# Advanced Hydrologic Prediction System (AHPS): Demonstration of Modernized Hydrologic Services for the Des Moines River Basin, Iowa

## INTRODUCTION

Floods are the leading weather related hazard. Our nation's most recent and prominent events, such as "The Great Flood of 1993" in the mid-west and subsequent flooding events in the western, eastern, and upper mid-western states, remind us that major floods will occur frequently and are devastating. Preparedness for these events can lead to saving billions of federal disaster relief dollars. Floods cause an average of nearly $4 billion in damages annually, and over 75 percent of Presidential disaster declarations are in response to flooding events. It is, therefore, important to make the mitigation of this hazard a high-priority task.

Droughts, while generally not life-threatening in the United States, do have a serious impact on agriculture, ecosystems and water management, and the economy in general. With the Advanced Hydrologic Prediction System (AHPS) implemented nationwide, the National Weather Service (NWS) will have the tools to provide drought related hydrologic information to users. This improved capability builds on the traditional expertise and responsibility of the NWS flood forecasting program, and will provide the public with a full set of water resources information.

Recognizing this hydrologic forecasting requirement, the NWS has developed, implemented, and demonstrated AHPS for the Des Moines River basin in Iowa. This is the first phase towards the national implementation of AHPS. The Des Moines basin was chosen for this first phase because of the devastating impacts of the "Great Flood of 1993," which included severe flooding in the city of Des Moines, Iowa.

Our Nation's floods and droughts have forced the need for improved predictions to support flood/drought management and damage mitigation. It is imperative that AHPS products be provided to assist the mitigation of these hazards. Furthermore, the allocation of water among competing demands looms as a national problem requiring improved water quantity forecasts for sustainable development. By increasing lead times and the content of hydrologic forecasts, AHPS products will greatly improve the Nation's capability to take timely and effective actions that will significantly mitigate the impact of major floods and droughts. AHPS will also provide products to water resource managers for the optimal use of water and appropriate allocation for water supply, agriculture, navigation, hydropower, and ecosystems.

AHPS implementation began in 1995 through a significant commitment by personnel of the North Central River Forecast Center (NCRFC), Chanhassen, Minnesota; the Regional Hydrologist and other staff of the NWS Central Region Headquarters, Kansas City, Missouri; the Des Moines Weather Forecast Office (WFO), Johnston, Iowa; and the NWS Office of

Hydrology, Silver Spring, Maryland. The March 1997 demonstration successfully met the implementation goals to demonstrate an operational long-term probabilistic forecast system. Furthermore, the demonstration revealed that AHPS is mature enough for implementation in other regions of the nation.

## DEMONSTRATION DEVELOPMENT

A meeting was held at the Weather Service Forecast Office (WSFO) Des Moines, October 2-3, 1996, to finalize plans for the AHPS demonstration in March 1997. Attendees at all or part of the 2-day meeting included NWS representatives from the Office of Hydrology, Hydrologic Research Laboratory; the National Operational Hydrologic Remote Sensing Center (NOHRSC); the North Central and Missouri Basin RFCs; WSFO Des Moines; and the Regional Hydrologist, Central Region. Other attendees represented the U.S. Geological Survey, Rock Island Army Corps of Engineers (USACE), City of Des Moines, City of Des Moines Water Works, State of Iowa, and Iowa State Emergency Managers. The specific primary goals for the AHPS March 1997 demonstration agreed to at that meeting were:

- Use Quantitative Precipitation Forecasts (QPF) in the short-term forecasts.
- Use climate coupling and Ensemble Streamflow Prediction (ESP) techniques in long-range hydrologic products.
- Provide probability information in hydrologic products.
- Demonstrate a flood inundation mapping capability.

Additional conclusions from that meeting were:

- Internet would be the primary system for issuing AHPS products to users. The WSFO Des Moines home page would incorporate the following AHPS products:
  - Map of Des Moines Basin showing all hydrologic forecast points including appropriate E-19 data. E-19 data provides the details at each location including flood stage, equipment, site history, maps, etc.
  - Short-term products that would normally be 1- to 3-day river/flood forecasts with 24 hours of QPFs and displayed as a hydrograph.
  - Long-term ESP products incorporating climate coupling.
  - Flood Inundation Map.

- Miscellaneous graphics products including data such as precipitation totals, Flash Flood Guidance displays, etc.

- AHPS products would be generated once per week, on Wednesdays, beginning with the first Wednesday in March (5th) and ending with the last Wednesday in March (26th).

- NCRFC would continue to produce all previous routine products during the AHPS demonstration. The AHPS products would be in addition to the usual hydrologic products prepared by NCRFC such as flash flood guidance, River Forecast, and Extended Streamflow Guidance products.

- AHPS products, including the use of QPF and climate coupling, would include:

  - ESP probability Time Series (weekly) for flow, volume, and stage out to 60 days for 21 forecast locations in the Des Moines basin.

  - 60-day Exceedance Probability Plot for flow and stage for all forecast locations.

  - Flood inundation map showing 25, 50, and 75 percent probability of flooding at 60 days. Area covered by the map would be approximately downstream of Saylorville Dam to 14th Street in Des Moines, and up the Racoon River from the Des Moines River to the confluence of Walnut Creek.

- Verification of the AHPS demonstration would be based on a comparison of observed crests with Spring Flood Outlooks based on ESP procedures and NCRFC standard procedures. Also included would be a summary of user evaluations as to the quality and usefulness of ESP-type products. (See Figure 1, taken directly from the AHPS home page, for forecast locations.)

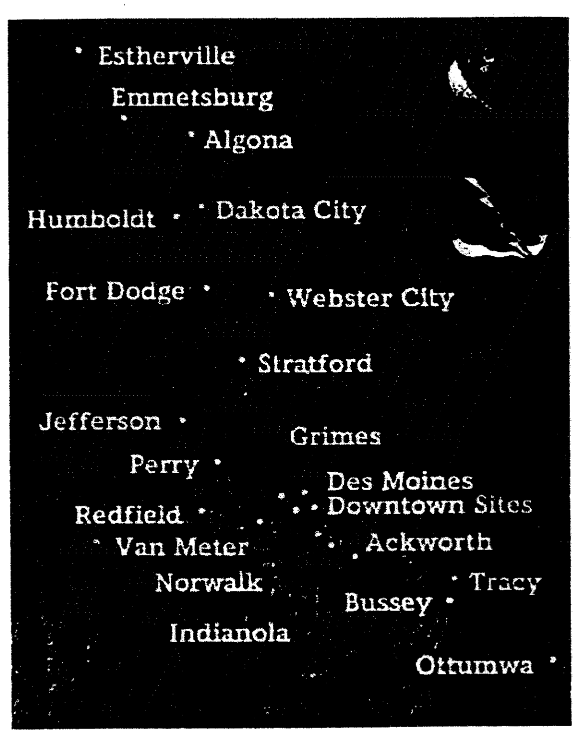



Figure 1

## DEMONSTRATION DESCRIPTION

### Computation of Forecasts

Forecasts distributed during the AHPS demonstration in Des Moines, Iowa, were computed using the ESP technique. To forecast with the ESP technique, an ensemble of possible streamflow hydrographs are calculated by initializing hydrologic models with the current states of the hydrologic system and then forcing those models with historical precipitation and temperature time series. A distribution is then fit to a sample taken from this ensemble of streamflow hydrographs. The fitted distribution describes the likelihood of an event occurring. It is from this fitted distribution that forecast products are derived. An empirical distribution was used as the underlying distribution for all the AHPS demonstration forecasts.

For the demonstration, a method was developed to integrate long-range meteorological forecasts into the streamflow forecasts. This method consists of shifting the historical precipitation and temperature time series by daily $\lambda$ values prior to using them as input to the hydrologic models. The daily $\lambda$'s were calculated from the 2- to 6-day Hydrometeorological Prediction Center precipitation and temperature forecasts, the 7- to 11-day Climate Prediction Center (CPC) precipitation and temperature forecasts, the 1-month climate outlook from CPC, and the seasonal climate outlooks from CPC. WSFO preceded the 24-hour QPFs that were also blended into the ESP forecasts.

The implementation of the ESP technique and the hydrometeorological coupling technique are a part of the NWS operational flood forecasting system called the NWS River Forecast System.

### Description of Forecast Products

<u>Probability Interval Plot for Maximum Flow</u>. This plot shows the probability that the Maximum Flow at a point on a river will exceed a particular value in a 7-day period. The vertical axis shows flow measured in cubic feet per second and the horizontal axis shows time. Each vertical bar represents the probabilities for a 7-day period. The three probability levels are: greater than 75 percent, 75-50 percent, and 50-25 percent.

<u>Probability Interval Plot for Maximum Stage</u>. This plot shows the probability that the Maximum Stage at a point on a river will exceed a particular value in a 7-day period. The vertical axis shows river stage measured in feet and the horizontal axis shows time. Each vertical bar represents the probabilities for a 7-day period. The three probability levels are: greater than 75 percent; 75-50 percent; and 50-25 percent.

