Advanced Hydrologic Prediction Service (AHPS)

Strategic Requirements Document

August 25, 2006

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1 Introduction

1.1 Background

The continual improvement of fresh water forecasting, analysis, and decision making tools and the provision of associated hydrologic information are crucial to the nation's well-being and interest as well as the future of our commerce. Increasing customer needs and improving technologies offers NOAA's NWS a challenge to provide improved and expanded information for managing the waters of the United States. The Advanced Hydrologic Prediction Service (AHPS) is the NWS program to meet that challenge by modernizing its hydrologic forecasting service and expanding it with new capabilities. AHPS features new science and technology that will make available new and better decision making tools. Regional and local forecasts of floods, drought, snowmelt, river flow, soil moisture content, and inflow to coastal estuaries will enhance the management of the nation's waters. 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 accurate 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 implementing improved hydrologic science in our current operations, developing and 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 provides an enhanced and comprehensive set of tools and information in the following areas to help decision makers make informed decisions.

1. Flash flood forecast services
2. Short- to long-term forecasts including low-flow and drought information
    - Improved deterministic forecasting
    - Probabilistic forecasting
3. Flood forecast mapping at selected locations and graphical dissemination services

1.2 AHPS Implementation Strategy

AHPS forecasting services will be provided to customers as "Flash Flood Forecast" "Short- to Long-Term Forecast" and "Flood Forecast Mapping and Graphical Dissemination" Services. The implementation strategy is to provide immediate benefit to customers by expanding and improving existing forecast services and support a parallel effort of development and implementation of new (verified) science into operations. These categories of services are defined as:

- Flash Flood Forecast Services
    - Implement enhanced analysis, forecasting, and decision making capabilities at appropriate AHPS forecast locations or Hydrologic Services Areas
- Short- to Long-Term Forecast Services
    - At all AHPS forecast locations: provide enhanced forecast information including observed and forecast river levels and/or flow, when available, in graphical format.
    - At appropriate AHPS forecast locations: provide long-term probabilistic forecast information
    - At water supply AHPS forecast locations: provide probabilistic water supply volume forecasts in a standardized format
    - At appropriate AHPS forecast locations: provide short- to long-term probabilistic forecasts which include low-flow and drought information
- Flood Forecast Mapping and Graphical Dissemination Services
    - Implement static graphical E19 and static map inundation library capabilities and/or dynamic real-time inundation mapping capability at most appropriate AHPS forecast locations through partnered development and financing by both federal and other funding sources such as state and local governments.
    - Provide enhanced access to a broader suite of improved hydrologic information, primarily via the web.

1.3 Field Services Implementation

River and flood forecasts are now provided for approximately 3,550 locations. Of these locations, both graphical hydrographs and appropriate probabilistic forecast information are available at approximately 1360 locations. By the end of implementation, graphical hydrographs and appropriate probabilistic forecast AHPS information will be available for 4,011 forecast locations. The increase in forecast locations is attributed to a combination of adding new streamgage forecast locations and expanding the number of ungaged forecast locations through distributed modeling.

1.4 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 graphical hydrographs and appropriate probabilistic forecast AHPS information and the expansion to additional sites. This schedule, however, is a function of available resources. In recent years a portion of AHPS funding has been redirected to the Susquehanna River Basin Flood System and/or address NWS budget issues. Any redirected resources will adversely impact AHPS scheduled deployment. Appendix II depicts the 2005 status maps for each the different AHPS services.

AHPS and other NWS hydrologic programs (e.g., HADS, precipitation frequency, etc…) 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.

Another NWS hydrologic program is the Fiscal Year 2006 Water Resources Plan (WRP). The WRP will develop a nationwide water resources forecasting capability. Through this capability, NOAA will provide America with economically valuable high resolution water resource and soil condition forecasts. WRP builds on AHPS by advancing a national hydrometeorological digital database and the Community Hydrologic Prediction System (CHPS). Component prototypes of both the digital database and CHPS are included as part of AHPS.

A complementary program to the NWS hydrologic program is NOAA's Environmental Real-time Observational Network (NERON). The Hydrology program requirements for real-time data from NERON include 5-minute precipitation data; hourly soil moisture and soil temperature data; daily ground water data; 5-minute streamflow data; hourly snow depth, cover and water equivalent data; 5-minute meteorological data; and hourly water quality parameters. Improved data sources identified in NERON would increase the benefits provided by AHPS. However, the implementation of the AHPS Program Plan assumes only existing real-time data sources are available. For this reason, AHPS funding is directed to science development and new services implementation activities and not on the development of new data sources.

1.5 Document Purpose and Structure

This document provides an overview of the Advanced Hydrologic Prediction Service (AHPS) and serves as a guide for the AHPS Program. Specifically, this document identifies the requirements necessary to meet and implement the Advanced Hydrologic Prediction Services Concept of Services and Operations (April 2002). The document defines in total the science development and service implementation activities that constitute AHPS as they are currently known.

