Advanced Hydrologic Prediction Service (AHPS)

Development and Implementation Plan

August 2, 2004

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Introduction

This document provides an overview of the Advanced Hydrologic Prediction Service (AHPS) and serves as a guide for the development and implementation of AHPS services. The document will be reviewed and updated annually to reflect the current state of AHPS and provide a road map for future implementation.

Background

The 21st century offers NOAA and the NWS a challenge to expand its focus to provide more and better information to manage all water resources. Fresh water forecasting and decision making tools are crucial to the nation's well-being and interest as well as the future of our commerce. The Advanced Hydrologic Prediction Service (AHPS) is the NWS program to modernize the river forecasting capability and expand it to new waterways. It will feature new science and technology that will expand and provide additional capabilities that will make available new and better decision making tools that will help predict the impact of all phenomena affecting the nation's fresh water supply. Regional estimates of drought, snow, river flow, soil moisture content, pollutant dispersion, and inflow to coastal estuaries will enhance the health and safety of our fresh water supply. A new generation of user-friendly information and forecasting tools will be used by a variety of customers to help them make better and more informed water wise decisions. This information will also help us manage our precious water resources and to secure the well-being of the nation.

AHPS priorities are to sustain current NWS hydrological services, deliver more precise forecasts with magnitude and certainty of occurrence information, leverage collaborative research to infuse new science and provide better water forecasting products and information for more informed decision making to benefit the public and the Nation's commerce. Through AHPS, the NWS will deliver:

- ***Better forecast accuracy*** **–** by incorporating new verified science into hydrologic modeling operations and more effectively coupling atmospheric and hydrologic models and forecast information on all time scales.

- ***More specific and timely information on fast-rising floods*** **–** by using tools which make it easier to: (a) rapidly identify small basins affected by heavy rainfall, identify excessive runoff locations, and predict the extent and timing of the resulting inundation, and (b) forecast the impacts of dam failures.

- ***New types of forecast information*** **–** by incorporating new techniques for quantifying forecast certainty and conveying this information in products which specify the probability of reaching various water levels.

- ***Longer forecast horizons*** **–** by regularly issuing hydrologic forecast products and information covering one to two weeks into the future and beyond.

- ***Easier to use products*** **–** by delivering information in new and easier to understand formats, including graphics.

- ***Increased, more timely, and consistent access to products and information*** **–** through the expanded use of advanced information and communications technologies.

- ***Expanded outreach*** **–** by engaging partners and customers in all aspects of the hydrologic services improvement effort.

AHPS will provide a comprehensive set of tools and information in the following areas to help decision makers make informed decisions.

1. Flash-flood services
2. Short- to long-term probabilistic forecasts including low-flow and drought information
    - Short-term 1-7 days
    - Medium-term 7-28 days
    - Long-term 1-6 months
3. Flood-forecast mapping at Selected locations

AHPS Implementation Strategy

AHPS forecasting services will be provided to customers as “Basic,” “Enhanced” and “Partnered” services. This approach allows the NWS to provide immediate benefit to its customers and increase those benefits with the parallel development and implementation of new (verified) science into operations. AHPS forecasting services will be provided to customers as “Basic,” “Enhanced” and “Partnered” services. These categories of services are defined as:

- Basic services will be provided at all AHPS forecast locations. Basic services are defined as:
    - At flood forecast locations: provide enhanced forecast information including observed and forecast river levels and/or flow, when available, in graphical format, as well as probabilistic forecast information
    - At water supply forecast points: provide water supply volume forecasts in graphical format

- Enhanced services to be implemented at all appropriate AHPS forecast locations.
    - Flash-flood forecasts; or
    - Short- to long-term forecasts which include low-flow and drought information

- Partnered services to be implemented at the most appropriate AHPS forecast locations. The partnered services are financed by both federal and other funding sources such as state and local governments. Partnered services include:
    - Flood-forecast mapping.

Field Services Implementation

River and flood forecasts and probabilistic outlook information are now provided for approximately 3,400 locations. Of these locations, AHPS information was available at 717 locations at the end of Fiscal Year (FY) 2003. By the end of FY 2013, AHPS information will be available for 4,011 forecast locations.

AHPS Implementation Activities & Envisioned Schedule

National implementation of AHPS is currently underway. Research and development of new AHPS features are also underway. Appendix I depicts the schedule for the provision of basic AHPS services and the expansion to additional sites.

AHPS and other NWS hydrologic programs are being integrated into a NOAA hydrologic strategic focus area. NOAA is in the process of incorporating separate component hydrologic programs to produce an integrated capability. The NWS Strategic Plan and management direction clearly demonstrate a commitment to the NOAA corporate initiatives. Recently, NOAA defined hydrology as a priority to help achieve its goal for providing better and more integrated information to enhance management of the Nation’s water resources. AHPS is a key component of the NOAA hydrology strategic objectives.

Flash-Flood Services

Introduction

Flash floods are the fastest-moving type of flood, occurring within six hours or less of the causative event. Most flash flooding is caused by slow-moving thunderstorms or heavy rains from hurricanes and tropical storms but can also be caused by events such as a dam or levee break. While the number of fatalities can vary dramatically with weather conditions from year to year, the national 30-year average for flood deaths is 127. That compares with a 30-year average of 73 deaths for lightning, 65 for tornadoes and 16 for hurricanes.

To meet the forecast challenges posed by flash floods, AHPS provides a comprehensive set of products and information to provide decision makers with more timely and accurate flash-flood predictions. This information will assist in meeting the Government Performance Results Act (GPRA) goals committed to in the NWS Strategic Plan, and presented in the FY 2004 budget. The goals range from 48 minutes lead time with an accuracy of 88% in FY 2004 to 52 minutes lead time with an accuracy of 90% in FY 2008. AHPS also will augment conventional text-based flash-flood warnings and related products, with graphical watch/warning products and information. Key system components for providing flash-flood services are shown in Figure 1.

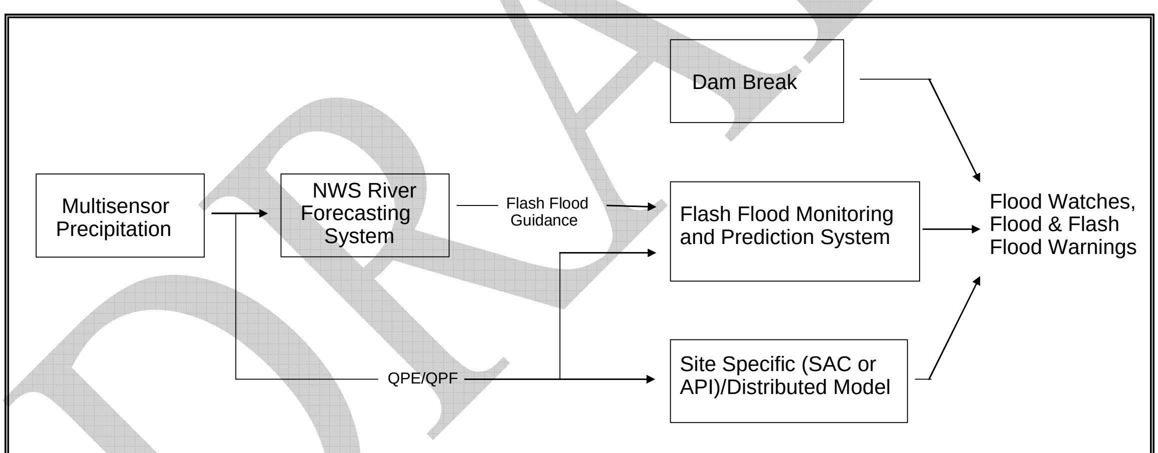

Figure 1 - System Components for Flash-Flood Services

Service enhancements will be realized through the use of the Flash-Flood Monitoring and Prediction (FFMP) system which uses flash-flood guidance along with high-resolution quantitative precipitation estimates (QPE) from radar, ground based gauges, and satellites as well as short-term quantitative precipitation forecasts (QPF) to determine areas of flash flooding. Advanced hydrologic models (distributed), dam failure analysis tools, and processing of high resolution geographic information system (GIS) and hydrometeorological data sets will also allow products to include much more detailed information on the location and magnitude of events. New products for additional locations in smaller basins will contain information in the form of numerical forecast values (e.g., stage or water level) or categorical threat levels (e.g., minor, moderate, major). Training for partners and customers as well as NWS personnel will be developed to support the implementation of new science and technology.