<u>Probability Interval Plot for Volume</u>. This plot shows the probability that the Total Volume of flow at a point on a river will exceed a particular value in a 7-day period. The vertical axis shows flow volume measured in acre feet and the horizontal axis shows time. Each vertical bar represents the probabilities for a 7-day period. The three probability levels are: greater than 75 percent; 75-50 percent; and 50-25 percent.

60-day Exceedance Plot for Maximum Flow. This plot shows the probability distribution for the Maximum Flow over the identified 60-day period. The vertical axis shows the flow values measured in cubic feet per second, and the horizontal axis shows the probabilities. The triangles indicate sample points, and the line through the points represents the distribution that has been fit to those sample points. A point on the line indicates the probability that a specific flow will be exceeded some time during the identified 60-day period.

60-day Exceedance Plot for Maximum Stage. This plot shows the probability distribution for the Maximum Stage for the identified 60-day period. The vertical axis shows the stage values measured in feet, and the horizontal axis shows the probabilities. The triangles indicate sample points, and the line through the points represents the distribution that has been fit to those sample points. A point on the line indicates the probability that a specific stage will be exceeded some time during the identified 60-day period.

Inundation Map for Maximum Stage. The AHPS Flood Inundation Map is intended only to demonstrate the capability of generating real-time inundation maps derived from NWS hydrologic forecasts. The inundation map depicts the probabilities that specific areas around Des Moines will be flooded during the identified 60-day period. Any given area is assigned one probability range for the specific 60-day period: a greater than 75 percent chance of flooding; a 50-75 percent chance of flooding; a 25-50 percent chance of flooding; or a less than 25 percent chance of flooding. The map does not give information about flood depth above the ground, river stage, or flood return interval and is not related to any hypothetical 25-, 50-, or 75-year return-interval flood. The inundation map is based on the best digital elevation model (DEM) data available. If a DEM of greater resolution and accuracy were available, it could be used with the demonstration software and procedures to produce a more accurate flood inundation map based on the NWS hydrologic forecasts (Appendix C).

## AHPS PRODUCT EXAMPLES AND EVALUATION

The NCRFC was responsible for creating the AHPS product suite during the Des Moines AHPS demonstration period. This involved the creation of daily river forecasts for each forecast point within the Des Moines river basin, as well as the generation of longer term weekly probabilistic forecasts. Figures 2 through 7 are representative samples of the daily and weekly products for the Des Moines river near Emmetsburg, Iowa. These products were also provided for 20 additional locations during the demonstration.

Snow conditions at the beginning of March were 8-13 inches of snow for the Upper Des Moines river basin, with unusually high water equivalents of 3- 6 inches; central and southeast Iowa had 2-4 inches of snow, with less than 2 inches of water equivalent. Average temperatures across the Des Moines river basin ranged from around 30 degrees in the northwestern sections in Minnesota to the lower 40s in southeastern Iowa. This was between 2-4 degrees below normal in the northwest to around 4 degrees above normal in the southeast. Precipitation amounts ranged from 0.5-1 inch in the Minnesota sections to 1-2 inches in Iowa.

This was 50-75 percent of normal. Most of the precipitation fell the first week of March when Des Moines received almost an inch and a quarter of precipitation.

These conditions led to a few minor flood events within the Des Moines river basin during the month of March, with the majority of forecast points remaining below flood stage. Nine locations experienced minor above-flood stage conditions; however, at least three of these were largely due to ice affects (Algona, Jefferson, and Perry). It should be noted that an early melt occurred just prior to the beginning of the AHPS demonstration period. The benign hydrometeorologic conditions during the demonstration period, and the short period involved, minimized the amount of data analysis that was possible.

The RFC AHPS products consisted of three types of products: 5-day deterministic forecasts (Figure 2); Probability Interval plots (Figures 3-5) with weekly intervals; and Exceedance Probability plots (Figures 6-7) for the 60-day forecast period. These products are all new and give the user an enormous amount of additional information over traditional or current long-range hydrologic techniques.

Figure 2 is the AHPS hydrologic product that incorporates short-range QPFs in the hydrologic forecast. For now, the demonstration included only the first 24 hours of forecast future precipitation in this product. In the near future, QPFs for 48 and 72 hours will be available and included. The short-term product (Figure 2) with QPF then blends into the AHPS ESP products, which include long-range meteorological adjustments to the historical climate data. As a comparison, all of these products should be compared to the current long-range hydrologic forecast techniques that basically give only two values, A and B, as described and shown in Table 1, and are shown along with AHPS products on Figure 7a.

To evaluate the Probability Interval plots, the observed data were overlaid on the plots for verification. The 60-day probability interval plots were examined by comparing observed hydrographs for the 60-day period to the interval plots issued on March 5. It was found that most of the observed maximum stages for each week were distributed almost equally in the 25-50 percent and 50-75 percent intervals; this is what would logically be expected. However, the number of observed stages in the greater than 75 percent interval was zero, while the number in the less than 25 percent interval was 11. This was probably a result of below-normal precipitation during the demonstration period. The observed stages for each interval for the 12 sites were as follows.

| Interval | No. of weekly maximum stages |
|---|---|
| less than 25% | 11 |
| 25%-50% | 36 |
| 50%-75% | 37 |
| greater than 75% | 0 |

The Exceedance Probability plots provided the most complete information and allowed more flexibility in utilization. The 60-day exceedance probabilities for a given observed data value were determined directly from the ESP output. Examining the 60-day products indicates that, in some cases, the observed data had exceedance probabilities in excess of 70 percent, with some observations having probabilities greater than 98 percent.

AHPS-generated products and "traditional" spring outlook products were compared by determining the conditional exceedance probabilities of the outlook numbers on February 27, and the 1997 observed crests from the ESP generated product (Table 1). [Due to the early melt and benign river conditions, the analysis was confined to the initial (March 5th) AHPS products and the first numerical spring outlook product.] In cases where the river remained below flood stage, or the crest was ice affected, the data indicate a wide variation in probabilities associated with the seasonal crest. These locations are generally in central or southern Iowa, routinely have lesser amounts of accumulated snow, and are more likely to experience rises due to Spring rain storms. However, for the northern locations of Jackson, Estherville, Emmetsburg, Humbolt, Fort Dodge, and Stratford, results indicate that the outlook numbers verified well.

| | Feb 27 Outlook | | Mar 13 Outlook | | 1997 Observed | | Mar 6 ESP Exceedance Probabilities | | |
|---|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | Crest | Date | Outlook A | Outlook B | Crest |
| JCKMS | 14 | 16 | 14 | 16 | 14.6 | 31-Mar | 0.999 | 0.42 | 0.98 |
| ESVI4 | 11.5 | 13.5 | 11.5 | 13.5 | 12.1 | 6-Apr | 0.999 | 0.48 | 0.98 |
| EMTI4 | 10.5 | 12.5 | 10.5 | 12.5 | 11.3 | 7-Apr | 0.999 | 0.44 | 0.85 |
| HBTI4 | 9 | 11 | 9 | 11 | 9.7 | 8-Apr | 0.94 | 0.38 | 0.65 |
| FODI4 | 9 | 11 | 9 | 11 | 8.2 | 14-Mar | 0.46 | 0.19 | 0.7 |
| STRI4 | 16 | 18 | 16 | 18 | 15.3 | 14-Mar | 0.5 | 0.37 | 0.7 |

**Table 1.**

It should be noted that the current "Outlook A" corresponds to the potential crest for existing conditions only and does not include future precipitation. ESP does not produce a directly corresponding number (i.e. with no future precipitation), but instead computes a statistical distribution using observed historical climatological data. It is also important to note that the observed crests generally occurred within a month or less of the initial AHPS release date of March 5. Outlook "B" corresponds to the potential crest for existing conditions plus future climate precipitation. Figure 6, the Exceedance Probability plot for EMTI4, can be used as an example as to how the exceedance probabilities in Table 1 were determined. For example, "Outlook B" (i.e., 12.5 feet) equates to a probability of 44 percent.

