The heavy rainfall produced a wall of water rushing down a small stream. Water levels rose up to 25 feet in minutes in some areas. Because of the flash flood watch issued by the NWS, the Emergency Manager for the Cherokee Indian Reservation reacted immediately and the 911 dispatcher sent fire/rescue units to begin an evacuation. As a result of the flash flood watch , subsequent flash warnings, and quick actions by the authorities, no lives were lost. It is reasonable to assume in similar flash flood events occurring at night in canyons, over 20 people would have drowned. Much property damage was averted.

Appendix B - Description of NHWC

The National Hydrologic Warning Council (NHWC) was established in 1993 by the ALERT Users Group and the Southwestern Association of ALERT Systems (SAAS) to provide a focal point for national cooperation and become an effective voice for the flood warning community. ALERT is a National Weather Service (NWS) acronym which stands for "Automated Local Evaluation in Real-Time". Before the formation of the Council, the two organizations conducted 18 prior conferences in their respective regions over a 12-year period.

The First National Conference of the NHWC occurred in Baltimore in 1995. The primary objective of this conference was to spark interest in forming a new regional users group for eastern states involved with both ALERT and Integrated Flood Observations and Warning Systems (IFLOWS) technologies. Cooperating organizations at the initial conference included Baltimore County, the Maryland Department of Natural Resources, the U.S. Army Corps of Engineers (USACE), the Federal Emergency Management Agency (FEMA) and the NWS. The ALERT-FLOWS East Coast Users Group was subsequently formed and joined the NHWC in 1999.

The NHWC has held national conferences and exhibitions every two years since the 1995 kick-off event. The intent of the biennial conference is to foster information exchange among scientific, governmental, and commercial interests involved in local flood warning programs. Federal, state and local government officials concerned with hydrological and meteorological warning activities, emergency management officials, and operators/managers of local warning systems actively participate in the conferences. Some specific examples of active NHWC organizations include: the Urban Drainage and Flood Control District in Denver, Colorado; the Los Angeles County Flood Control District; the Orange County Environmental Management Agency in Anaheim, California; the Harris County Office of Emergency Management in Houston, Texas; the Lower Colorado River Authority in Austin, Texas; the St. Johns River Water Management District in Palatka, Florida; and the Flood Control District of Maricopa County in Phoenix, Arizona. Almost every state with interest in flood warning is represented.

The general purpose of the NHWC is to improve the performance and utilization of real-time environmental/hydrological monitoring systems with the ultimate goal being the protection of public health, safety and welfare. Specific NHWC activities include: promoting public awareness of ALERT and other real-time hydrologic collection systems used in flooding monitoring/forecasting, reservoir management and other governmental data collection applications; exchanging information; encouraging new research and development; and assisting with flood preparedness and related emergency management planning when asked. Additionally, NHWC organizations routinely provide both real-time and historic data to many entities and individuals including the news media and the general public. Federal

agencies like the NWS, FEMA, and USACE benefit greatly by the availability of these data paid for largely by local governments.

The NHWC and the NWS are both concerned with minimizing damages caused by floods and reducing the threat to human life. Every effort is made to insure that timely data are available along with the latest and best scientific advances in hydrology and meteorology. The NHWC agencies and the public rely on the NWS to provide accurate and timely hydrologic forecasts and warnings nationwide. Although the NHWC is primarily concerned with reducing flood damages, many of its members are interested in other water uses.

Appendix C - NHWC Review Committee

The National Hydrologic Warning Council (NHWC) volunteered a Review Committee of four individuals to comment on the report prepared by EASPE, Inc. Unfortunately, the events that took place on September 11, 2001 prevented one of these recognized experts from serving on the committee. In addition to the formal committee, information on flood experiences and operational issues was requested by many NHWC members on Case Histories. The response to this request was favorable. Biographies are provided for the three principal reviewers, in addition to the NHWC Consultant and Member.