Envisioned Sequence of enhancements

Figure 2 shows the proposed sequence of enhancements for Flash Flood Services, with the approximate delivery to WFOs/RFCs. The final schedule is dependent on allocation of resources and success during the research, analysis and operational development phase.

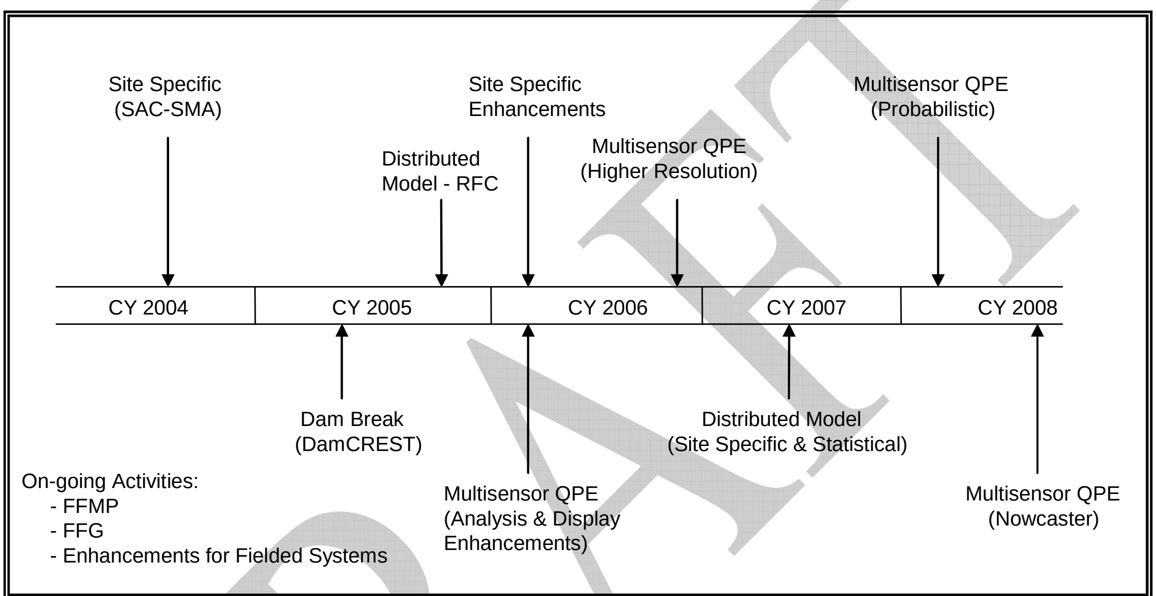

Figure 2 - Envisioned Sequence of Enhancements

Site Specific Model

The site specific model, in conjunction with guidance provided by the River Forecast Center (RFC), will provide Weather Forecast Office (WFO) staff the ability to generate short time-step streamflow predictions. For some forecast points, the 6-hour time step forecasts of the NWSRFS are not granular enough to provide timely and specific stream-based warnings of flash flooding to the public. The site specific model operates on smaller basins with one-hour time steps allowing the WFO staff to provide more timely and specific stream-based forecasts and warnings to the public.

The Sacramento Soil-Moisture Accounting (SAC-SMA) rainfall-runoff model is being incorporated into the Site Specific application which uses the Kansas City API rainfall-runoff model. This will allow Site Specific application to be run with a choice of rainfall-runoff models. Beta testing was initiated at the Southeast River Forecast Center (SERFC) for San Juan, Puerto Rico in March, 2004 with full deployment planned to start in August, 2004 following AWIPS Release OB4.

Additional work is needed to support operational use of the Site Specific/SAC-SMA. This includes:

- Software Tools for Model Calibration – Existing River Forecast Center (RFC) calibrations are made for larger basins and time steps (6-hour) than Site Specific/SAC-SMA, which can operate on smaller basins with a 1-hour time step;

- Maintain Model State Variables – Maintaining the proper values for model state variables is critical in producing accurate and meaningful forecasts. This will be accomplished by integrating a variational assimilation, VAR, state adjustment function into the Site Specific/SAC-SMA; and

- Implement Routing & Snow Modeling Techniques – This will allow the Site Specific model to be used for additional hydrologic conditions.

Flash-Flood Guidance (FFG)

Efforts are ongoing at the national, regional and local levels to enhance performance. This includes the need for accelerated development of new techniques for computing FFG. A more scientific approach was outlined by the National Flash-Flood Guidance Improvement Team (FFGIT). The following recommendations were made by the FFGIT:

a. Proceed with proposed solutions toward improving FFG system performance;
b. Develop methodologies to provide Flash-Flood Potential information;
c. Develop or oversee training materials to educate RFC and WFO staff members on all aspects of the generation and application of FFG;
d. Provide internal NWS coordination needed to optimize current FFG;
e. Implement a national FFG verification system; and
f. Develop the Statistical Distributed approach for producing flash-flood forecast information.

Distributed Model

Distributed modeling approaches are being developed to fully exploit new data sets that describing the spatial and temporal variability of features such as rainfall, vegetation, soils, terrain, evaporation, temperature, and others. Accounting for the spatial variability of these features marks a significant advance in NWS modeling capability. In addition, it forms a solid point from which to progress into water resource modeling according to planned NWS initiatives. With distributed models, one has the capability to simultaneously simulate basin outlet hydrographs as well as the hydrologic response at points within the basin boundary. This capability is well suited for simulating small scale events such as flash floods.

The Office of Hydrologic Development (OHD) Hydrology Laboratory (HL) has followed a two-part strategy for developing a distributed model for river and flash-flood forecasting as follows:

1. In-house development of a distributed model; and
2. Leading an international comparison of distributed models called the Distributed Model Intercomparison Project (DMIP).

Following this strategy, the HL has developed the NWS's first distributed hydrologic model called the HL Research Modeling System (HL-RMS). HL-RMS performed well in DMIP and is the foundation for further distributed model research and development.

The current version of HL-RMS uses the 4km Hydrologic Rainfall Analysis Project (HRAP) grid as the basic computational element of a basin. In each grid cell, the Sacramento Soil Moisture Accounting model is used to convert rainfall to runoff. Kinematic routing is used in each grid cell and in river channels to move water through the network to the basin outlet. Prototype testing is underway using a version of HL-RMS at two RFCs. Moreover, the HL is in the midst of a large software engineering effort to migrate the science of HL-RMS into an AWIPS supported tool referred to as the Distributed Hydrologic Modeling System (DHMS). Continued HL-RMS and DHMS research and development is expected to provide advancement in a number of areas including flash flooding, river flooding, and water resources.

Implementation of DHMS capabilities for flash flood applications will be incremental. The first stage of operational implementation is slated for RFCs because most of the initial scientific validation has been for RFC scale applications. Implementation at RFCs is a critical first step for flash flooding because, as with the current lumped modeling approaches (FFG and Site Specific), support for distributed modeling at WFOs is likely to come from the RFCs. For example, the statistical distributed modeling approach, which is being researched as an alternative to the FFG approach for ungauged locations, will have both a historical pre-processing component and an operational component. From a logistical standpoint, the pre-processing component is analogous to preparation of the FFG, which is currently done at RFCs. In addition, a calibrated, distributed model implemented at an RFC would facilitate rapid implementation of site specific models at WFOs for any point within the distributed modeling domain. This would require less work than developing separate site specific models for each point of interest, as required with the current lumped approach.

Finer scale implementation of distributed models at WFOs requires continued research and analysis, operational development, and implementation. Research and development is progressing from coarse resolution applications to finer and finer scales. Thus, the first implementations of DHMS for flash floods will likely use hourly forcing data, while later releases will use sub-hourly data. Major milestones in distributed model research and development for flash floods include:

- DHMS to RFCs (hourly)
- DHMS with Statistical Distributed Capability to WFOs (hourly)
- DHMS with Site Specific Capability to WFOs (hourly)
- DHMS with sub-hourly capabilities to RFCs and WFOs

The DHMS statistical distributed component is expected sooner than a DHMS site specific capability because the standard for success, improvement over the FFG approach, may be attainable without extensive hydrologic model calibration. A DHMS site specific implementation will likely require some level of calibration (locally or at some downstream point) to produce comparable or improved results relative to a calibrated lumped model.

Implementations of distributed models at RFCs and WFOs will depend on data availability and progress in other key areas of distributed model research and development. DHMS will have wider applicability as planned enhancements such as snow and frozen ground modeling, additional routing options, and alternative rainfall-runoff techniques are included. Other enhancements currently being investigated that will improve the ease of implementation include variational streamflow assimilation (VAR), improved a priori parameter estimation, and better calibration techniques.