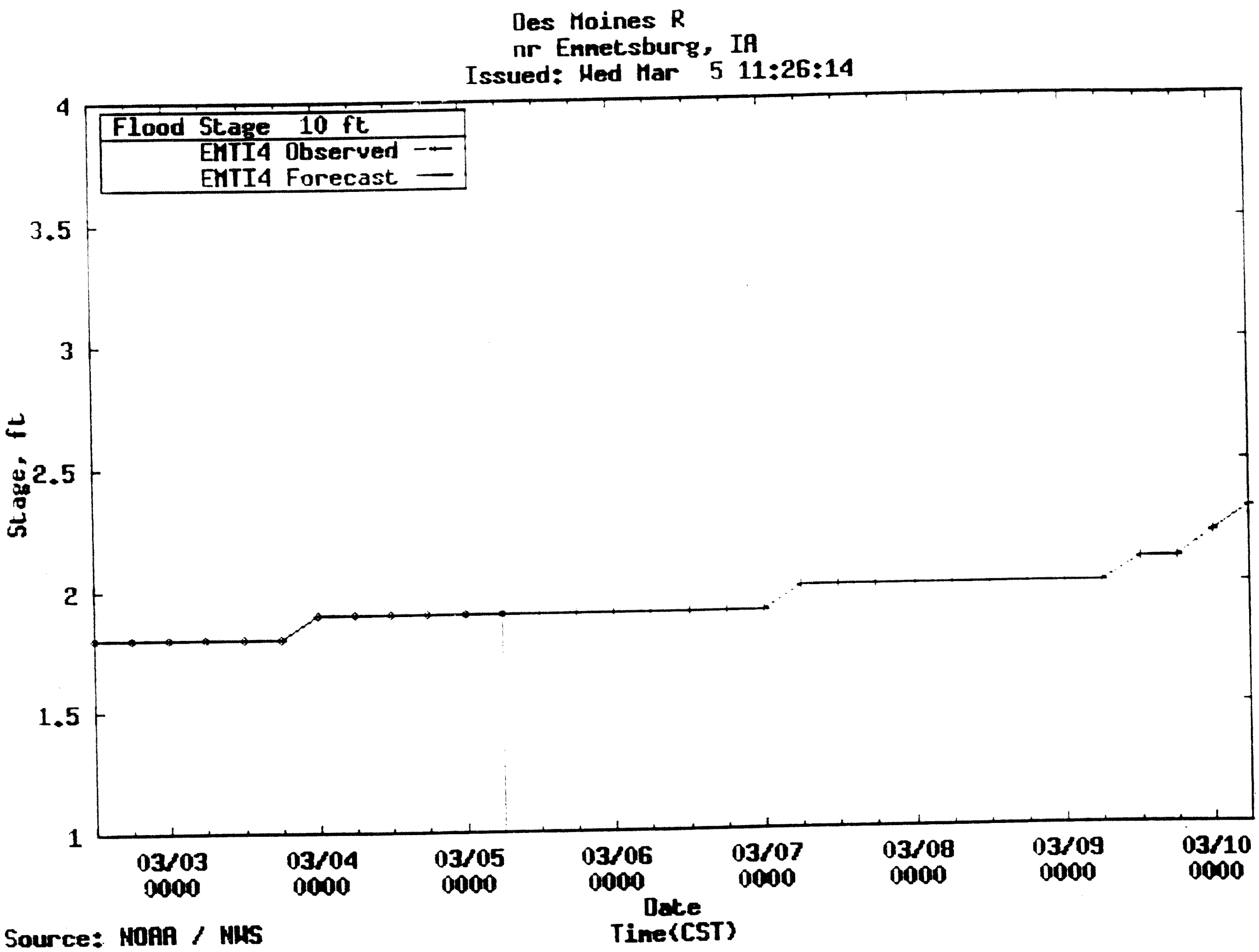
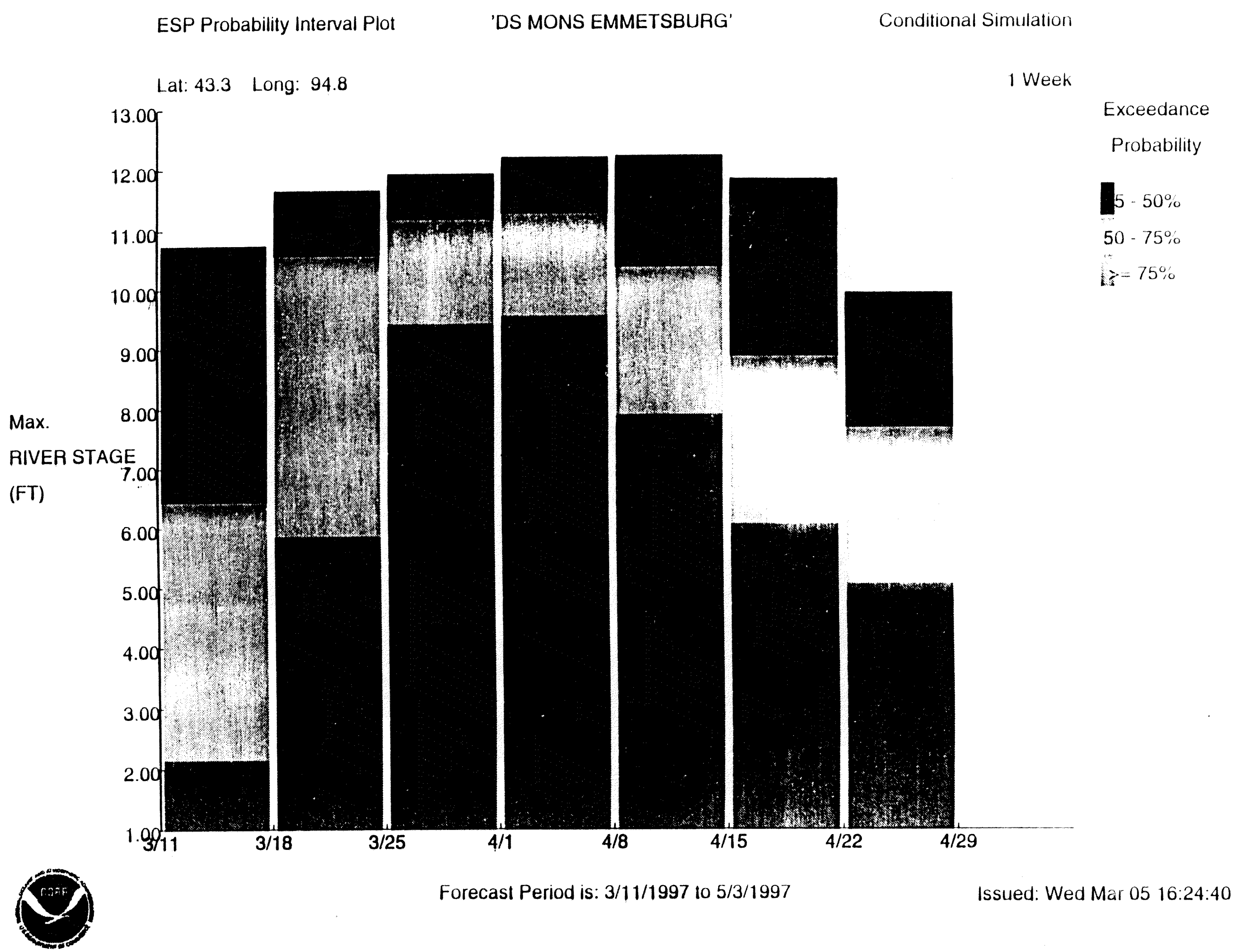

Des Moines R
nr Emmetsburg, IA
Issued: Wed Mar 5 11:26:14
Flood Stage 10 ft
EMTI4 Observed
EMTI4 Forecast
Stage, ft
4
3.5
3
2.5
2
1.5
1
03/03 0000
03/04 0000
03/05 0000
03/06 0000
03/07 0000
03/08 0000
03/09 0000
03/10 0000
Date
Time(CST)
Source: NOAA / NWS

Figure 2



ESP Probability Interval Plot
'DS MONS EMMETSBURG'
Conditional Simulation
Lat: 43.3 Long: 94.8
1 Week
Exceedance Probability
5 - 50%
50 - 75%
>= 75%
Max. RIVER STAGE (FT)
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
3/11
3/18
3/25
4/1
4/8
4/15
4/22
4/29
Forecast Period is: 3/11/1997 to 5/3/1997
Issued: Wed Mar 05 16:24:40