It is envisioned that this document will serve as a tool to assist the AHPS budget theme teams in the annual task and budget prioritization process. The budget theme teams will be able to use this document to identify priorities and dependencies of the many tasks and allocate resources appropriately. The document will also be useful to identify any gaps in funding and needed science and implementation. As a task is funded through the AHPS budget prioritization process, the task will be entered into the Hydrologic Operations and Services Improvement Process (HOSIP) and tracked in both this document and HOSIP. Those tasks which require broader NWS resources for implementation (e.g. via AWIPS), will also be entered into the Operations Service Improvement Process (OSIP).

The AHPS Program Plan is a living document and will be modified as science and technologies mature and as user requirements become known or change. The document will also be modified to accurately track the status of the specific tasks. The document will be reviewed and updated annually to reflect the current state of AHPS and provide a road map for future implementation.

Each requirement identified throughout the document essentially has five components for successful completion. These components include:

- Develop methods and procedures to meet the requirement,
- Prototype and validate the developed methods and procedures in an operational environment,
- Implement the methods and procedures into operations through standard AWIPS delivery mechanisms,
- Document the operational methods and procedures,
- Train the users on the new operational methods and procedures.

These five components for each requirement will be tracked in the accompanying AHPS Program Plan spreadsheet. For brevity these five components for successful implementation are not included with each requirement in this document.

2 Flash Flood Forecast Services

Through AHPS Flash Flood Forecast Services, the NWS will deliver more specific and timely information on fast rising rivers and in areas prone to flash flooding. NWS forecasters will be provided analysis, forecasting and decision assistance 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. Flash Flood Forecast Services are to be implemented at appropriate AHPS forecast locations or Hydrologic Services Areas.

2.1 Operational Concept of Flash Flood Forecast Services

To meet the forecast challenges posed by flash floods, AHPS provides a comprehensive set of products and information to afford 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 NOAA's Weather and Water Hydrology Program Operating Plan. AHPS also will augment conventional text-based flash flood warnings and related products, with graphical watch/warning products and information.

Service enhancements will be realized through the use of an enhanced Flash Flood Monitoring and Prediction (FFMP) system which includes expanded and improved precipitation and guidance inputs. The precipitation inputs will include super high resolution radar data (1/4km by ½ degree), rectilinear gridded multi-sensor quantitative precipitation estimates (MPE), and short-term quantitative precipitation forecasts (QPF). Precipitation inputs must be on the highest spatial and temporal resolution possible of at least 1km^2 and a refresh rate of every 5 minutes. The real-time provision and use of high-resolution and rectilinear multi-sensor precipitation estimates should enhance the utility of FFMP in areas of limited radar data. For those WFOs with multiple dedicated radars, only one instance of FFMP will be required with the gridded multi-sensor precipitation data source. The forecaster will have the capability to choose the desired precipitation input for monitoring and prediction. A multiple guidance capability will be provided to allow the forecaster to monitor debris flow as well as monitor with alternate and improved flash flood information. Near-term improvements to Flash Flood Guidance will be realized through modest improvements to the FFG system performance as recommended by the Flash Flood Guidance Improvements Team. Mid-term improvements to flash flood information will be realized through the implementation of the relative flash flood potential index and the statistical distributed model. Other improvements to flash flood information will be realized through the planned improvements of the deterministic forecasting capabilities including the development to support continued implementation of lumped model forecasting and ultimately from implementing a distributed hydrologic model (see Section 3.1).

Service enhancements will also be realized through the enhancements to the Site Specific Hydrologic Predictor (SSHP). The enhancements for the SSHP include providing the tools necessary to support the model calibration at the 1 hour temporal resolution and smaller spatial resolution of the SSHP/SAC-SMA model (i.e., AB_OPT functionality), variational assimilation capabilities, snow modeling capabilities, and routing capabilities. Service enhancements may also be realized through the evaluation and operational implementation of other fast-responding hydrologic forecast models.

Additional service enhancements will be realized through the automation and implementation of hydraulic modeling and analysis tools. These tools will give forecasters the capability to provide timely and accurate watches and warnings for locations downstream from dams in the event of dam failure or imminent indication of a dam failure.

Advanced distributed hydrologic models, dam failure analysis tools, and processing of high resolution Geographic Information Systems (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 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.

2.2 Current Capabilities of Flash Flood Forecast Services

The primary tool for assisting WFOs in predicting flash floods is the FFMP system. FFMP provides a visual comparison of radar precipitation to Flash Flood Guidance (FFG) to identify areas of flash flooding risks. The ability of FFMP to identify areas of flash flood risk is directly related to the skill of the radar precipitation estimates and FFG inputs. Both inputs have shortcomings and are not appropriate to use in all locations. Radar derived precipitation estimates are not available for all locations and FFG is not appropriate for regions where the dominate flash flood factors are rainfall intensity and physiographic features (e.g. significant slope and/or impenetrable soils). Additionally, FFG is typically computed from models calibrated for RFC scale river flooding and may not be appropriate for the small scale basins of flash floods. With forecaster oversight, FFMP should automate and streamline the process of identifying areas of flash flood risk to actually producing flash flood watches and warnings.

The SSHP, operationally available to WFOs, 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 SSHP was recently enhanced to include the SAC-SMA soil moisture accounting model. The SSHP has limitations in the procedures to calibrate and maintain model states that need to be addressed before it becomes an operational solution. Additionally, the current SSHP cannot model basins with snowmelt or downstream basins requiring routing.