Statistical Distributed Model

The statistical distributed model is an extension to distributed modeling designed to account for the uncertainty in our ability to predict flash flooding, particularly at ungauged locations. The physical processes causing flash floods and river floods are not much different. However, predictive uncertainties tend to be greater for flash floods than for river floods. This is partly due to errors in rainfall data which tend to average out over the larger spatial and temporal scales associated with river floods. Lack of information about stage-discharge relationships also adds to the difficulty of assessing flood risks at ungauged locations on small streams, even if accurate discharge estimates are available from a distributed model.

The basic idea of the statistical-distributed modeling approach is to use retrospective distributed model runs as a measure of flood severity for ungauged locations. To implementation this, a distributed model pre-processor would be run using historical archives of gridded Multi-sensor Precipitation Estimates (MPE), then results would be analyzed to establish flood frequency information for each model element (e.g. grid cells or small subbasins). For any model element, simulation results obtained by running the same distributed model in real-time can be compared to the flood frequency information derived for that element. This frequency based approach allows one to establish an objective measure of risk at the many locations where stage-discharge relationships are unavailable.

For model elements where actual flood damage levels are known and observed streamflow data are available, observed flood frequency information can be used to indicate which modeled flood frequencies are of concern in a given area. Both flood frequency statistics and real-time simulations are produced using the same model, so the comparison is useful even when modeled flows are not a perfect match for reality. Because of this, the method can be tested using a-priori model parameter estimates and may provide improvements relative to the current FFG system without requiring a fully calibrated distributed model.

HL-RMS will be used to validate the science of the statistical distributed modeling approach, making the transfer of the scientific enhancements to the operational software package DHMS as smooth as possible.

Dam Break

The dam break analysis application software allows the user to store and view dam information and create, store, and view various dam break scenarios from a simplified dam break model (SMPDBK). The program was originally developed as the Catalogue of Dams (DAMCAT) with approximate dam break flood forecasting information using (SMPDBK). DAMCAT is a menu driven package that allows the user to search for a particular dam or a group of dams by supplying one of the following: dam name, dam identification number, river name, nearest downstream town name, county name or county FIPS code.

The enhancements to the Dam Break functions include:

1. Dam Break Catalog Reviewer and Estimation Tool (DamCREST) – The goal of DamCREST is to deliver an updated application as part of the Advanced Weather Interactive Processing System (AWIPS) Release OB6, in terms of the graphical user interface (GUI), the database design, and the maintainability of code while retaining capability already delivered for non-AWIPS users. DamCREST will provide a more meaningful and user-friendly application developed for a more modern and easier maintained platform, i.e. JAVA/Linux.

2. Improve Model Input Data – The current data makes assumptions which limit the use and accuracy of dam break failure scenarios. The Colorado Basin River Forecast Center (CBRFC) has demonstrated the benefits of collecting detailed geographic data, using GIS techniques, for improving dam break failure scenarios.

Multisensor QPE

Since the employment of the WSR-88D network, radar-based flash-flood prediction has focused on interpreting information from a single radar. This approach was the most logical one when transmission of digital radar information between forecast offices was limited, and limited functionality existed for automatic merging of precipitation information.

Multisensor QPE (MPE) ingests radar, rain gauge, and satellite observations and synthesizes gridded precipitation fields based on input from a combination of these sources. Multisensor QPE estimates are useful in flash-flood applications because they provide forecasters seamless precipitation fields using data from the nearest radar, as well as ancillary data from gauges and satellites.

The following new data sets and software will be provided to accommodate MPE:

New Data Sets

- Objective Analysis Techniques – The existing methods for merging the unbiased radar data with gage rainfall do not adequately address certain hydrometeorological events. Alternate methods have been proposed and used in local applications at some RFCs, and other methods have been prototyped at OHD but not implemented in national applications. Incorporation of additional methods for producing the gridded estimates would provide WFOs and RFCs a choice of the best available methods, and improve the estimates. Furthermore, the speed at which the applications are able to process the data is critical to ensure its timely usability.

- Higher Resolution - The QPE spatial and temporal resolution will be reduced from the current 4x4 km hourly updates to 1x1 km resolution every volume scan. This will be accomplished in conjunction with changes to the NEXRAD Open Radar Product Generator (ORPG) software to provide a 1 km by 1 degree Digital Storm Total Precipitation (DSP).

- Probabilistic - Probabilistic QPE will provide more information on precipitation intensity than can now be obtained from deterministic (single-value) products. Though rainfall estimates, from the NEXRAD Precipitation Processing Subsystem (PPS), are subject to systematic and random errors, the error distribution can be quantified to some extent. Thus the probabilistic QPE system will supply users with information such as the probability rainfall has exceeded some given amount, or upper and lower bounds on the rainfall amount. Such information may be very useful in flash flood situations specifically when radar estimates are subject to substantial absolute error.

- Nowcaster - Improvements to flash-flood prediction will require not only better precipitation estimates but useful short-range forecasts. The MPE system will be enhanced with a 0-1 hour rainfall forecast system to make use of mosaicked reflectivity data to create a gridded rainfall forecast covering most of a county-warning area or RFC area of responsibility. The system employs an economical extrapolation method, similar to one used in other applications. A prototype version of the nowcasting system has shown considerable ability in pinpointing likely areas for heavy rainfall.

- Range Correction - The current WSR-88D reflectivity data quality degrades with range from the radar due to many factors. The Range Correction Algorithm (RCA) calculates range-dependent rain rate correction factors and passes them to the Precipitation Processing System (PPS) in the WSR-88D Radar Product Generator (RPG) system, where, at the discretion of the forecaster, they are applied to the accumulation estimates in existing rainfall products. The RCA will enhance QPE by:

    1. Using data close to the radar to create a mean Vertical Profile of Reflectivity (VPR) for current conditions
    2. Using the VPR to adjust reflectivity values at longer ranges from the radar.

- Dual Polarization - The application of both horizontally- and vertically-polarized radar pulses enables radar processing software to estimate the aspect ratio and other features of precipitation not determined with horizontally-polarized information alone. It also enables discrimination between different phases of hydrometeors and between hydrometeors and other common targets such as birds and insects. Finally, dual-polarization has proven to be effective for rainfall estimation in the presence of hail, which has long prevented the WSR-88D from providing reliable estimates in some intense convective storms.

<u>New Display and Analysis Software</u>

- Graphical Editing Tools – Additional interactive graphical editing features are needed to allow the forecaster to perform quality control and edit the point data and gridded precipitation estimates in order to produce the highest quality point gage data and gridded fields. This includes the incorporation of "post-analysis" tools to handle the integration of 24-hour data within the hourly precipitation fields.

- Enhanced Performance – Some MPE interactive processing and display operations do not complete in a timely manner. These operations need to be optimized through use of enhanced software and data store design changes. This applies to both the interactive operations and the background field generation analysis.

- National Implementation of RFC Enhancements – Various RFCs have adopted local methods for managing QPE grids. These methods can be adopted into MPE to create a national baseline application to benefit all RFCs.

Flash-Flood Monitoring and Prediction (FFMP)

Enhancements to the FFMP application will use high resolution QPE from radar, gauge and satellites as well as short-term QPF. The following enhancements will be incorporated into FFMP:

a. Multiple radar service back-up
b. Enhance Graphical User Interface (GUI)
c. Integrate Hydro View in D2D
d. Integrate QPF into FFMP
e. Incorporate Basin Trace

Basin Legacy Support

The National Severe Storms Laboratory (NSSL) provides basin customization technical support; basin data set access and distribution; and redelineation of basins in areas where significant errors exist within individual Weather Forecast Offices (WFOs). This ongoing support of FFMP in the area of basin mapping will continue until the end of FY05.

Training

Workshops, tele-training and class-room training will be provided to support the implementation of new science and technology. This will ensure that those involved in the support and operation of the program have a sound understanding of system enhancements and upgrades

Short- to Long-Term Forecasting Services

Introduction

The current NWSRFS is basically a deterministic forecasting system. Short- to long-term forecasting services called the Ensemble Streamflow Prediction (ESP) system will add a probabilistic forecasting capability to increase the accuracy of forecasts and to convey a quantitative measure of the forecast uncertainty. The ESP system will aim at producing short term (hours to five days), medium term (six to fourteen days), and long term (monthly to seasonal) probabilistic forecasts. In AHPS, probabilistic forecasting will cover the process of assessing the uncertainty of forecasts and provide additional information and products based on that uncertainty. One way to produce probabilistic forecasts is by means of ensembles. Ensemble prediction provides the flexibility required to satisfy the complex mix of operational and scientific requirements associated with AHPS.