Figure 3

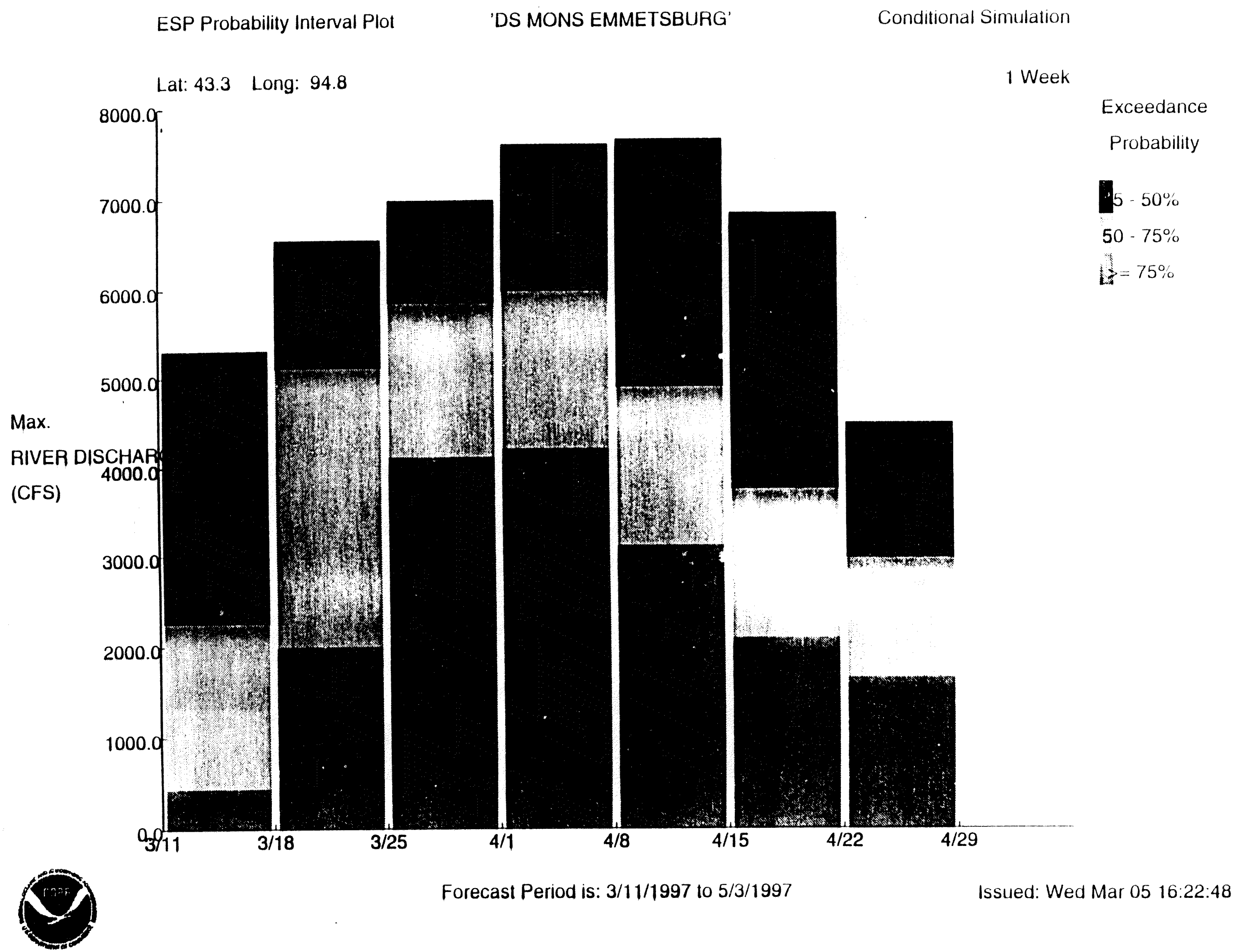

ESP Probability Interval Plot
'DS MONS EMMETSBURG'
Conditional Simulation
Lat: 43.3 Long: 94.8
1 Week
Exceedance
Probability
5 - 50%
50 - 75%
>= 75%
Max.
RIVER DISCHAR
(CFS)
8000.0
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
3/11
3/18
3/25
4/1
4/8
4/15
4/22
4/29
Forecast Period is: 3/11/1997 to 5/3/1997
Issued: Wed Mar 05 16:22:48

Figure 4

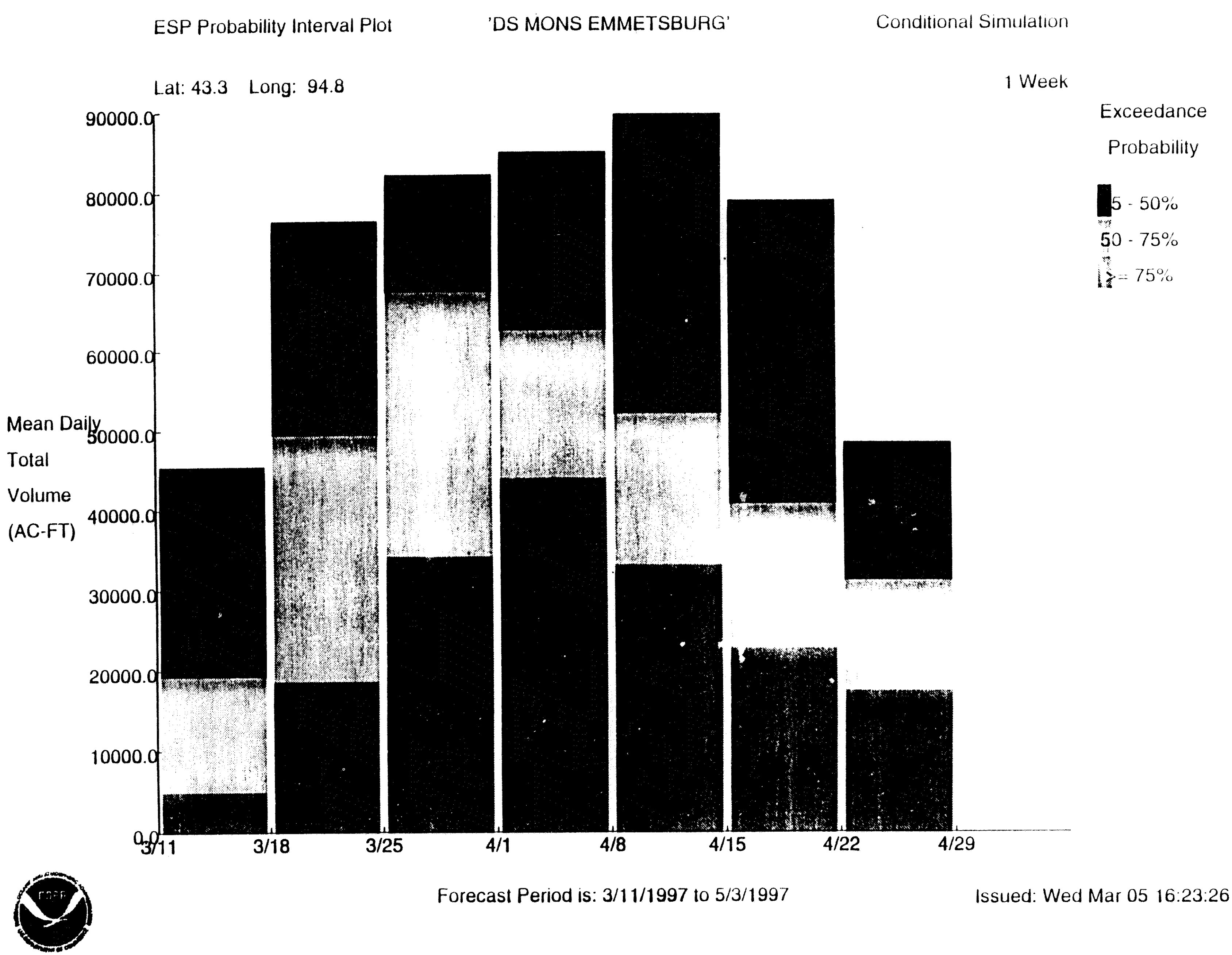

ESP Probability Interval Plot
'DS MONS EMMETSBURG'
Conditional Simulation
Lat: 43.3 Long: 94.8
1 Week
Exceedance
Probability
5 - 50%
50 - 75%
>= 75%
Mean Daily
Total
Volume
(AC-FT)
90000.0
80000.0
70000.0
60000.0
50000.0
40000.0
30000.0
20000.0
10000.0
0.0
3/11
3/18
3/25
4/1
4/8
4/15
4/22
4/29
Forecast Period is: 3/11/1997 to 5/3/1997
Issued: Wed Mar 05 16:23:26