For flash floods caused by dam breaks RFCs and WFOs have access to the Dambreak Catalog Reviewer and Estimator (DAMCREST). DAMCREST is essentially a graphical user interface that allows the forecasters to create and analyze flash flood scenarios with the use of the simplified DAMBREAK model with a catalog of reference inputs. Currently, the operational validity of the Dambreak Catalog and the simplified hydraulic models used in these tools are being analyzed. Additionally, the operational framework policy between RFC and WFO on dam break analysis and warning issuance is being updated.

2.3 Requirements to Provide Improved Flash Flood Forecast Services

Enhancements to the hydrometeorological and Flash Flood Guidance inputs that drive FFMP are needed to improve the lead time and accuracy of flash flood warnings. Grid based multi-sensor precipitation estimates must be available at the finest spatial and temporal resolution. Enhancements to radar technologies (e.g. dual-polarization, low tilt angles, etc.) and precipitation estimation algorithms will improve precipitation estimation. FFG performance must be enhanced as identified by the Flash Flood Guidance Improvement Team. New technologies for estimating FFG should be explored such as CBRFC's relative Flash Flood Potential Index, the Hydrology Lab's Statistical Distributed Model, and distributed hydrologic models.

Additionally, a multitude of FFMP enhancements are needed to improve operational flash flood prediction and warning services. These enhancements include providing FFMP service backup among WFOs; using higher resolution QPE from radar, gage and satellites as well as short-term QPF; adding multiple monitoring time-frames and thresholds; adding user selectable precipitation source; and adding the capability to monitor multiple guidance values. FFMP should be integrated into the Next Generation Warning Tool where basins or groups of basins are easily identified and selected to quickly produce flash flood warnings. To increase the ability to provide more timely and specific stream based information the SSHP must be enhanced to include snowmelt runoff modeling and routing capabilities. Additionally, the calibration and maintenance of model states in the SSHP must be streamlined and automated. Other hydrologic forecasting models should be evaluated for their suitability for NWS flash flood forecasting operations. For flash floods caused by dam failures, hydraulic modeling and analysis tools must be streamlined, automated and implemented in the operational framework of RFCs and WFOs.

2.3.1 Quantitative Precipitation Estimates/Short-Term QPF

The operational requirements for Quantitative Precipitations Estimates (QPE) and short-term QPF are to provide accurate precipitation estimates and forecasts at the highest spatial and temporal resolution. Precipitation estimates and short-term precipitation forecasts are driving inputs for FFG, FFMP, Statistical distributed, and SSHP models. Since the deployment of the WSR-88D network, radar-based flash flood prediction has focused on interpreting information from single radars. 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. However, now Multisensor QPE (MPE) ingests radar, rain gage, and satellite observations and synthesizes gridded precipitation fields based on input from a combination of these sources. The MPE estimates show promise in flash flood forecasting applications because they provide forecasters seamless precipitation fields using data from the nearest radars, as well as ancillary data from gages and satellites. In addition to the OHD efforts in MPE, a parallel precipitation estimation effort, National Mosaic and Multi-sensor QPE (NMQ), has been underway at NSSL.

Improvements to precipitation estimation can be made by improving the source of data, improving algorithms to estimate precipitation, and quantifying the uncertainty associated with rainfall estimation and forecasts. Improving the precipitation estimation source data includes using dual-polarization radar estimation algorithms, adding Terminal Doppler Weather Radar (TDWR) data, and adding the Canadian Radar System data to precipitation estimation methods. The requirements to improve precipitation estimation algorithms include tasks in the Precipitation Processing Sub-system (PPS), MPE, and NMQ. Additionally, the parallel effort of precipitation estimation (MPE and NMQ) must be resolved by first creating the next generation QPE (Q2) which will glean the best practices of the two precipitation estimation algorithms and provide a clear operational framework for the use of Q2. Short-term QPF must be enhanced to include radar-based statistical extrapolative methods as well as multi-sensor nowcaster methods. The final improvement to precipitation estimation and forecasting will be realized by quantifying the uncertainty of these estimates. This uncertainty information must be known to give a forecaster confidence in issuing flash flood watches and warnings.

1. Improving precipitation source data
    a. Improve Quantitative Precipitation Estimation Algorithms by including Dual-polarization radar estimation algorithms.
        i. Adapt NEXRAD Precipitation Processing System (PPS) for dual polarization radars.
    b. Improve Quantitative Precipitation Estimation Algorithms by including Terminal Doppler Weather Radar (TDWR) data.
    c. Mitigate the effects of bright-band contamination by providing Range Corrections and Convective Stratiform Separation capabilities into the WSR-88D and AWIPS MPE systems.
    d. Distribute Digital Hybrid Reflectivity (DHR) and Digital Storm Total Precipitation (DSP) products in real-time to all WFOs with CWAs covered by the radar
2. Improve precipitation estimation and forecast procedures
    a. Upgrade the NEXRAD PPS so that it can support multiple new Volume Coverage Patterns (VCP), negative elevations, higher resolution data from the RDA, and migration to Linux
    b. Evaluate NSSL's National Mosaic of QPE (NMQ) as input to FFMP
        i. Establish computing hardware and infrastructure at NWS facilities to support NMQ generation for ingest by FFMP.
        ii. Create and disseminate NMQ products on a Cartesian grid of 1-km resolution updated every five minutes for ingest by non-radar centric FFMP applications.
        iii. Create and disseminate one-hour statistical extrapolative QPF on a Cartesian grid of 1-km resolution updated every five minutes for ingest into FFMP.
    c. Enhance the MPE to support WFO Flash Flood Services.
        i. Integrate existing Western Region Mountain Mapper Daily QC functionality and OHD MPE application functionality into a single set of nationally supported operational applications.
        ii. Integrate existing ABRFC P3 and OHD MPE application functionality into a single set of nationally supported operational applications. This includes alternate methods for generating multi-sensor precipitation