The main goals of developing the ESP system are:

- To produce seamless and consistent probabilistic forecasts for all lead times, relative to specific RFCs sub-areas at the appropriate time steps. The ESP system will integrate any available meteorological forecasts and will account for both forecast uncertainty and hydrologic model uncertainty.
- To verify ESP performance in both space and time.

Key system components to provide short- to long-term probabilistic forecasting services are shown in Figure 3.

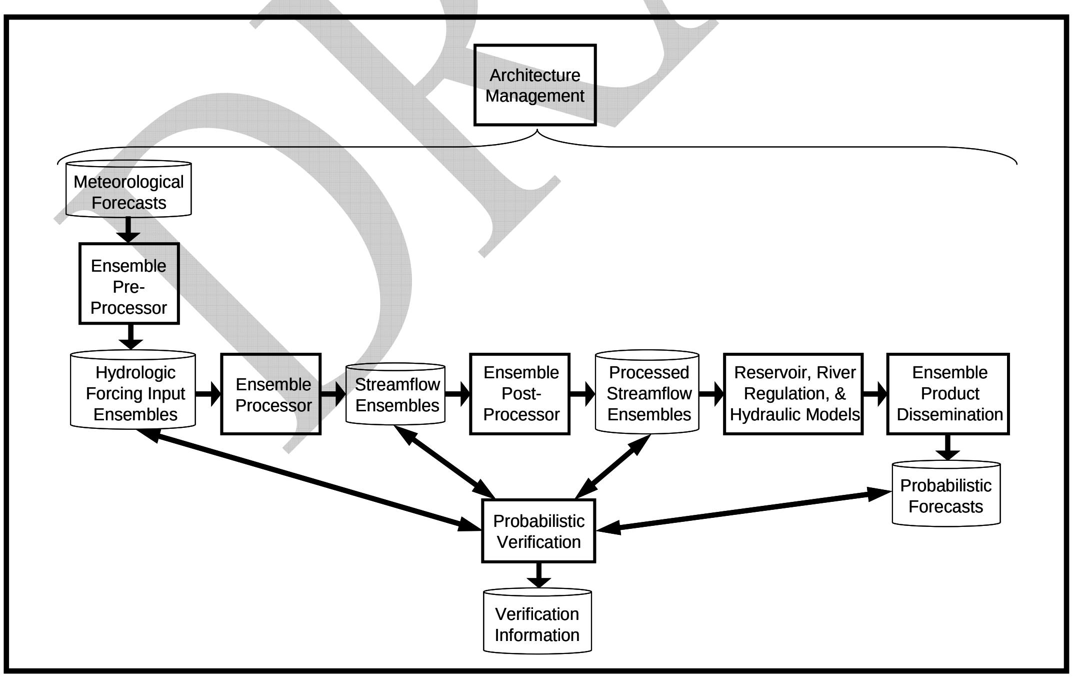

Figure 3 – System components for the Ensemble Streamflow Prediction (ESP) system

The main components of the ensemble system shown in Figure 3 and described briefly below are:

- The Ensemble Pre-Processor - This system takes meteorological information from a number of sources to generate all the hydrologic forcing inputs required by hydrologic modeling for producing streamflow ensembles.
- The Ensemble Processor - This system produces streamflow ensembles from the hydrologic forcing inputs generated by the pre-processor.
- The Ensemble Post-Processor - Before the streamflow ensembles can be used, they need to be statistically corrected, which is the role of the Ensemble post-processor.
- Reservoir, River Regulation, and Hydraulic Models - Reservoir operations, water withdrawals and returns all affect streamflow forecasts and must be included into a comprehensive ESP. River routing is necessary to get streamflow and streamflow-related variables at any point in the river system.
- Probabilistic Verification - This component aims at verifying the quality of all probabilistic forecasts.
- Ensemble Product Generation and Dissemination to visualize, analyze, generate and disseminate user-friendly products.
- Architecture Management to ensure that progressive system development and enhancements proceed in a smooth manner.

Envisioned Sequence of Ensemble System Implementation

Figure 4 shows the proposed sequence of enhancements for Short- to Long-Term Forecasting Services with the approximate delivery to RFCs. The final schedule is dependent on allocation of resources and success during the research, analysis and operational development phase.

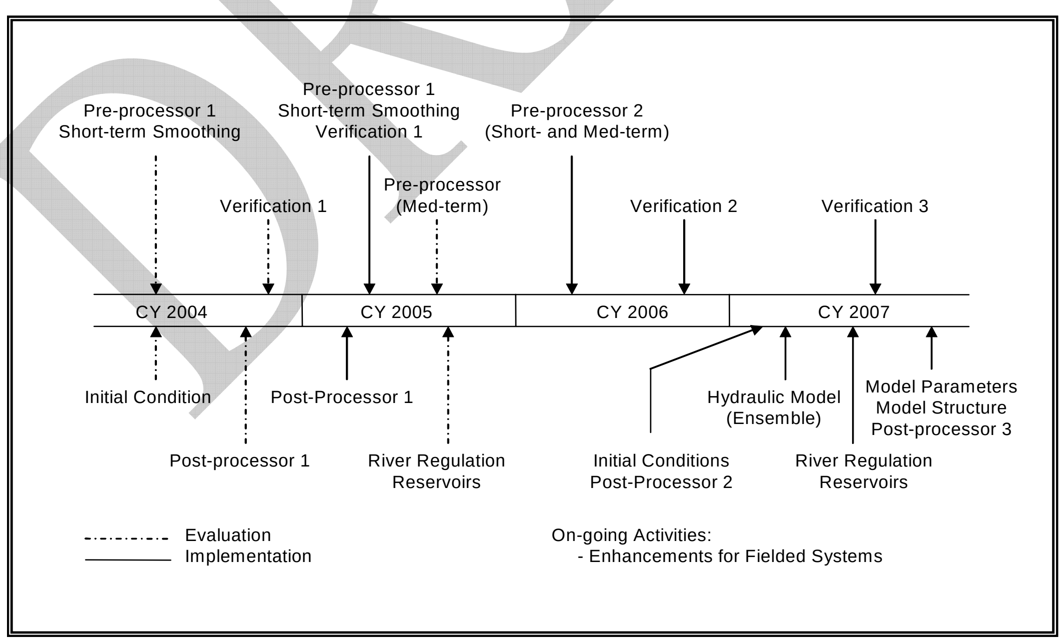

Figure 4 – Envisioned sequence of implementation of the ensemble system

Ensemble Pre-Processor

The ensemble pre-processor aims at producing hydrologic forcing inputs for the ensemble processor. Forcing inputs are: precipitation, temperature, potential evaporation, and freezing heights. These inputs are required for specific RFC sub-areas and all lead times (from 1 hour up to 1 year) at time steps used by the hydrologic models (from minutes up to 6 hours). The current priority is to generate skillful precipitation and temperature ensembles for the hydrologic models. Other forcing inputs will be considered later. The ensemble pre-processor will account for the meteorological uncertainty; the hydrologic uncertainty will be accounted for in the ensemble processor and post-processor.

The current ensemble pre-processor integrates meteorological forecasts/climate outlooks from NCEP/CPC to adjust the historical temperature and climate time series to generate precipitation and temperature ensembles. However, there are some limitations in the current procedure: the climate time series are too noisy and too sparse to represent properly the probable future events, and the system needs to integrate other available meteorological forecasts, for which the uncertainty needs to be quantified. The new procedures will serve until the hydrometeorological community can produce skillful and unbiased ensembles.

Implementation of the ensemble pre-processor is being carried out in stages. During the first stage, the current procedure will be enhanced by applying a smoothing algorithm to the historical time series in order to get more appropriate climatology forecasts. In the second stage, the system will incorporate the skill of available meteorological forecasts. This process is based on modeling the joint probability distribution of forecasts and observations for each time step for each forecasting point. The probability distribution of future events that may occur for a particular forecast is then derived from the joint distribution and is used to rescale the climatologic forecasts. By rescaling climatologic values, the underlying space-time patterns between any two points and between any two variables (e.g., precipitation and temperature) are preserved. The third and final stage will be the incorporation of bias- and spread-corrected hydrologic forcing input ensembles from global and regional climate models using adequate downscaling processes. These ensembles may replace the interim ensemble pre-processor outputs of the previous stage.

The enhancements of the ensemble pre-processor necessary to generate skillful forcing input ensembles include the following activities:

- Merge the different procedures for all lead times to produce the most skillful ensembles at each lead time using a unified ensemble pre-processor system.