Figure 5

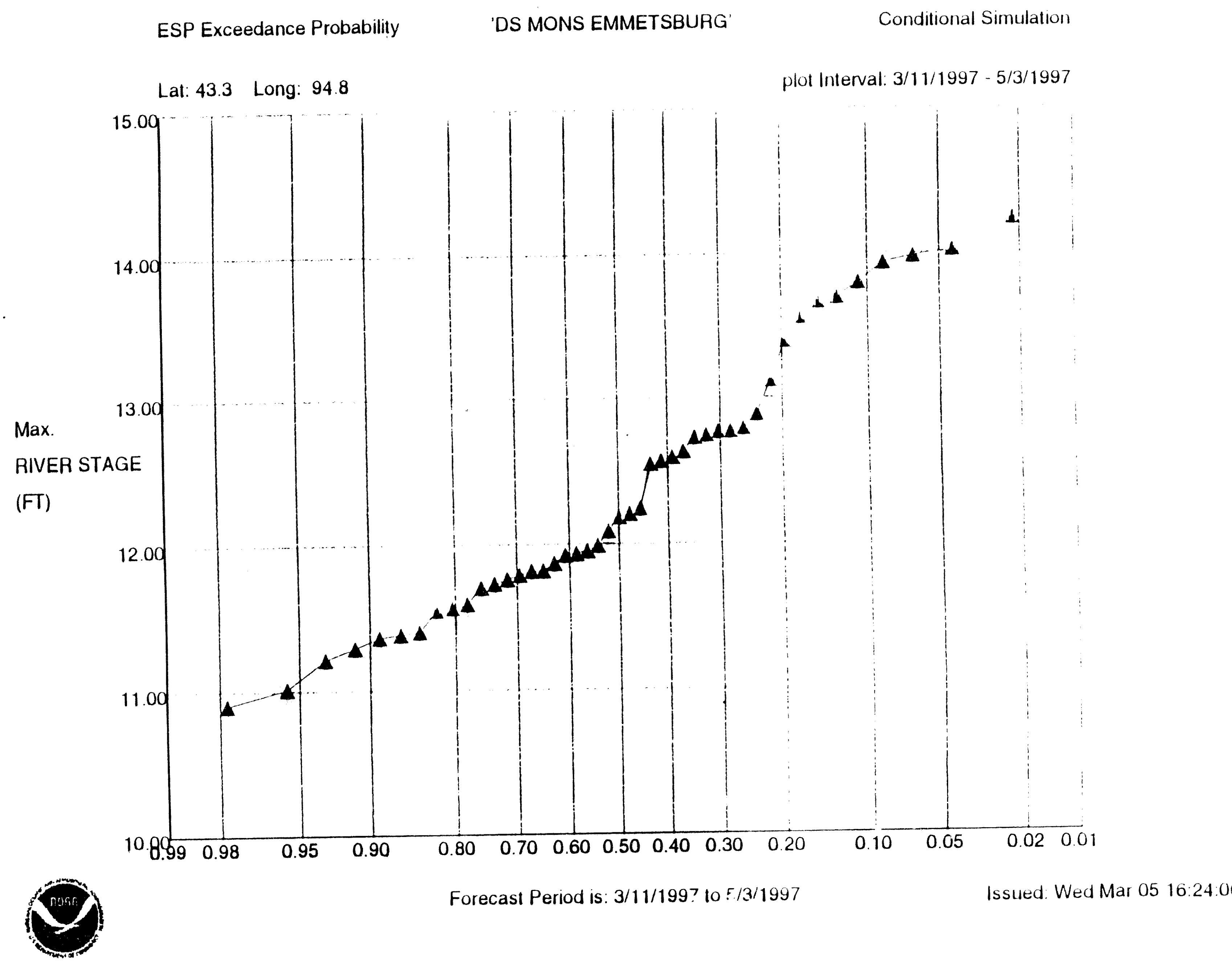

ESP Exceedance Probability
'DS MONS EMMETSBURG'
Conditional Simulation
Lat: 43.3 Long: 94.8
plot Interval: 3/11/1997 - 5/3/1997
15.00
14.00
13.00
12.00
11.00
10.00
Max.
RIVER STAGE
(FT)
0.99 0.98 0.95 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.05 0.02 0.01
Forecast Period is: 3/11/1997 to 5/3/1997
Issued: Wed Mar 05 16:24:06

Figure 6

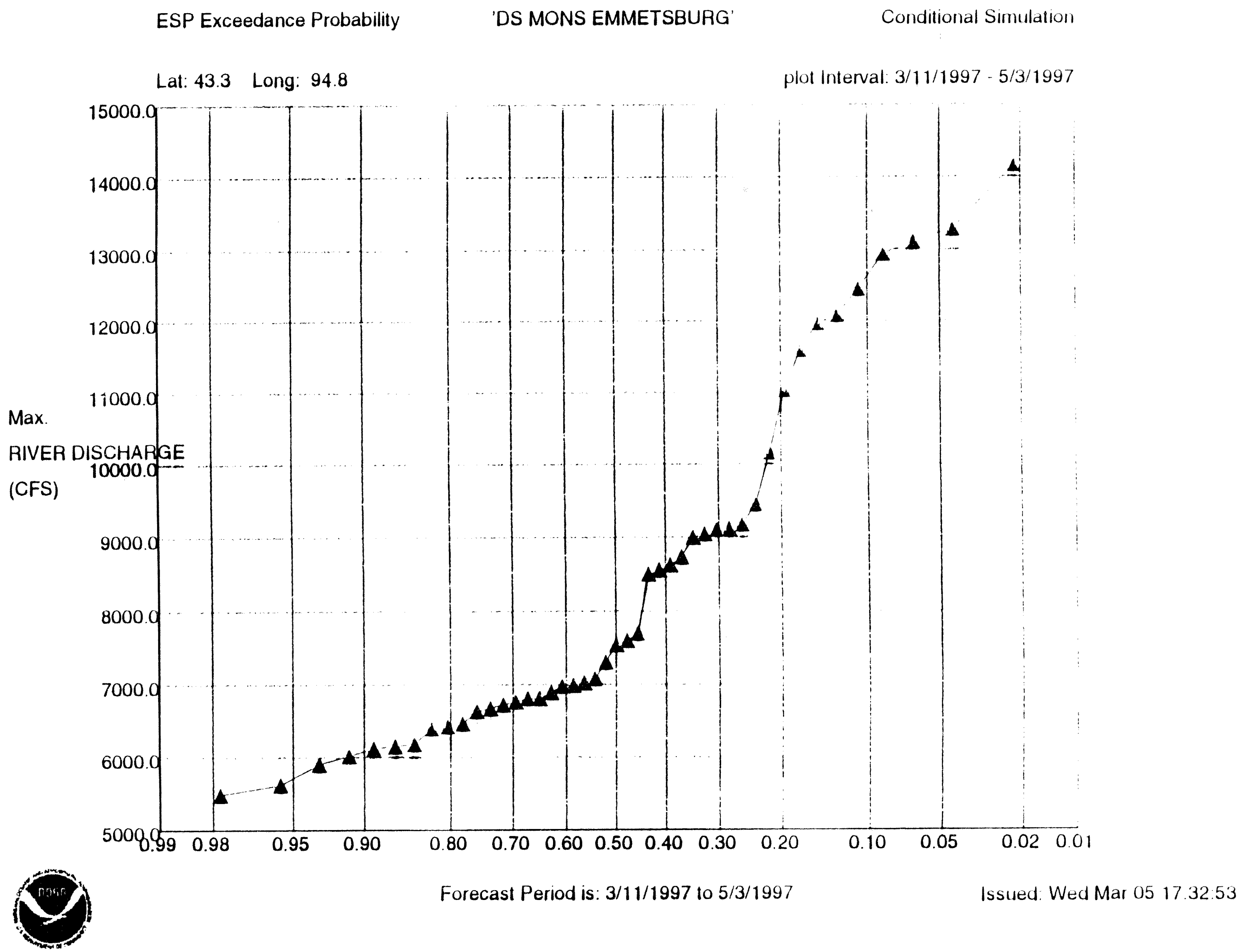
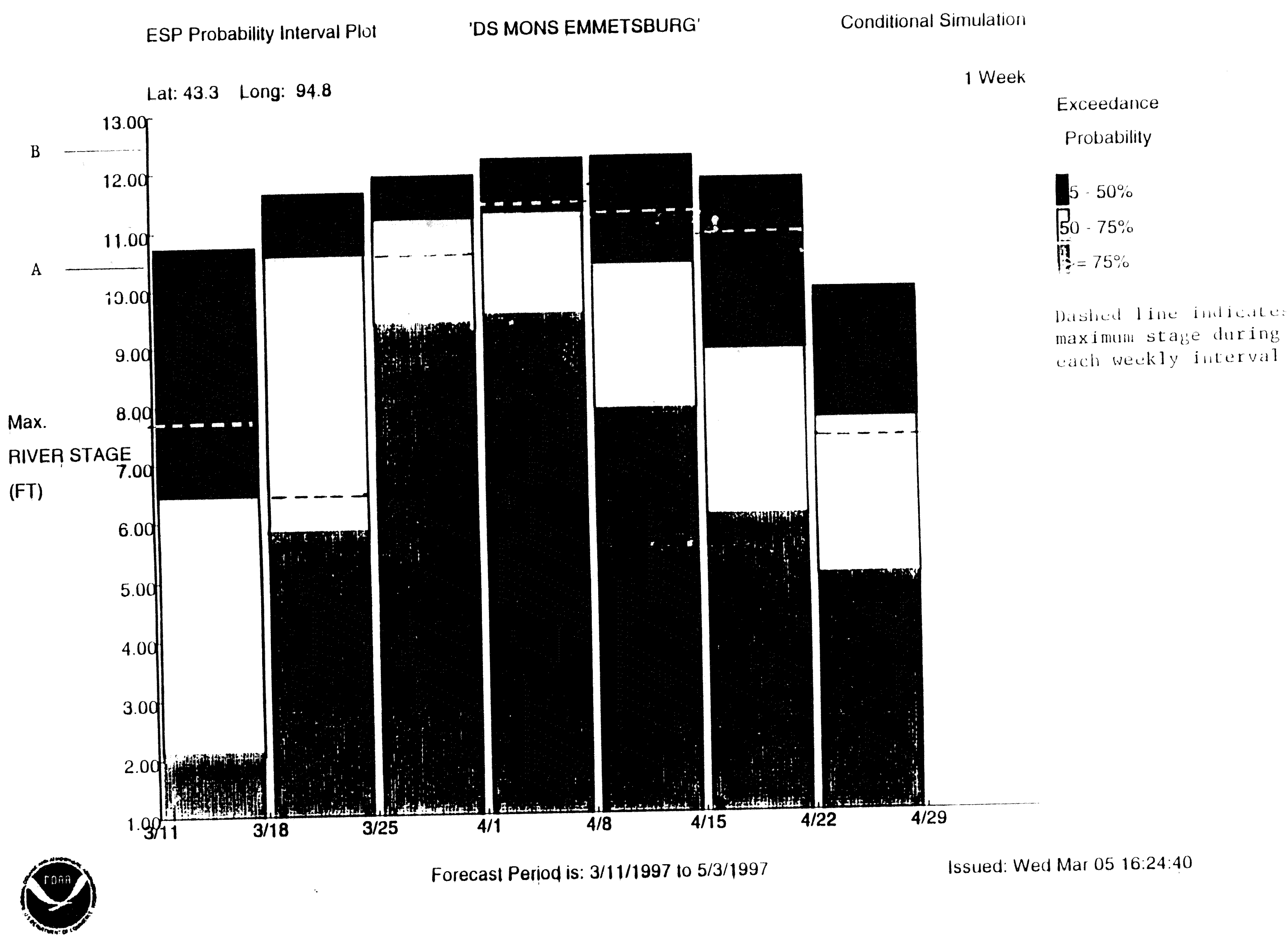