and additional interactive quality control methods including a more powerful polygon edit feature.

iii. Integrate satellite information into MPE calculations
iv. Improve speed and efficiency of MPE field generating processing to facilitate more frequent runs, and for time spans shorter than one hour.
v. Provide the forecaster graphical editing tools to quality control and edit the point data and gridded precipitation estimates in order to produce the highest quality point gage data and gridded fields.
vi. Provide automated mosaicking of radar estimates.
vii. Provide automated rain gauge quality control
viii. Increase MPE space/time resolution to 1 degree x 1 km and less than 1 hour precipitation refresh; Enhanced MPE (EMPE)
ix. Enhance the rainfall nowcasting algorithm to produce short range (0-3 hours) regional, multi-sensor gridded precipitation forecasts using MPE-WFO products; Multisensor Precipitation Nowcaster (MPN).
x. Integrate HydroView in D2D
xi. Provide North-American Scale Remote Sensor Precipitation Estimator capability

d. Develop the next generation of precipitation estimation (Q2) that promotes the best features of OHD and NSSL's multi-sensor precipitation estimation methods.
   i. Conduct an assessment/inter-comparison of the two multi-sensor precipitation estimation methods.
   ii. Develop a collaborative Q2 precipitation estimation (TAR River Basin Project)
   iii. Enhance Q2 to address outstanding operational, science, and science-to-operations needs for QPE
   iv. Provide operational testing of Q2.
   v. Provide operational framework that identifies the role of the WFO, RFC and NSSL in the production and use of next generation precipitation estimation.

3. Quantify precipitation estimation uncertainty
   a. Develop radar-based Ensemble/Probabilistic Quantitative Precipitation Estimation (PQPE) as a measure of the uncertainty of Quantitative Precipitation Estimation and support operational decision making.
   b. Provide a measure of uncertainty in the manually produced HPC 6 and 24-hour Quantitative Precipitation Forecast. (complete)

2.3.2 Flash Flood Guidance

The operational concept is for RFCs to provide meaningful Flash Flood Guidance to WFOs to assist with the localized issuing of Flash Flood Watches and Warnings. The RFCs have the tools to issue Flash Flood Guidance (FFG) operationally. However, the performance of this tool has limitations and may not be appropriate in all regions, specifically the Western region. Efforts are ongoing at the national, regional and local levels to improve FFG system performance. The

National Flash Flood Guidance Improvement Team (FFGIT) was chartered to determine what steps could be taken to improve the state of Flash Flood Guidance. The following recommendations were made by the FFGIT:

1. Improve FFG System Performance
    a. Remove threshold runoff information gaps inside a single RFC's area of responsibility
    b. Fix overlapping values of FFG along the shared border between neighboring RFCs.
    c. Fix inconsistent gridded FFG across adjacent RFC boundaries.
    d. Create Tools to manually edit FFG product before dissemination
    e. Improve gridded Threshold RunOff (TRO) derivation
2. Enhance Archive of critical FFG data
    a. Improve Storm Data archived information to include corresponding RFC and more specific county/river basin location if available.
    b. Utilize all available information from existing USGS gage networks including the existing crest-stage gage network used to establish flood frequencies of small streams and include in Storm Data.
    c. Archive both RFC precipitation input used to determine FFG and WFO precipitation input used in FFMP to determine if inherent problems exist in using precipitation input from two different sources.
    d. Separate flash flood storm types as either over bank (appropriate to use FFG), mountainous terrain, or urban inundation in Storm Data.
3. Develop FFG Verification Program

The Flash Flood Guidance Improvement Team also recommended investigating new science techniques to improve Flash Flood Guidance. These new science techniques include CBRFC's relative Flash Flood Potential Index, the Hydrology Lab's Statistical Distributed Hydrologic Model and the distributed hydrologic model. The requirements for these new science techniques are presented in Sections 2.3.5, 2.3.6, and 3.1.2, respectively.

2.3.3 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 task has been expanded from the radar centric repository to a seamless hydrologically connected national repository of the FFMP basin and stream dataset. It is envisioned that this data set will work in conjunction with the mosaicked data sources of precipitation. NSSL continues to provide support of FFMP in the area of basin mapping.