- Enhance short to long range ensemble prediction to integrate the skill of other available meteorological forecasts:

    - Single-value forecasts from the Hydrometeorological Prediction Center and potentially data from the National Digital Forecast Database will be used.

  - Regional and global ensembles from the Environmental Modeling Center/NCEP and from the Climate Prediction Center/NCEP will be corrected (for bias and ensemble spread error) and integrated; since the forecasts are not necessarily relative to the hydrologically relevant scales and since the forecast skill is scale dependent, space-time aggregation and disaggregation procedures need be developed.

- Improve calibration and assess data requirements:

  - One of the limitations for modeling the joint distribution of forecasts and observations is the short length of available archive; techniques such as temporal or spatial smoothing and forecast simulation will be needed to improve the robustness of the calibration parameters

  - It is also necessary to develop a historical data pre-processor in order to reduce the cost of data preparation and increase the reliability of the data sets used for calibration

- Integrate the new precipitation estimate products described above in the Flash-Flood Services, to use more reliable precipitation estimates and the uncertainty information about these estimates.

- Develop a unified calibration prototype for all lead times in order to enable the forecasters to develop ensembles for any specific sub-area.

- Define quality control procedures for forecasters and integrate forecaster control.

Ensemble Processor

The role of the ensemble processor is to receive precipitation and temperature ensembles from the pre-processor, and together with the potential evaporation and freezing heights inputs, produce streamflow ensembles by means of one or more hydrologic models. These ensembles will convey the uncertainty in the precipitation and temperature forecast, but will not include the uncertainties of the hydrologic model, which are relative to: the initial conditions, the model parameters, and the model structure. Various processors to explicitly account for the individual sources of hydrologic uncertainties and to simplify post-processing will be developed.

Hydrologic Model

For the foreseeable future, the hydrologic model will continue to be the model used at each of the RFCs (Sacramento or Continuous API). Once the distributed model is released for operational use, it will take over the role of forecasting streamflows from each set of forcing inputs.

Hydrologic Uncertainty Processors

Three different hydrologic uncertainty processors are envisioned to individually quantify: 1) the initial conditions uncertainty; 2) the model parameters uncertainty; and 3) the model structure uncertainty.

For the initial conditions uncertainty processor, the goal is to develop new data assimilation functionality to provide updated state variables for the ESP system. Therefore, it will reduce errors in the initial and boundary conditions and quantify the uncertainty. The current functionality needs to be enhanced to work for any point, including downstream forecast points and forecast points with upstream regulated flow. In addition, new data assimilation procedures are needed for ensemble forecasting to serve the Run Time MOD function used in deterministic modeling. Data assimilation enhancements include the automatic adjustment of the hydrologic model parameters in operational real time for all lead times and at the time steps that are relevant to the hydrologic model.

A new functionality is required to capture the propagation of long-memory errors and extremely non-linear errors for the parametric uncertainty processor.

Finally, a new structural uncertainty processor will be developed to account for the model structure errors.

Ensemble Post-Processor

Even though the input to the ensemble processor will be corrected for bias and spread errors, it is likely that the generated streamflow ensemble will have bias and errors of its own arising from the hydrologic uncertainties and errors of the ensemble processor. Indeed, the recent improvements of the ensemble pre-processor have shown the need to account for the hydrologic uncertainties and to implement the ensemble post-processor complementarily to the ensemble pre-processor in order to generate skillful streamflow ensembles.

The current post-processor prototype corrects bias and accounts for all the hydrologic uncertainties collectively and has a fully automated calibration component. It needs to be further evaluated since only limited experience has been gained. The robustness of the post-processor and the calibration parameters need to be improved. It is also necessary to better assess the data requirements for calibration and to develop an interactive calibration component. The post-processor enhancements also includes testing other approaches (e.g., perturbation approach, strict Monte-Carlo approach), which are required to maintain the temporal and spatial consistency for all forecast points and all variables. Finally the usefulness of post-processing needs to be demonstrated from the end-users' point of view, based on risk analysis.

The development of the post-processor will necessarily be carried out in stages. The post-processor takes into consideration in an implicit way the uncertainties in streamflow forecasts arising from initial conditions, model parameters and model structure. Once each of those contributions to the uncertainty is explicitly included in the ensemble processor, it will be necessary to modify the post-processor accordingly.

Reservoir, River Regulation, and Hydraulic Models

Before a streamflow forecast can be issued, it is necessary to account for the effect of reservoir operations and other river regulations, such as diversions from and returns to the streams. Reservoir operations generally follow some operating guidelines known as rule curves. In most cases, those rule curves allow enough flexibility to the operator to the point that it is essentially impossible to predict exactly, ahead of time, what the operator's actions would be. Similarly, river regulation presents an extremely complex problem, since water withdrawals and returns to streams may be subject to a web of water rights administration rules; the amount to be withdrawn is typically not known ahead of time. Returns to the river and stream/aquifer interaction may be subjected to pumping from the groundwater, etc. These factors typically do not play a role in flood forecasting, but are increasingly important for the cases of normal flow and drought forecasting. Therefore it is clear that the uncertainty from reservoir operations and streamflow regulations will have to be quantified to produce streamflow ensembles.

For the near future, the goal is to develop a new functionality to account for flow regulations that could be implemented for any forecast point. Accounting for streamflow regulation is currently one of the major limitations of ensemble forecasting. This is because the current ESP system could only be tested on basins modeled with the available res-J and res-SNGL options. The capability to estimate regulated streamflow needs to integrate all the available and usable data, including rules of operation for the flow regulation structures.

Hydraulic models are required to produce river stage and flow at un-gauged points and to provide all the information needed to generate probabilistic forecast maps. The hydraulic model of the NWSRFS, FLDWAV, uses some automatic "fix-up" procedures to deal with the problem of numerical stability which is common in most hydraulic models. The current procedures may distort the ensemble values. Therefore, it will be necessary to enhance FLDWAV to allow compatibility with ensemble processing. In addition, FLDWAV is computationally intensive. In order to run it operationally within the ESP system, some improvements are needed to obtain a consistent and workable compromise between efficiency and accuracy (e.g., longer time steps, fewer cross sections).

Probabilistic Verification

Another component of the ensemble prediction system is the ESP Verification System (ESPVS). It provides essential information to forecasters about forecast qualities and needed improvements, as well as to users about the most effective way to use the forecasts. Therefore the probabilistic verification system needs to support both operations and research.

The probabilistic verification system requires two different components: the retrospective verification based on a retrospective simulation of ESP forecasts and the forecast verification to provide information on the current probabilistic forecasts. Verification is needed for the forcing input ensembles and the river forecast outputs. The river forecast outputs generated from raw climatology need to be evaluated. To assess the performance of a given uncertainty processor of the ESP system, the ensemble forecasts both with and without running the uncertainty processor, need to be assessed. This ensemble verification will have to be performed for all lead times at any forecast point.

The retrospective verification is essential to provide a scientific basis for developing and using hydrologic ensemble forecasts. Since probabilistic verification requires a large sample size of probabilistic forecasts and observed events, the only possible way to get a large enough sample size for a given location is through retrospective ensemble forecasting. The current retrospective verification system needs to be enhanced to integrate all the uncertainties processors, from the pre-processor to the post-processor. This requires a statistical approach to simulate historical forcing forecasts because the forecasts used in the ensemble pre-processor may be available only for a limited number of years. Additional capability is also needed to study the scale dependency properties of forcing forecasts and river forecasts. Model calibration also is essential for the reliability of the forecast analyzed or scored in the ESP system.

It will be necessary to evaluate the key statistics to be selected from the existing verification procedures to develop more diagnostic verification measures. Furthermore user-friendly verification information needs to be developed and displayed in graphical format.

As is the case with the post-processor, the verification system will necessarily be developed in stages. One stage will follow each implementation of the pre-processor, processor and post-processor.

Ensemble Product Generation and Dissemination

The goal will be to develop and deliver useful end-products to all customers using the streamflow and streamflow-related ensemble forecasts produced by the ESP system for all lead times. The Ensemble Streamflow Prediction Analysis and Display Program (ESPADP) was initially developed to provide interactive analysis and display of ESP time series. New functionality is needed to provide the forecasters with quality control of ensemble products. Probabilistic forecasts in terms of ensembles require new end-products to be defined and delivered to the customers, especially since the probabilistic forecasts are helpful to numerous decisions based on risk analysis. Training is also required for forecasters and users given the fact that they are familiar with deterministic forecasts. Therefore, scientific training materials (technical documentation, and user's guides), will be developed to describe all the components of the ESP system and help forecasters and users to use the short- to long-term probabilistic forecasting services in the most effective way.