ESP Exceedance Probability
'DS MONS EMMETSBURG'
Conditional Simulation
Lat: 43.3 Long: 94.8
plot Interval: 3/11/1997 - 5/3/1997
Max.
RIVER DISCHARGE
(CFS)
15000.0
14000.0
13000.0
12000.0
11000.0
10000.0
9000.0
8000.0
7000.0
6000.0
5000.0
0.99 0.98 0.95 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.05 0.02 0.01
Forecast Period is: 3/11/1997 to 5/3/1997
Issued: Wed Mar 05 17.32:53

Figure 7



ESP Probability Interval Plot
'DS MONS EMMETSBURG'
Conditional Simulation
Lat: 43.3 Long: 94.8
1 Week
Exceedance
Probability
5 - 50%
50 - 75%
>= 75%
Dashed line indicates maximum stage during each weekly interval
B
A
Max.
RIVER STAGE
(FT)
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
3/11
3/18
3/25
4/1
4/8
4/15
4/22
4/29
Forecast Period is: 3/11/1997 to 5/3/1997
Issued: Wed Mar 05 16:24:40


Figure 7a

Figure 7a shows the maximum stages observed on the Des Moines River at Emmetsburg for each of the weekly probability plots issued on March 5. It can be seen that the maximum observed stages fell in the 50-75 percent plot in 3 out of the 7 weeks, and in the 25-50 percent plot in 4 out of the 7 weeks. The maximum stage at Jackson occurred on April 7, while the probability interval plot shows a maximum expected stage in the same week. So, the weekly maximum observed stages fell primarily in the 25-50 percent intervals, while the timing was quite good, falling in the maximum week as indicated by the probability interval plot. Also shown on Figure 7a are the traditional A and B forecast stages which would have been the only information available to the public without AHPS and which do not contain timing information.

Figure 8 shows a comparison of the forecasts with the observed crests using the exceedance probability plot for each location. These data indicate that the traditional outlook products (A and B) tend to encompass a wide variety of conditions and contain some degree of subjectivity, as indicated by the range of probabilities associated with the outlooks. The AHPS products provided information over a broad range of stages, but it is as yet undetermined how a user could arrive at a best single forecast number as "most likely," if that was what was desired. It is encouraging to note, however, that in most cases from Figure 8, the 50 percent exceedance probability stage was as close or closer to the final observed crest than either Outlook A or B. Since the demonstration was limited to 1 month, verification data is limited; additional data should be gathered and examined.

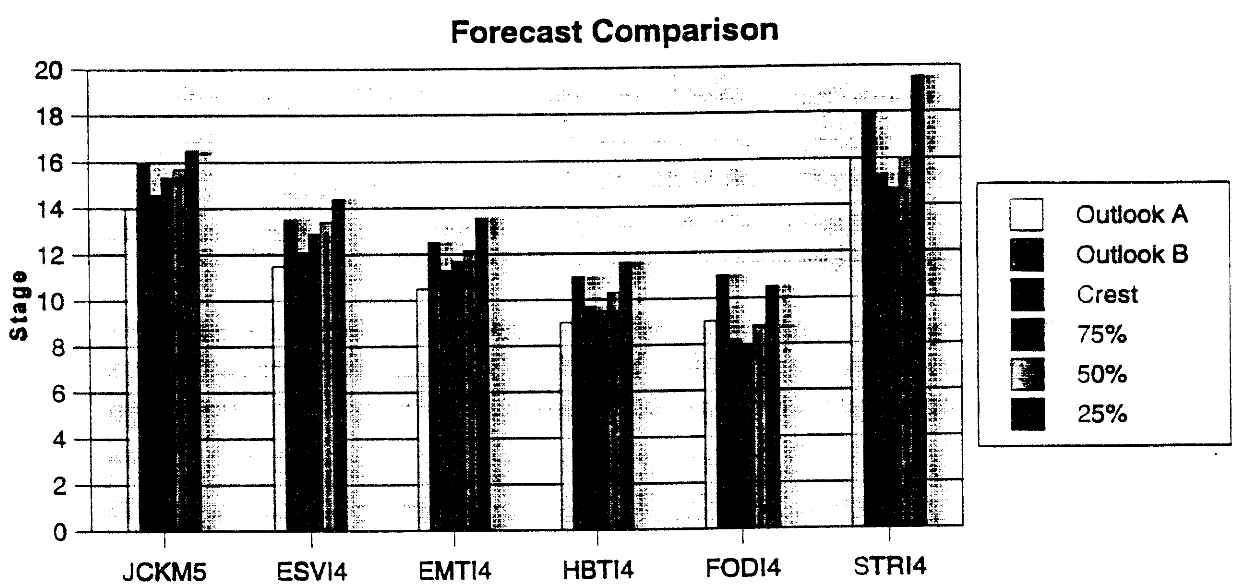



Figure 8

## OBSERVATIONS AND RECOMMENDATIONS

The AHPS demonstration was very successful in that all major implementation goals were met and demonstrated. However, as an initial effort, there were areas where improvements can be made. Some observations and recommendations follow:

- ESP spring flood outlook values, particularly at the 50 percent probability of exceedance level, compared well to traditional forecast techniques in areas where snowmelt flooding occurred, but in addition, gave significantly more information to the users.

- Users of AHPS products, both external and within the NWS, generally said the new product formats were very useful and contained additional information. Lack of flooding activity during the demonstration reduced interest by some users, especially external users.

- Inundation mapping was successfully demonstrated in the Des Moines area. Again, lack of flooding events during the demonstration minimized usefulness of this product to the users. A problem in this area is the lack of sufficiently accurate digital elevation data sets for use in generating the maps. Creating such data sets over large areas could be difficult.

- The use of an Internet home page for outside user access of AHPS products was very successful. The home page at WSFO Des Moines is still in use and can be accessed at:

  http://www.crh.noaa.gov/dmx/ahps

  This concept opens up an entirely new and easy access of NWS products by users.

- The use of QPF and climate products (1- to 5-day, 6- to 10-day, 30-day, and seasonal) were all successfully demonstrated. The ESPADP-generated forecast products (stage, flow, and volume) out 60 days was demonstrated as a viable and extremely useful product.

- Consideration should be given to linking the conditional exceedance probability graphs with flood frequency curves from flood insurance studies. This would provide additional helpful information for external users in a format with which they may be more familiar.

- Staff time required to create the AHPS suite of products is an issue. The time required to generate the daily forecast products averaged 1 hour; more during active conditions. The time required to generate and issue the AHPS ESP products averaged 4.5 hours. This relates to both staff and system (computer) resources (Appendix B). Techniques should be reviewed and revised to reduce runtime and staff time. Experience and optimization should reduce this concern significantly.

- Additional training resources need to be developed for the interpretation and understanding of the statistical products and procedures. There were occasions where users misunderstood the various AHPS products.

## SUMMARY

It should be remembered that the primary purpose of this demonstration was to show that all the necessary operations required for AHPS could be developed, implemented, and operated in an operational real-time environment. From that perspective, the AHPS demonstration was a total success.

The ESPADP software was developed and implemented at NCRFC. The Sacramento soil moisture accounting model had to be calibrated and running at NCRFC for the Des Moines basin. All of the necessary software and data necessary for inundation mapping had to be acquired by the NOHRSC and tailored for the Des Moines basin. Staff at WSFO Des Moines and NCRFC had to design a home page for disseminating the AHPS products, become familiar with the products, and work with the local users of the products. All of these many varied and critical requirements were accomplished on schedule.