1. Establish a National Basin Repository of FFMP GIS datasets
    a. Establish a National Basin Repository computer server hardware and communications infrastructure to allow access to the FFMP GIS datasets. (complete)

    b. Create a seamless high quality hydrologically-connected FFMP basin and stream dataset for the United States, including Alaska, Hawaii, Puerto Rico, and Guam.
    c. Implement software for web interface to FFMP GIS dataset.
    d. Create instructions for users to download data and prepare it for localization in AWIPS. The instructions will also detail how WFOs can incorporate previously customized basins into the files obtained from the national repository.
    e. Disseminate instructions to WFO staff.
    f. Train WFO staff on accessing FFMP GIS datasets through the National Basin Repository.
2. Provide radar centric FFMP Basins GIS datasets
    a. Create radar centric FFMP Basins GIS datasets for CONUS Sites (complete)
    b. Create radar centric FFMP Basins GIS datasets for OCONUS Sites (complete)
    c. Provide radar centric FFMP Basins GIS datasets for new radars as radars are added to the operational network (ongoing)
    d. Enhance radar centric FFMP Basin GIS datasets to include hydrologic connectivity (complete)
    e. Provide Basin Customization documentation and training. (complete)
    f. Provide Basin Customization Support and Data Access (ongoing)
    g. Update Basin Customization scripts from Avenue (supported in ArcView 3.X) to Visual Basic (supported in ArcGIS 9.0) (ongoing)
    h. Create a functionality to include latitude/longitude delineation of customized basins for use in GIS-based flash flood warnings

2.3.4 Flash Flood Monitoring and Prediction

The operational requirement of the FFMP system is to assist forecasters in the issuing of localized flash flood watches and warnings to the public in a timely manner with the largest possible lead time and accuracy. Currently, the operational version of FFMP provides a visual comparison of observed precipitation and Flash Flood Guidance to identify areas of flash flood risks. To improve the lead time and accuracy of flash flood warnings there are planned enhancements to FFMP. These enhancements include providing FFMP service backup among WFOs, using higher resolution QPE from radar, gage and satellites as well as short-term QPF, adding multiple monitoring time-frames and thresholds, archiving precipitation accumulation to allow Weather Event Simulator playback capability, and adding user selectable precipitation source. Additionally, there is an operational requirement to expand FFMP guidance input to include debris flow guidance and allow for monitoring and prediction of multiple guidances. FFMP can then be used to monitor and predict debris flows allowing NWS forecasters the capability to provide debris flow warnings. Expanding FFMP to ingest and monitor multiple guidances prepares FFMP to ingest and monitor future flash flood information inputs currently being investigated in the ‘Distributed Hydrologic Modeling for Flash Flood Forecasting’ OSIP project and Colorado Basin River Forecast Center Flash Flood Potential Index project. For a full list of FFMP requirements please refer to the NWS Operational Requirement Document for FFMP.

1. Provide Basin Layering capability (complete)
2. Provide Basin Trace Capability (complete)
3. Add multiple monitoring time frames and thresholds (complete)
4. Provide multiple radar service back up capabilities.
    a. Allow FFMP to ingest non-dedicated radar data. (complete)
    b. Allow WFOs the ability to obtain the basin customization data for non-dedicated radar sites. (complete)
5. Archive precipitation accumulation data in a format compatible with Weather Event Simulator playback capability.
6. Monitor rainfall in FFMP with gridded, high resolution multi-sensor mosaicked data. Initial assessment with NSSL's National Mosaic QPESUMS (NMQ) and OHD's Enhanced MPE
7. Enable multiple user-selectable inputs (e.g. DHR, EMPE, NMQ)
8. Integrate nowcasting capability (with MPN) into FFMP
9. Provide the ability to monitor multiple guidance values in FFMP. This will allow FFMP to be used to monitor and predict other phenomena such as debris flow or multiple sources of flash flood information (i.e., statistical distributed flash flood guidance versus flash flood potential index flash flood guidance).
10. Adapt FFMP to interpret precipitation estimates and forecasts expressed as probabilities, as well as those expressed as deterministic amounts.
11. Integrated FFMP into the Next Generation Warning Tool where basins or groups of basins are easily identified and selected to quickly produce flash flood warnings.
12. Expand FFMP capabilities to create digital/graphical Flash Flood Products

2.3.5 Relative Flash Flood Potential Index

The FFGIT identified that other methods to assist with the localized issuing of Flash Flood Watches and Warnings should also be investigated. These methods include CBRFCs relative Flash Flood Potential Index, which characterizes the potential for flash flood as a function of slope, vegetation, soil type and land use.

1. Develop a static relative Flash Flood Potential Index as a function of slope, vegetation, soil type and land use for the entire conterminous U.S.
2. Enhance the relative Flash Flood Potential Index to include a dynamic soil moisture component.
3. Provide ability through standard AWIPS delivery (either D2D or FFMP) to view the Relative Flash Flood Potential Index.

2.3.6 Statistical Distributed Modeling

The operational requirement is to produce flash flood information at the distributed model scale in an effort to predict flash flooding particularly at ungaged locations.

The basic idea of the statistical-distributed modeling approach is to use retrospective distributed model runs as a measure of flood severity for ungaged locations. To implement this, a distributed model pre-processor will run using historical archives of gridded Multi-sensor Precipitation Estimates (MPE). Results will then 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 has shown improvements relative to the current FFG system without requiring a fully calibrated distributed model. Additionally, the statistical distributed model may be run with precipitation forecast grids from the MPN in an effort to improve flash flood forecast lead time.