Conveying the concept of a probabilistic forecast is not a trivial task. The appropriate design of the user interfaces will ensure the success of any product. We will enlist specialists in Human Factors Engineering, specifically a Sociologist to design the most suitable user interfaces.

Architecture Management

To ensure processing integrity and faster science infusion, an architecture management function needs to be developed and implemented for NWSRFS. The purpose of this effort is to standardize data management and delivery (especially crucial for calibration and verification of the uncertainty processors), and to follow a structured development process. Use cases will be developed to help discover the complete operational requirements and requirements will be documented and used to develop more useable and maintainable software. The architecture management capability will be built on the completed Workflow Management System (WMS) that has demonstrated the ability to easily replace CRON or manual startup of applications, and to provide a flexible workflow configuration and a logging capability to track status of implementations. This architecture management component is essential to control and unite the developments and enhancements of the different ensemble system components.

Training

Workshops, tele-training and class-room training will be provided to support the implementation of new science and technology. This will ensure that those involved in the support and operation of the program have a sound understanding of system enhancements and upgrades

Flood-Forecast Mapping Services

Introduction

Flood-Forecast Mapping Services are partnered services that add graphics, animation, GIS and possibly other information display techniques to the flood forecast capability. For example, an animation capability will allow an event scenario to be reviewed through the short-, medium-, and long-term forecast horizons as appropriate. The partnered services are financed by both federal and other funding sources such as sate and local governments. Key system components for providing flood forecast maps are shown in Figure 5.

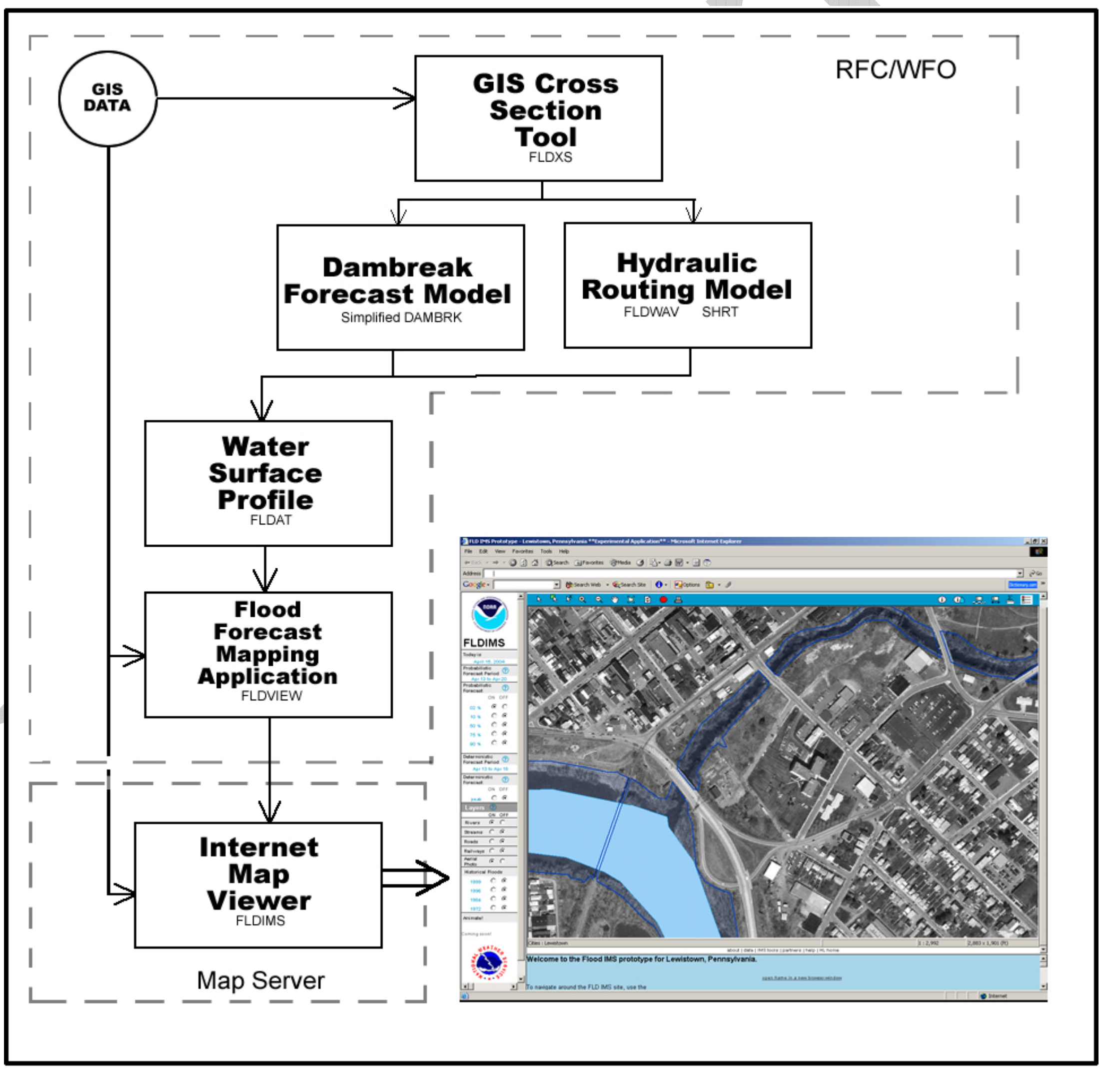

Figure 5 – System Components for Flood-Forecast Mapping

The methodology used to implement flood-forecast mapping services will depend on the need and available resources in an area. This may range from a single sheet map depicting flood inundation areas to real-time flood-forecast maps using advanced hydrologic and hydraulic models with high resolution GIS and hydro-meteorological data sets to include more detail on the location and magnitude of an event.

GIS data is available for the entire country from various sources on the World Wide Web. Ground elevation data can be obtained from the USGS National Elevation Dataset (NED). This data is available at a 30 meter resolution. Higher quality data is available for most locations from varying sources. The flood forecast mapping application, FLDVIEW, is automated to produce flood forecast maps using USGS 30m data and other higher resolution data types. River reach data is available from the USGS' National Hydrography Dataset (NHD). Other types of data include U.S. Census Tiger shape files which add layers like roads, USGS DOQQs showing aerial images, and CAD data containing many layers of detailed survey information like structures and railroads. NWS Flood-Forecast mapping tools utilize these various data types along with NWS forecasts to obtain a visual representation potential and actual flood inundation.

Flood-Forecast Mapping Activities

Figure 6 shows the proposed sequence of enhancements for Flood-Forecast Mapping, with the approximate delivery to WFOs/RFCs. The finial schedule is dependent on allocation of resources and success during the research, analysis and operational development phase.