All of the required AHPS products began flowing from NCRFC and NOHRSC to WSFO Des Moines and then to the public on schedule on March 5, 1997, and continued through March 26, as planned.

This critical demonstration was simply to show that all of the necessary pieces of AHPS were viable. Of course, the next step will be to demonstrate the technical superiority of these techniques by more rigorous verification and comparison with other procedures. However, even a cursory review of the types of products made available to the public, and an examination of Figures 2-8, shows the obvious advantages of AHPS because of the wealth of additional probabilistic information available through AHPS techniques.

Interaction with forecasters and external users before, during, and after the demonstration clearly showed the usefulness and applicability of ESP probability type hydrologic products. The capability to utilize QPF and climate information in long-range hydrologic forecasting was also demonstrated.

While the lack of significant flooding activity in the Des Moines basin during the demonstration was disappointing, it was not a problem for the overall project. In the early implementation stages of AHPS, the primary goals were to implement the AHPS at NCRFC, generate the forecast products as required, produce the inundation maps, and transfer all of this information to NWSFO Des Moines. At NWSFO Des Moines, the AHPS products were placed on the Internet home page, along with significant amounts of additional hydrologic information (E-19 information such as site history, location, maps, historical flood data, stage damage information, etc.) for access by outside users. All of this was accomplished and successfully demonstrated during this project. An evaluation by NWS staff and key customers with regard to AHPS is contained in Appendix A.

The most significant aspect of the demonstration was user response to AHPS. On a scale of 1 to 10, NWS staff rated the quality and usefulness of AHPS as 8. All the AHPS products were evaluated as being "useful" to "essential" for NWS operations. NWS staff cited the probabilistic forecasts, graphical output, and consolidation of hydrologic information as the things they liked best about AHPS.

External users rated AHPS products as 7 or 8 (on a scale of 1 to 10). The external users evaluated most AHPS products as "essential" to their operations. The external users stated that what they especially liked about AHPS was "the information was right before you and then you could plan your strategies."

## ESTIMATED PROJECT COSTS

It is estimated that AHPS implementation and demonstration costs for the Des Moines demonstration amounted to approximately $435,000. Allocated costs were: $63K for project development and management, $150K for contractor support and development, $24K for inundation mapping support, $120K for RFC enhancements and calibration, $54K for WFO support and enhancements, and $24K for operational costs. It is felt that national implementation would be more efficient. At a minimum, project implementation and management costs and contractor development costs would be reduced, bringing total costs for a Des Moines size project to about $222K, or a little over $10K per forecast point.

## FUTURE

The AHPS continues to run at NCRFC and is available to the public via the NWSFO Des Moines home page. It presently runs once per month in conjunction with CPC updates, but would be updated more often as the hydrologic situation in the Des Moines basin dictates. It is recognized that additional operational verification data must be developed and analyzed.

The demonstration clearly showed the forecast and water management benefits of AHPS-type products. AHPS needs to be implemented nationally to fully utilize the benefits of NWS modernization and to provide state-of-the-art hydrologic products to the public. At present, a slow implementation of AHPS over several additional basins in the north central states is anticipated. Possible limited deployment in the Pacific northwest, the Colorado River in Texas, and the Susquehanna basin in Pennsylvania is also anticipated. However, widespread major deployment of AHPS across the entire country must await additional funding.

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# Appendix A
# AHPS Survey Results

The AHPS was demonstrated in the Des Moines river basin in March of 1997. Following the demonstration, the Warning and Coordination Meteorologist at WSFO Des Moines asked NWS staff, 30 emergency managers, and several "key" customers their opinions of AHPS. Survey results are divided into NWS responses and external responses.

## NWS Personnel Survey Results

Surveys were given to 21 operational personnel at WSFO Des Moines. About 60 percent were returned and evaluated.

Question 1 - *How often did you access the AHPS products?*

| | |
|---|---|
| multiple times per day | **0** |
| daily | **4** |
| every few days | **4** |
| weekly | **2** |
| less often than weekly | **2** |
| never | **0** |

Question 2 - *For the following, please rate 1 to 10 with 1 being "unsatisfactory", 5 being "satisfactory" and 10 being "outstanding".*

| | **Des Moines Mean Responses** |
|---|---|
| Ease of access to AHPS products | **8** |
| Understandability of AHPS products | 7 |
| Quality of AHPS products | **8** |
| Display of AHPS products | **8** |
| Timeliness of AHPS products | **8** |
| Usefulness of AHPS products | **8** |

Question 3 - *Please rate the following WSFO Des Moines Home page products:*

| | Not Useful | Useful | Essential |
|---|---|---|---|
| Current stages | 0 | 4 | 7 |
| 5 day forecasts | 0 | 7 | 3 |
| Probability time series | | | |
| Stage | 0 | 4 | 6 |
| Flow | 1 | 5 | 5 |
| Volume | 2 | 5 | 3 |
| 60-day Exceedance probabilities | | | |
| Stage | 1 | 8 | 1 |
| Flow | 2 | 6 | 1 |
| Site information | 0 | 4 | 5 |
| Site map | 0 | 5 | 5 |
| Gauge information | 1 | 5 | 4 |
| Inundation map | 0 | 5 | 6 |
| Help products | 1 | 4 | 5 |

Question 4 - *What do you like best about AHPS?*

- Probabilistic forecasts.
- Exceedance probabilities - used it to issue spring ESP products.
- Real-time information.
- All information in one location.
- User friendly.
- Inundation maps.
- Amount of information available.
- Graphical output easy to use.
- Makes RVS/FLS preparation much easier.

Question 5 - *What do you like least about AHPS?*

- Short duration of "demonstration" period.
- Graphics and site maps were difficult to manipulate since they did not fit one page and required adjustment to view.
- Need support from "higher-up".
- Need more frequent updates.

**External Survey Results**

Surveys were given to emergency management and other critical customer groups along the Des Moines basin. The following external customers returned an AHPS survey: West Des Moines Fire and Civil Preparedness; USACE; Des Moines Water Works; USACE, Rock

Island; Emmet County EMD; Kossuth County EMD; Wright County EMD; Marion County EMD; Calhoun County EMD; Madison County EMD; Polk County EMD; Clarke County EMD; and an unknown.

External Survey Results.

Question 1 - *How often did you access the AHPS products?*

| | |
|---|---|
| multiple times per day | 2 |
| daily | 0 |
| every few days | 2 |
| weekly | 0 |
| less often than weekly | 5 -- (due to lack of flood threat) |
| never | 4 -- (due to lack of flood threat) |

Question 2 - *For the following, please rate 1 to 10 with 1 being "unsatisfactory", 5 being "satisfactory" and 10 being "outstanding".*

| | **External Mean Responses** |
|---|---|
| Ease of access to AHPS products | 7 |
| Understandability of AHPS products | 7 |
| Quality of AHPS products | 7 |
| Display of AHPS products | 7 |
| Timeliness of AHPS products | 8 |
| Usefulness of AHPS products | 8 |

Question 3 - *Please rate the following WSFO Des Moines Home page products:*

| | Not Useful | Useful | Essential |
|---|---|---|---|
| Current stages | 0 | 1 | 7 |
| 5-day forecasts | 0 | 2 | 6 |
| Probability time series | | | |
| Stage | 0 | 1 | 6 |
| Flow | 0 | 1 | 6 |
| Volume | 0 | 2 | 4 |
| 60-day Exceedance probabilities | | | |
| Stage | 0 | 5 | 3 |
| Flow | 1 | 4 | 3 |
| Site information | 0 | 5 | 2 |
| Site map | 0 | 3 | 3 |
| Gauge information | 0 | 0 | 7 |
| Inundation map | 1 | 2 | 4 |
| Help products | 0 | 4 | 2 |

Question 4 - *What do you like best about AHPS?*

- The information was right before you and then you could plan your strategies.
- Rainfall potentials.
- Accuracy, timeliness, uncertainty, length of future forecast, ease of graphics.
- Timely information.

Question 5 - *What do you like least about AHPS?*

- No Internet access.
- Did not use since flooding was not a problem during the demonstration.
- Occasional trouble accessing.
- First time user - I found it confusing.
- Download slow.
- Timeliness of access.