The requirements outlined below identify steps to explore and develop a statistical distributed model to learn if it can produce improved flash flood information.

1. Investigate the use of a statistical distributed model as a means to improve accuracy and lead time of flash flood forecasts.
    a. Develop methods and procedures to create simulated flood frequency information for each model element using a distributed model and an archive of historical data.
    b. Develop methods and procedures to use the simulated flood frequency information with distributed modeling to produce flash flood information.
    c. Ingest forecast grids from MPN into the statistical distributed model in an effort to improve flash flood forecasting lead times.
2. Investigate the use of probabilistic Quantitative Precipitation Estimates with the Statistical Distributed Model as a means to generate probabilistic FFG.
    a. Develop methods and procedures to incorporate probabilistic Quantitative Precipitation Estimates into the statistical distributed model to produce probabilistic flash flood information.
    b. Develop methods and procedures for probabilistic flash flood information to be ingested into and used by FFMP.

2.3.7 Site Specific Hydrologic Predictor

The Site Specific Hydrologic Predictor (SSHP), 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 SSHP 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 SSHP application which currently uses the Kansas City API rainfall-runoff model. This will allow the SSHP 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 nationwide deployment in August, 2004 following AWIPS Release OB4.

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

1. Provide software tools to support the model calibration at the 1 hour temporal resolution and smaller spatial resolution of the SSHP/SAC-SMA model.
2. Provide methods and procedures to integrate the variational assimilation (VAR) state adjustment function into the SSHP/SAC-SMA in an effort to maintain proper model state variables.
3. Integrate snowmelt modeling techniques to the SSHP/SAC-SMA model.
4. Integrate routing techniques to the SSHP/SAC-SMA model.

2.3.8 Evaluation of other Hydrologic Models

Other hydrologic forecasting models should be evaluated for their suitability for NWS flash flood forecasting operations.

1. Evaluation of Hydrologic Forecasts in Puerto Rico based on the use of USGS hydrologic models.

2.3.9 Hydraulic Modeling and Analysis Tool

The operational requirement is to provide timely and accurate watches and warnings for locations downstream from dams in the event of dam failure or imminent indication of a dam failure. The following requirements are proposed to automate the existing methodologies and procedures used to generate such forecasts.

1. Enhance the Dambreak Catalog Reviewer and Estimator (DAMCREST)
    a. Validate current Dambreak Catalog used in DAMCREST
    b. Validate current simplified hydraulic models used in DAMCREST
    c. Add the current rule of thumb methods used by field offices to DAMCREST.
    d. Add the regression component that is currently in the CBRFC catalog to DAMCREST as a measure of comparison.
    e. Interface DAMCREST with National Inventory of Dams to provide RFC/WFO with the most up to date dam information.
2. Develop an application Dam Analysis Tool (DamAT) to automate the functionality of the DAMCREST, the FLDWAV Cross Section Tool (FLDXS) and the flood wave viewer (FLDVIEW) to provide timely and accurate dam failure forecasts.

   a. Add the current rule of thumb methods used by field offices to DamAT.
   b. Add the regression component that is currently in the CBRFC catalog to DamAT as a measure of comparison.
   c. Add the Breach erosion model (BREACH) component DamAT to improve dam breach parameters.
   d. Expand DamAT to include simplified dynamic routing to improve dam failure forecasts.
3. Quality control critical input data (dam and town location, dam and reservoir information, field boundaries for the dams)
4. Provide operational database interaction capability to exchange dam break information between RFC/WFO/OHD/OCWWS/Regions.
5. Provide operational framework policy for RFC and WFO dambreak analysis and forecast issuance.

2.3.10 Flash Flood Services Training

Universities and private industry can provide the training to support basic hydrologic understanding. A spectrum of approaches and training entities (COMET, NWSTC, WDTB, OHD, etc) will provide training to support the hydrology forecast program's implementation of new science and NWS specific technology. This will ensure that those involved in the operation and support of the program have a sound understanding of system enhancements and upgrades.

The training outlined below describes the training needed to support flash flood services. This includes training in GIS, FFG, FFMP, Basin Customization and Flash Flood/Heavy Rainfall.

1. GIS Training - Provide a basic GIS course for RFC forecasters and WFO Hydrologic Program Managers. The course content should include the background to understand and use GIS with regard to hydrology.
2. FFG Training - Provide a basic hydrologic science course for RFC forecasters and WFO Hydrologic Program Managers. The course content should include the scientific background to understand and use FFG. Specific subject matter should include underlying science and implementation of FFG, strengths and limitations of FFG, how FFG should be used to address flooding in urban and mountain areas, how the science and implementation of FFG are advancing.
3. FFMP Enhancement training - Provide a FFMP enhancement training for WFO Hydrologic Program Managers and forecasters. The course content should include the scientific background to understand and use FFMP. Specific subject matter should include underlying science and implementation of FFMP and how the science and implementation of FFG are advancing.
4. Basin Customization - Provide Basin Customization training for WFO Hydrologic Program Managers. The course content should include the skills and tools needed to customize high resolution basins that have been delineated for use with the FFMP application included in AWIPS. Specific subject matter provide the trainee skills to identify, create, alter, and redefine basins to better support local flash flooding needs.
5. Flash Flood Hydrology and QPE Workshop - Provide Flash Flood Hydrology and QPE Workshop for WFO Hydrologic Program Managers. The course content should

include Flash Flood Guidance and the hydrometeorology of flash floods. Specific subject matter should include strengths and limitations of Flash Flood Guidance, events which can lead to the onset of flash flooding, the use of the FFMP application as a decision-making tool during heavy precipitation events; and use case studies as training tools.