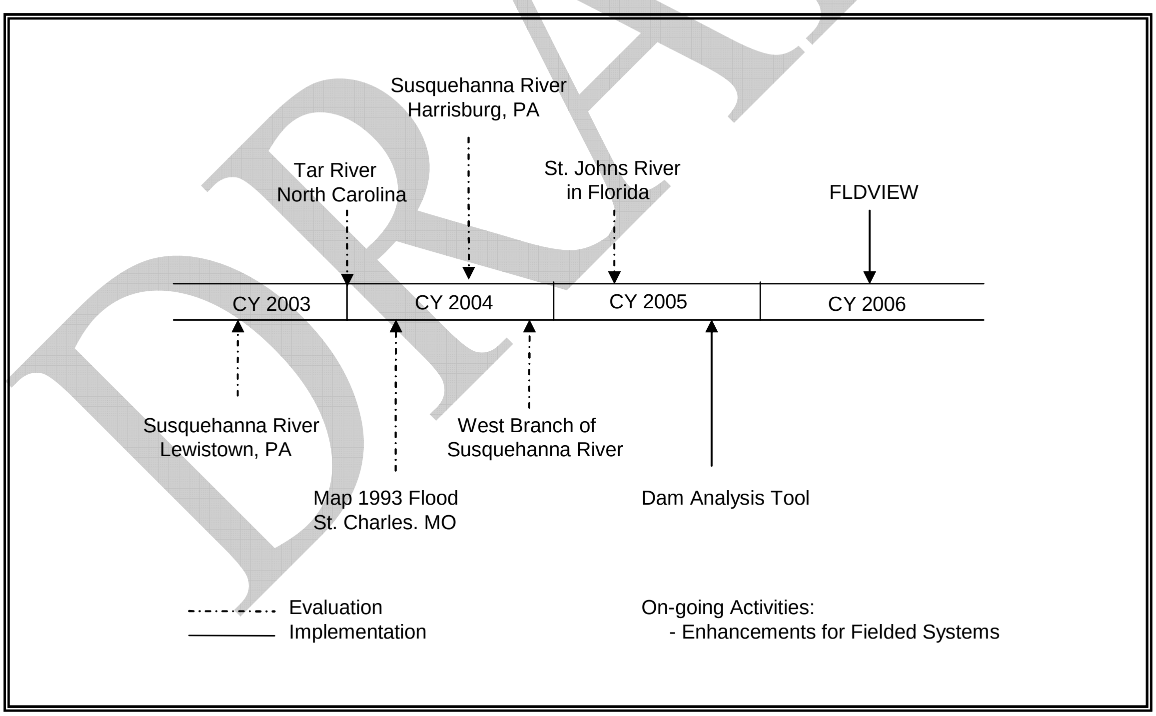

Figure 6 - Envisioned Sequence of Enhancements

Flood-Forecast Map Evaluations

Evaluations will be conducted to test the flood-forecast mapping application, FLDVIEW to address issues of accuracy and data requirements. This will include validation for FLDVIEW operations as additional functions are added to support more complex areas to be mapped.

Susquehanna River, Lewistown, PA - Operational implementation of FLDVIEW at Lewistown, PA (development of fully automated process of generating FLDVIEW input within NWSRFS, generating flood map with FLDVIEW and exporting the flood maps to the server which are displayed using FLDIMS).

Tar River, North Carolina – Provide graphical representation of peak forecast inundation for a 73 river miles of the Tar River from Rocky Mount, North Carolina to Greenville, North Carolina. User feedback is being solicited from January to November, 2004.

West Branch of Susquehanna River - Operational implementation of FLDVIEW on the West Branch of the Susquehanna River which has five towns (evaluate the ability to map multiple areas and fine-tune the process).

Susquehanna River, Harrisburg, PA - Operational implementation of FLDVIEW on the Susquehanna River in the vicinity of Harrisburg, PA. This will be a full blown application of FLDIMS to display potential products on the web.

Map 1993 Flood, St. Charles, MO - Generate flood-forecast map of the 1993 flood for St. Charles, MO area to test the limitations of FLDVIEW (mapping a flat area with failed levees) and to evaluate the quality of the flood map when the quality of the Digital Elevation Model (DEM) data was different (USGS 30 m DEM vs. 3 m DEM).

St. Johns River in Florida - Generate flood-forecast map of St. Johns River in FL to test the limitations of FLDWAV in coastal areas. Also, integrate flood-forecast map with forecast coastal grid to have one flood-forecast map which represent both the river and coastal area.

FLDXS

FLDXS is a geographic information system (GIS) application which generates cross section profiles and tables containing elevation information of cross sections along a river using ESRI's ArcView and its extensions (Spatial Analyst and 3-D Analyst). The development of cross section information in FLDXS involves four activities:

- Drawing or importing a river centerline using USGS 1:24000 maps;
- Drawing cross sections along a reach;
- Determining elevations along cross sections using ground grids (digital elevation models); and
- Creating cross section elevation profiles and exporting the cross section elevation tables combined as text file.

The processes are being automated so the user is not required to have extensive knowledge of any particular GIS.

FLDVIEW

A flood-forecast mapping application, FLDVIEW will visually display the flood inundation areas at various forecast points. The current technique has been developed and tested on the Juniata River at Lewistown, PA.

Real-time flood-forecast maps can be generated using water surface profiles from any hydraulic routing model. NWS uses either the Simple Hydraulic Routing Technique (SHRT) model or with a dynamic routing model such as FLDWAV. Dam break flood-forecast maps can be generated using output from the Simplified Dam Break (SMPDBK) model.

Hydraulic Models

Simple Hydraulic Routing Technique (SHRT) - The SHRT model is a unified coefficient routing method which can emulate several hydrologic routing methods currently in NWSRFS. Because it can use routing parameters from existing hydrologic models, the need for calibration is often eliminated. It should only be applied to areas where backwater effects are minimal.

Dynamic Routing Model - A dynamic routing model such as FLDWAV can handle a variety of hydraulic conditions including backwater, the effect of hydraulic structures (e.g., dams, bridges, levees), and various flow regimes (i.e., subcritical, supercritical, critical, and mixed). Dynamic routing models must be calibrated at least once.

Simplified Dam Break (SMPDBK) – The SMPDBK model allows the user to store and view dam information for various dam break scenarios.

FLDIMS

FLDIMS is an Internet based application built using Autodesk MapGuide. The application overlays flood inundation shape files over geographic data layers showing aerial photographs, roads, structures, and other relevant information. It is hosted on a web server for assessment by government agencies, emergency management personnel and the general public. As forecasters generate daily forecasts, the shape files can be uploaded to the server for viewing. The viewer has basic functionality found in GIS applications including zoom, feature selection and layer activation.

FLDAT

The NWS FLDAT program was developed as a set of enhancements to the existing FLDINP program, which provides the user a visual workspace where Flood Wave decks can be built. These enhancements not only improve the building of Flood Wave decks, but allow for these decks to be tested and the results analyzed. FLDAT outputs a water surface profile which is used in flood-forecast mapping to show the depth of water.

The creation of Flood Wave decks is improved by allowing the user to now import the river and cross section information from files using the HEC-2 and HEC-RAS data formats defined by the US Army Corps of Engineers. Once the deck has been defined, the FLDAT program provides the ability to launch the stand-alone FLDWAV executable on this data set. The output produced from this FLDWAV process can then be loaded and analyzed graphically through a series of profile and hydrograph displays that are available for a significant portion of the output data. These graphics are a superset of those provided by the Unix FLDGRF program.

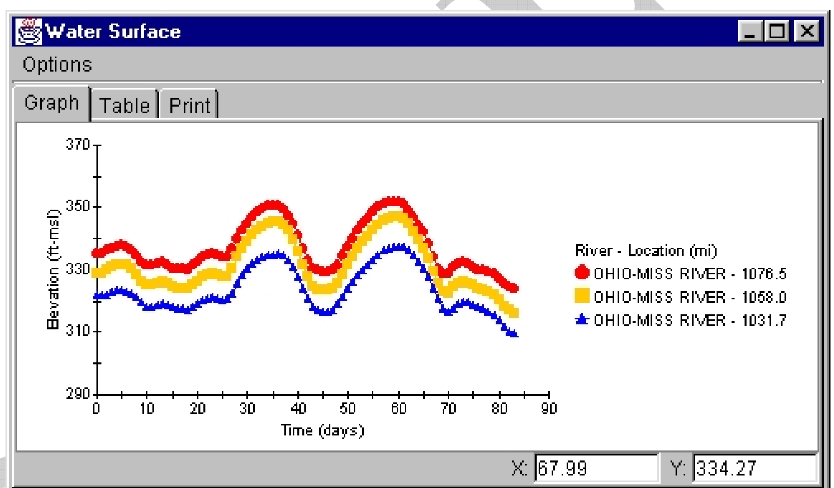

Figure 6.2 - Water Surface Profile generated by FLDAT

DamAT

DamAT is a methodology that implements supporting software to allow forecaster to generate a dam failure forecast in a relatively short period of time (~15 min). DamAT is a Graphical User Interface (GUI) which integrates three applications to meet this goal:

1) FLDXS – an ESRI ArcView application used to quickly obtain the cross section data needed by DAMCREST
2) DAMCREST- a simplified dam break GUI which imports dam information from the National Inventory of Dams (NID) and cross section information from FLDXS, generates a dam failure forecast, and export the data needed for a flood forecast map

3) FLDVIEW - and ESRI ArcView application which maps the extent of flooding using the output from DAMCREST, FLDWAV, or other hydraulic routing models.

Training

Workshops, tele-training and class-room training will be provided to support the implementation of new science and technology. This will ensure that those involved in the support and operation of the program have a sound understanding of system enhancements and upgrades

Collaborative Research

The AHPS program is reaching out to the research community to assist NOAA in meeting program goals and objectives. With this purpose the NWS has sought proposals from academic institutions, research organizations and other federal agencies. This effort engages others in basic and applied research to improve the scientific understanding of river forecasting. Ultimately the efforts will improve the accuracy of forecasts and warnings of rivers and flash floods by applying the most contemporary scientific knowledge and information to NWS research methods and techniques, resulting in a benefit to the public.