Eugene A. Stallings is a registered Professional Engineer in Maryland and graduated from the University of Maryland, College Park with a BS in Civil Engineering. Mr. Stallings began his career with the Baltimore District of the USACE. His initial assignments included the hydrologic planning, design, and operation of reservoirs and local flood control projects. He conducted stage damage surveys in the field for planning and design phases of several projects and conducted windshield surveys during actual flood events. Mr. Stallings was responsible for the operation of all reservoirs in the mid-Atlantic area. He prepared Situation Reports documenting all flood fighting efforts. He transferred to Headquarters Office for promotion to a higher grade in 1970. Mr. Stallings prepared daily briefings on hydrologic events: floods and droughts for very senior level Corps of Engineers Management, including the Chief of Engineers and the Director of Civil Works. Mr. Stallings was responsible for approving operations plans and schedules for over 700 reservoirs nationwide. He originated and prepared the Annual Report to Congress on floods and flood damages. Other responsibilities included the review of Field Office Reports and formulated and issued national policy on operational hydrology to Division and District offices of the Corps of Engineers.

Mr. Stallings tranferred to the NWS serving as the Technical Advisor to the Director of the Office of Hydrology, where he represented the NWS on high level interagency committees on hydrology and water resources. In the period from 1988-1995, Mr. Stallings served as Chief, Hydrologic Services Branch. He supervised 12 people while continuing International and Interagency concerns. He provided oversight to the NWS Flash Flood Programs and served as liaison and Technical Editor on all NWS Disaster Survey Reports on extreme flood events.

In 1995, he formed EASPE, Inc. to provide consultant services to the NWS, principally on WMO operational hydrology activities, such as coordination of an ongoing international training course on hydrologic forecasting and the technology transfer of hydrology components. Mr. Stallings authored an innovative major report on economic benefits associated with hydrologic forecasts issued by the NWS. In addition to the major report on flood damages incurred and damages prevented, several companion technical papers were presented nationally and internationally. For the past three years he has served as a consultant for the NHWC at various meetings related to hydrology and water resources.

Kevin G. Stewart is a registered Professional Engineer employed by the Urban Drainage and Flood Control District (UDFCD) in Denver, Colorado. The District serves 38 local governments in the Denver/Boulder area. Mr. Stewart is the District's Information Systems and Flood Warning Program Manager. His responsibilities include overseeing the operation and maintenance of an area-wide ALERT system consisting of approximately 150 real-time reporting stations, as well as other duties related to the District's local flood prediction program, which has served the region for the past 23 years. Mr. Stewart also chairs the National Hydrologic Warning Council and represents the Southwestern Association of ALERT Systems (SAAS) in that capacity. Before joining the UDFCD staff in 1984, Mr. Stewart worked three years for a consulting engineering firm in Lakewood, Colorado, and prior to that, for the State of Iowa in its floodplain management and regulatory programs. He received a B.S. in Civil Engineering from Iowa State University in 1977.

Dolores (DeDe) B. Taylor graduated from the University of California, Berkeley and went to work for the Naval Civil Engineering Laboratory in Port Hueneme working on jet pavement design and admixtures to Portland Cement Concrete. Ms. Taylor was employed as a college instructor for the State University of New York, Plattsburgh, teaching Physics and Astronomy laboratories. Subsequently, she moved to Ventura, California to work for the Ventura County Flood Control District for 30 years. Her work assignments were initially in Design and then ultimately in Hydrology. Ms Taylor is currently a Senior Hydrologist working large flood warning systems, GIS modeling, and detention studies. Additionally, she supervises a large data collection program. Ms. Taylor has intimate working knowledge of the ALERT systems and in-depth experience of operation and maintenance issues.

Jerry W. Webb is a Supervisory Hydraulic Engineer in the Water Resources Engineering Branch of the Huntington District, USACE. Mr. Webb manages and directs the Huntington District's water resources engineering program. He is responsible for hydrologic and hydraulic design, remote sensing/flood warning system design, river sedimentation analysis and river stabilization design. Mr. Webb performs all aspects of water resources engineering analysis associated with the formulation of flood control and water control projects. He serves as the District water control manager coordinating activities with USACE Headquarters water management personnel and working closely with the Operations Division in making daily operational decisions for 35 lake projects and 9 navigation projects. Additionally, Mr. Webb is responsible for water quality and water control decisions which require intensive coordination with federal and state agencies to optimize use of water resources with appropriate consideration to all competing demands. He participates in the Inland Navigation and Innovative Flood Fighting Field Review Groups. Mr. Webb received a Master of Science, River Mechanics and Sedimentation from Colorado State University. He is a registered Professional Engineer in Tennessee.