6. Hydraulic Modeling Operations - Provide a hydraulic modeling operations course for WFO personnel. The course content should include the necessary skills required to perform hydraulic operations.
    a. Develop a tutorial that explains how to run the Simplified Dam Break model including data acquisition (i.e., cross-section selection and the selection of dam break parameters).

3 Short- to Long-Term Forecast Services

Short- to long-term forecast services aim to improve forecast accuracy, provide new types of forecast certainty information, and provide longer forecasts horizons with easier to use products. By providing the forecasts in graphical format to a national web presence of AHPS products, short- to long-term forecast services addresses the operational concept of creating products that are easier to use and understand, more timely, and offer consistent access. The operational concept of short- to long-term forecast services is to provide to the customer enhanced forecast information including observed and deterministic forecast river levels and/or flow, when available, in graphical format. This service is also to provide long-term probabilistic forecast information at appropriate AHPS locations. At water supply forecast points this service is to provide probabilistic water supply volume forecasts in a standard format. Additionally, at appropriate AHPS forecast locations this service provides short- to long-term probabilistic forecasts which include low-flow and drought information.

Improving forecast accuracy will be accomplished with improvements to deterministic forecasting, presented in section 3.1. Providing longer forecast horizons and certainty information will be accomplished with probabilistic forecasting. The operational concept, capabilities and requirements for a probabilistic forecasting capability is presented in section 3.2. Other capabilities that support AHPS short- to long-term forecast services include outreach, training, web page deployment and logistical verification. The requirements for these capabilities are presented in Sections 3.3, 3.4, 3.5 and 3.6 respectively.

3.1 Deterministic Forecasting

Deterministic forecasting can be improved through enhancing the existing operational lumped model and through developing a distributed model capability. The operational concept, capabilities and requirements to improve the existing operational lumped model is presented in section 3.1.1. The operational concept, capabilities and requirements for high-resolution distributed modeling capability is presented in section 3.1.2.

3.1.1 Lumped Model Forecasting

3.1.1.1 Operational Concept of Lumped Model Forecasting

Short- to long-term forecast services aim to improve forecast accuracy with easier to use products. Improving forecast accuracy will be accomplished by enhancing different components of the hydrometeorologic, hydrologic, and hydraulic models of the National Weather Service River Forecast System (NWSRFS) and the operational calibration and implementation of these enhancements.

3.1.1.2 Current Capabilities of Lumped Model Forecasting

Currently, with the National Weather Service River Forecast System (NWSRFS), River Forecast Centers (RFCs) have the tools necessary to provide lumped model forecasting at most headwater basins and downstream basins with simple hydraulic conditions. The tools provided by NWSRFS include the Calibration System, the Operational Forecasting System (OFS) and the Ensemble Streamflow Prediction (ESP) System. All three systems use the same hydrologic and hydraulic models. Limitations exist within NWSRFS that prevent the operational implementation of lumped model forecasting at all river forecast locations. Forecast locations with significant upstream river regulation (reservoirs, diversions, etc) and river routing affected by channel ice cannot be accurately modeled with the current system. Additionally, the existing model for dynamic river routing (FLDWAV) has computational limitations in the Ensemble Streamflow Prediction (ESP) System. Finally, deterministic forecasting capability can be improved by enhancing different components of the hydrometeorologic, hydrologic, and hydraulic models of NWSRFS.

For the basins where lumped model forecasting can be implemented, RFCs have the capability to implement NWSRFS operationally and provide streamflow and streamflow related information to all customers through the national AHPS web page. Current calibration procedures required for operational implementation are time consuming and complicated and will become more burdensome as the number of forecast locations increases.

3.1.1.3 Operational Requirements to Provide Lumped Model Forecasting Services

The operational requirement to provide lumped model forecasting to all forecast locations will be realized with improvements to the NWSRFS. First, the limitations in NWSRFS that prevent lumped model forecasting at all forecast locations must be removed. Methods to model river regulation and ice must be incorporated into the hydraulic models of the river forecasting system. Additionally, the architecture of NWSRFS should be opened up to allow increased access to alternative hydrologic, hydraulic and river regulation models. Improvements should be made to the hydrometeorologic, hydrologic and hydraulic models to improve forecast accuracy. NWSRFS should also support improved deterministic verification and standard product generation and graphical dissemination procedures. Calibration procedures must become more streamlined and automated, and operational implementation must be supported to provide quicker implementation of lumped model forecasting at all forecast locations. This section identifies requirements in the hydrometeorological inputs, hydrologic modeling, hydraulic modeling, reservoir and river regulation models, architecture, product generation and graphical dissemination, data archive, verification components, and operational calibration and implementation of NWSRFS to meet this objective.