For this purpose, NOAA has sought proposals in the following areas:

Hydrometeorologic Science Priorities

A quantitative precipitation estimation and hydrometeor identification using remote and in-situ observations; methods for estimating and predicting precipitation, temperature, or evapotranspiration, especially in remote or mountainous terrain forecasting capability will be a high priority. Forecasts may be deterministic, probabilistic, or ensemble; methods for automated quality control of rain gauge or radar data; use of Numerical Weather Prediction (NWP) models; and downscaling and rescaling of NWP output to scales relevant to hydrologic forecasting.

Hydrologic Modeling Priorities

The development of advanced methods of calibrating conceptual and physically based rainfall/runoff models also are a priority. These include the development of distributed modeling approaches, including:

- Parameterization of distributed rainfall/runoff models and channel flow models; the use of distributed models for simultaneous simulation at both parent outlets and interior points for flash-flood forecasting, conceptual and physically-based rainfall/runoff models, and analysis of variability of precipitation and basin physical features and subsequent effects on hydrologic processes.

- Cold season processes: this area includes conceptual and energy budget snow models, effects of ice and frozen ground on the rainfall/runoff process, cold season process modeling in a distributed modeling context.

- Parameterization of lumped and distributed models. Verification of deterministic and probabilistic river forecasts.

- Quantification of uncertainty in river forecasts including ensemble methods.

- Data assimilation methods for lumped and distributed models; Development and enhancement of land surface components of numerical weather prediction models.

- Use of numerical weather and climate model output for deterministic and probabilistic long-term seasonal and interseasonal water resource forecasts.

- New techniques for flash-flood modeling based on lumped or distributed modeling.

River Mechanics Priorities

Accounting for hydraulic conditions using unsteady-flow dynamic routing for real-time flood/river forecasting including sediment transport, pollutant transport, river ice modeling, channel losses, modeling the effects of hydraulic structures, reservoir modeling, mud/debris flow modeling, and dam failure modeling; improving probabilistic river forecasts; developing practical updating capabilities; and flood-forecast mapping are high priorities for collaborative research contributions to the NWS River Forecast System (NWSRFS).

AHPS Performance Measures

The NOAA has developed a set of metrics to measure the forecast improvements resulting from AHPS implementation. The Government Performance and Results Act (GPRA) and non-GPRA performance metrics to measure success are depicted in Figure 7 below:

Metric		Baseline	Target
GPRA	Flash-flood warning lead time (minutes) - Contributes to the protection of life and property	41 (2003)	54 (2010)
	Flash-flood warning accuracy (%) - Contributes to the protection of life and property	89 (2003)	91 (2010)
Non-GPRA	AHPS forecast locations (#) - Increases information to manage water resources	717 (2003)	4,011 (2013)
	River Flood Warning Accuracy (%) - Leads to increased confidence in forecasts	TBD (2005)	TBD
	New Science Operations (%) - Science enhancements implemented into operations	TBD (2005)	24% (2006)
	Probabilistic Forecast Reliability (%) - Leads to increased confidence in forecasts	TBD (2005)	TBD (2013)

Figure 7 - GPRA and Non-GPRA Performance Metrics

Risks & Risk Management

Risks

Risks must be addressed to ensure program requirements are met. Programs may not be successful when implementation tasks are met following misunderstood needs. This risk exists when leadership develops capabilities based upon perceived field needs rather than true requirements. This disconnect can be exacerbated by the following reasons:

- A fairly substantial amount of the science requires further research before it can be developed into robust operational tools. This almost ensures changes to what is to be developed.
- The products and information are being developed autonomously at multiple locations. This almost always ensures disconnects in understandings.
- Maintaining compatibility with other NWS, NOAA programs and systems
- Meeting the needs of partners, cooperators, and public and private users for water resource information

The collaborative approach to a more robust implementation strategy is necessary and risky. Change is inevitable and yet must be managed to ensure success. Lastly, AHPS must integrate into and form the basis of the NOAA water resource management and prediction services.

Risk Management

Identification of risks is the first step towards risk management. The second step is the identification of risk mitigation activities to eliminate or at least minimize their impact on the program. For this cause, the NWS has instituted and developed two such activities that will address the risk issue. They are:

- The AHPS Review Committee (ARC) – The ARC is a committee of senior headquarters and field personnel who meet twice yearly to review progress, set direction and expectations, and address conflicting understandings and priorities; and

- The Hydrologic Operations and Service Improvement Process (HOSIP) – The NWS is in the process of defining and implementing a requirements based process to structure the way new science is developed and infused into field operations.

- AHPS advisory committee composed of interagency representatives and the university/research community to assure AHPS is meeting the needs of users and the general public.

The ARC provides a mechanism to ensure an NWS agreement on direction and concept. HOSIP, because it is requirements based, provides a mechanism to document requirements at a very detailed level and defines what is going to be developed as a tool to obtain all stakeholder agreement throughout the entire development life cycle. The two risk management activities maximize the NWS ability to ensure the risks are mitigated.

Another activity to mitigate and minimize misunderstood requirements is to implement an AHPS Advisory Committee (AOC) composed of RFC Hydrologists-in-Charge and WFO Service Hydrologists.

Appendix I

Field Services Implementation

River and flood forecasts and probabilistic outlook information are now provided for approximately 3,400 locations. Of these locations, AHPS information was available at 717 locations by the end of Fiscal Year (FY) 2003.

AHPS models will be calibrated when implementing services. In addition, new models (new science) will be implemented for AHPS forecast locations, where appropriate and when verified for NWS operations. This approach extends AHPS benefits to new areas while promoting simultaneous implementation of the advanced AHPS services and minimizes delay to help emergency managers save lives and property. The strategy also enables the deployment of "enhanced" and "partnered" services during the life of the program.

Goal: Deliver new river, flood and drought forecast information through the infusion of new science and technology. This information is provided to National Weather Service (NWS) customers as web-based forecast information from minutes to days to months. The web-based information contains displays for the magnitude and certainty of occurrence of water quantities ranging from floods to droughts. The NWS will provide Advanced Hydrologic Prediction Service (AHPS) forecast information throughout the Nation at 4,011 locations by 2013.

Performance Gap: The National Oceanic and Atmospheric Administration's Hydrology Program meets the basic hydrologic service needs of its customers and partners. River and flood forecasts and outlook information are now provided for approximately 3,400 locations. Of these locations, AHPS information was available at 717 locations by the end of FY 2003. The increase in number of forecast locations from 3,400 to 4,011 with AHPS information may be provided through new calibrations or distributed modeling capabilities.

Schedule: AHPS will be deployed using the following schedule. The schedule considers the AHPS goal and the availability of new (verified) science.

	Base	New Service Locations	Total	Table 1. AHPS Operational Forecast Locations														
				FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	Total
Alaska Pacific Region																		
APRFC	103						1	6	8	12	12	12	14	14	14	10		103
		19	122													4	15	19
Western Region																		
CBRFC	262						20	28	29	29	29	29	29	29	30	10		262
		48	310													19	29	48
CNRFC	184						13	17	20	21	21	21	21	21	21	8		184
		34	218													13	21	34
NWRFC	404						12	16	50	50	50	50	50	50	50	26		404
		75	479													24	51	75
Southern Region																		
ABRFC	268					7	20	51	34	34	34	34	34	20				268
		49	317												16	16	17	49
LMRFC	207							25	27	27	27	27	28	28	18			207
		38	245												10	14	14	38
SERFC	217					3	10	34	26	26	26	26	26	26	14			217
		40	257												13	13	14	40
WGRFC	314							33	37	37	37	38	38	38	38	18		314
		58	372												19	19	20	58

AHPS Operational Forecast Locations (continued)

	Base	New Service Locations	Total	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	Total
Central Region																		
MBRFC	505					45	26	23	56	56	56	56	56	56	56	19		505
		93	598										18	18	19	19	19	93
NCRFC	366			27	79	72	112	49	27									366
		67	433										13	13	13	13	15	67
Eastern Region																		
MARFC	171					3	60	72	17	10	9							171
		31	202										6	6	6	6	7	31
NERFC	130					14	20	24	23	21	19	9						130
		24	154											6	6	6	6	24
OHRFC	257				56	45	72	41	32	11								257
		47	304										9	9	9	10	10	47
Total	3,388	623	4,011	27	135	189	366	419	386	334	320	302	342	334	352	267	238	4,011
Cumulative Forecast Locations					162	351	717	1,136	1,522	1,856	2,176	2,478	2,820	3,154	3,506	3,773	4,011	