# Appendix B
# AHPS Workload Summary for NCRFC

| DATE | FORECAST SITUATION | DES (hours) | Extra (hours) | ESP (hours) | COMMENTS |
|---|---|---|---|---|---|
| 2/19/97 | Routine | 2 | | | snowmelt activity |
| 2/20/97 | Routine | 2 | | | snowmelt activity |
| 2/24/97 | Routine | 1.5 | | | residual rises from snowmelt |
| 3/3/97 | Routine | 1 | | | |
| 3/4/97 | Routine | 1 | 1/2 | | had software glitch, extra time not counted |
| 3/5/97 | Routine | 1.17 | 2/3 | 5 | first forecast |
| 3/6/97 | | 1.75 | | | issued shef fcst with comments |
| 3/7/97 | | 1.25 | | | standard fcst, comments included |
| 3/8/97 | Routine | 0.5 | 1/3 | | RVF looks ok |
| 3/9/97 | Watch | 0.67 | 1/2 | | RVF showed fcst for EFW, PRO, STR |
| 3/10/97 | Watch | 1.75 | | | beginning snowmelt on the headwaters of nrn IA, sw MN |
| 3/11/97 | Active | 2 | | 4.5 | new snow data came during the forecast process. Active snowmelt in head-waters. DWOPER run in the evening, products generated Thursday AM. |
| 3/12/97 | Active | 1.67 | | | |
| 3/13/97 | Active | 1.5 | | | |
| 3/14/97 | Active | 1 | | | DWOPER producing bad stages |
| 3/15/97 | Routine | 1 | | | |
| 3/16/97 | Routine | 1 | | | |
| 3/17/97 | Watch | 1.17 | | | |
| 3/18/97 | Active | 1.25 | | | |
| 3/19/97 | Watch | 1.50 | | | |
| 3/20/97 | | 1.33 | | | |
| 3/22/97 | Active | 0.67 | 25 min | | "sendfcst" took a long time (5 minutes) "Surfed" down to DSM home page after about 30 seconds and it appeared all graphics had been transferred after about a minute. |
| 3/23/97 | Active | 0.45 | 10 min | | Had trouble making a .TSCHNG to the QINE TS at DEMI4. "sendfcst" only took about a minute today. |
| 3/24/97 | Active | 1.50 | | | |
| 3/25/97 | Active | 1.17 | | | |
| 3/26/97 | | | | 3 | Wed |
| | | | | 1 | Thu (dwop & send_esp_coe) Needed to redefine in ESP. Segment redefined in OFS but not with espinit. Had to punch, redefine and then recopy fs5files. |
| 3/27/97 | | 0.83 | 30 min | | Ice jam. Didn't do any work to get simulated to more closely match observed, let the blend span take care of it. |

With all the data available, it is taking about 1 hour and 15 minutes to prepare the forecast. It takes approximately an extra 26.5 minutes to produce the AHPS forecasts. The average ESP run takes 4 hours and 30 minutes.

# Appendix C
# Flood Inundation Mapping Project Summary

## Summary

The NOHRSC of the NWS Office of Hydrology developed a Geographic Information System (GIS) application for visualizing the areal extent of flood inundation by combining outputs from the ESP Analysis and Display Program (ESPADP) model with DEM and Reach File Version 1 (RF1) geospatial data sets. Within the limitations of the data, the inundation mapping algorithm adheres to sound hydrodynamic/hydrologic principles to produce accurate portrayals of flood events. The more accurate the inputs (especially the DEM), the more accurate the inundation maps will be. The flood mapping application uses model outputs reported in a standardized format. Therefore, any NWS program capable of generating outputs in this format may use this application as a visualization tool. For the purposes of the Des Moines demonstration, the flood inundation mapping system was used to generate predicted areas of inundation based on ESP generated probabilistic levels of exceedance forecasts. The mapping system can also be used to produce inundation maps from near-term forecasts or nowcasts.

## Introduction

The NWS traditionally produces and reports hydrologic forecasts for a finite number of gaging stations within a forecasting region. While informative to those who deal with these data on a daily basis, to most people it is difficult to correlate river elevations reported for a relatively small number of forecast points with predicted areas that might be inundated. As part of the NWS modernization program, the NOHRSC has developed a tool for mapping predicted areas of inundation using both GIS programming tools and data sets. In short, the flood mapping software places forecasted river elevations into a digital representation of the landscape. Points along the river that were not forecasted are estimated by interpolating between forecasted points. The forecasted and interpolated river elevations are then extended into the landscape, perpendicular to the river channel, until they are impeded by the terrain. The resulting predicted areas of inundation are then merged with GIS overlays (roads, hospitals, schools, etc.) to produce a flood inundation map easily interpreted by the general public.

## The Software

The flood inundation mapping software, as it exists now, consists of four major components:

a) forecast data management,

b) flood inundation mapping,

c) interactive flood inundation mapping display, and

d) flood inundation mapping product generation.

The first three elements are integrated into an NOHRSC-developed GIS software and data environment. The fourth element relies on an Arc/Info Macro Language (AML) application.

The forecast data management component keeps track of both forecast region parameters and forecast data required to interpolate river elevations between river forecast points. A one-time-only execution requires the user to provide basic information on each river and forecast point within the forecast region. River and forecast point parameters are stored in Informix database tables. As new forecasts are generated within the forecast region, their data are related to the river and forecast point parameters stored in the database. The result is a series of relational database tables that spatially correlate river forecast data with a digital representation of the landscape.

The mapping software accepts (as inputs) hydrologic model outputs in a specified format. While the Des Moines demonstration project focused on ESPADP output as inputs into the mapping system, any NWS system capable of generating output in the required format can use this mapping system as a visualization tool.

After a forecast is entered into the forecast data management component, the flood inundation mapping component generates a grid of inundated regions as follows:

a) for each point along each river in the forecast region, the river surface elevation is estimated by interpolating between river forecast points,

b) a path perpendicular to the course of the river is traced in both directions away from the river,

c) each point along the perpendicular path lower than the river's elevation is marked as inundated,

d) stop when the terrain exceeds the river's elevation, points are not marked as inundated,

e) areas behind islands within the inundated region are also marked as being inundated.

ESPADP produces a predicted river elevation for each forecast point for multiple probabilities of exceedance. The inundation mapping software cycles through each probability in ascending order. The result for each probability level is successively superimposed to produce a single inundation map.

Interactive visual GIS tools can be used to query the resultant product in the context of other geospatial data stored as GIS data layers. Ultimately, this component of the system will be used to generate custom soft and hard copy map products. The soft and hard copy maps generated by the flood mapping system are used directly by end-users to determine areas of the city subject to flooding or potential flooding. In addition to the map products, the flood mapping system can provide a georegistered raster that represents flooded areas, flood depths, or potential flood probabilities for the mapped region. The NOHRSC-generated flood raster can be imported into any digital image processing system or GIS used by disaster emergency services personnel, county planning offices, or other Federal or state agencies with an interest in further enhancing or displaying the flood raster analysis.

Presently, the flood inundation mapping system relies on an AML to generate soft and hard copy map products. The AML is designed to generate both GIF and Postscript files depicting areal extent of inundation with hardcoded GIS overlays. As a matter of expedience, AML was used in this demonstration to display the NOHRSC-generated flood raster with the cultural data layers. In the AWIPS environment, however, it will be necessary to provide the display functionality directly from the NOHRSC flood mapping system. In this way, the flood mapping system will not be dependent on AML and will be AWIPS compliant.

The accuracy of the mapping system is dependent entirely on the accuracy of the input data. We note two major limitations to the mapping procedure:

a) The areal extent of flooding is contained by terrain. If the quality of the DEM is poor the accuracy of the inundation map is necessarily poor, and

b) The areal extent of flooding is limited by volume. The output from ESPADP assumes a constant elevation perpendicular to the course of the river that, under certain circumstances, may be an unrealistic representation of the volume of water available for inundation.

**The Future**

The algorithmic portion of the flood inundation mapping system has proven itself to be both reliable and consistent with hydrodynamic/hydrologic principles. Major improvements to the accuracy of flood inundation maps are most likely to be realized by addressing the issues associated with the input data. The following recommendations for further development are proposed:

a) incorporate USACE cross-section data to improve the accuracy and precision of the DEM data,

b) generate accurate and precise DEMs for high risk areas,

c) modify ESPADP to generate cross-section elevations in addition to channel centerline elevations, and

d) modify the mapping software to read full DWOPER/FLOODWAV output.

The utility of the flood mapping software can be improved as follows:

a) remove the dependency on AML for generating soft and hard copy maps,

b) complete the development of flood depth mapping,

c) complete the development of multiple format outputs, and

d) develop an ability to interact with DWOPER/FLOODWAV to:

1) assist in calibrating DWOPER/FLOODWAV, and

2) provide interactive interface to DWOPER/FLOODWAV to model levee failures.

The flood mapping system was developed using the same architecture employed in IHABBS and, as such, is fully compatible with IHABBS installations scheduled for all the RFCs. The flood mapping system can, once it has fully matured, be deployed in each RFC as a companion to IHABBS.

Lastly, the flood mapping system was designed with AWIPS integration in mind. Continued implementation of the AWIPS design plan for the flood inundation mapping project should be pursued along with continued improvements in the quality of the DEM data.

# AHPS Flood Inundation Map — Des Moines, Iowa


## Probability of Flooding During March 12 to May 4, 1997

**Date forecast issued: March 5, 1997**

| | |
|---|---|
| less than 25 percent | natural rivers and ponds |
| 25 to 50 percent | underground storage tanks |
| 50 to 75 percent | hospitals |
| greater than 75 percent | industrial facilities |

**National Operational Hydrologic Remote Sensing Center**