3.1.1.3.1 Hydrometeorological Inputs

Hydrometeorological inputs drive the hydrologic forecasting process. An accurate representation of the hydrometeorological conditions is necessary for hydrologic forecasting. One limitation of the processing of hydrometeorological inputs in NWSRFS is that it cannot currently ingest WFO Quantitative Precipitation Forecasts (QPF), or other hydrometeorological inputs, from the National Digital Forecast Database (NDFD). Another limitation is the lack of snow water equivalent data in some snow critical areas. A shortcoming of NWSRFS is that although the Calibration System and the OFS use common hydrologic and hydraulic models, the systems use different sources of data and different processing routines to compute hydrometeorological inputs. Another limitation is that NWSRFS does not incorporate all available sources of hydrometeorological input data such as stranger reports. Additionally, the current source for potential evapotranspiration (PE) data used in NWSRFS is becoming obsolete. The functional requirements outlined below define a plan to address the shortcomings of the current methods used to incorporate hydrometeorological inputs. NWSRFS must have access to the hydrometeorolgical inputs available in the NDFD. Snow water equivalent data must be obtained and made available to NWSRFS. The inconsistencies between the Calibration System and OFS use of different sources of data and different processing routines must be mitigated to reliably model the hydrometeorological inputs. Stranger reports must be dynamically included in the MAP computation. New methods to estimate potential evapotranspiration must be identified and implemented.

1. Develop an NDFD preprocessor in NWSRFS to provide RFC access to other hydrometeorological inputs.
2. Add the capability to use WFO, HPC or model QPF.
3. Support NOHRSC activities to augment snow water equivalent data for Alaska.
4. Mitigate inconsistencies between calibration, observation and forecast computations of hydrometeorological inputs.
    a. MAT
    b. MAP
    c. Evapotranspiration
5. Dynamically include stranger reports in the MAP computation when available.
6. Create new sources of Potential Evapotranspiration estimates as current methods are becoming obsolete.
    a. Satellite based estimates of surface net radiation
    b. Combined satellite/ground-based cloud cover estimates as a replacement for the ‘sky cover’ observations used in the pre-ASOS computation of potential evapotranspiration.
7. Improve temperature forecasts
    a. Identify optimum methodologies for spatial and temporal interpolation of temperature observations and forecasts to grids
    b. Derive new conversion weights, or validate adequacy of existing weights, for western region.
    c. Examine NDFD, NAM forecasts grids to determine any biases relative to historic point temperature data.

3.1.1.3.2 Hydrologic Modeling: Calibration System Enhancements

Hydrologic forecast and simulation accuracy is dependent on the selection of appropriate models, calibrated model parameters, the quality of the calibration data, and how well the calibration data represents reality. Currently the calibration procedures are awkward and time consuming. Efforts must be made to improve and develop a calibration system that allows for more efficient and effective lumped forecast model implementation. Additionally, similar to the hydrometeorological inputs, inconsistencies exist between the USGS historical mean daily flows used in calibration versus the operationally available streamflow data. Another limitation is that the current calibration procedures within NWSRFS are limited to using 24-hour calibration statistics, which may be inappropriate to use in fast responding basins. The functional requirements define a plan to address the shortcomings of the calibration system. The calibration system enhancements include developing a new architecture with more effective GUIs, combining the redundant double mass analysis functions in the preprocessors, providing a link between the interactive calibration program and the automatic calibration procedures, and developing automated calibration procedures including a priori parameters. The inconsistencies between the Calibration System and OFS use of different sources of data must be mitigated to reliably calibrate the hydrologic model. Additionally, calibration statistics should be provided for 1-hour, 3-hour or 6-hour time steps.

1. Mitigate inconsistencies between USGS historical mean daily flows used in calibration, versus the operationally available data.
2. Automate procedures to acquire needed data for calibration.
3. Provide options for 1-hour, 3-hour, and 6-hour calibration statistics within NWSRFS.
4. Evaluate the impacts of historical data quality control procedures (specifically IDMA) on hydrologic model calibration.
5. Re-implement the Interactive Calibration Program (ICP) using a more modular design better enabling the addition of new features in the future.
6. Enhancements to re-implemented ICP
    a. Provide graphical statistical enhancements per Eric Anderson report.
    b. Provide capability to directly edit time series from the PLOT-TS window in ICP.
    c. Provide additional ICP functionality for modifying Unit Hydrographs
    d. Provide ICP enhancements to support analysis of Snow Area Depletion Curve
    e. Provide ICP enhancements to provide a display of a time lapse of Sacramento model states.
    f. Add AB_OPT functionality into ICP
7. Develop new architecture/GUIs to streamline the existing calibration system programs. This should combine the functions in the existing programs such as the Calibration Assistance Program (CAP), the ICP, the Interactive Double Mass Analysis (IDMA), the Air Temperature Plotting program (TAPLOT), PXPP, MAP, MAT, MAPE, etc…
8. Provide a link between the interactive calibration program and the automatic calibration procedures.
9. Incorporate multi-objective automatic optimization methods for model parameter calibration

3.1.1.3.3 Hydrologic Modeling: Deterministic Forecasting

Hydrologic modeling within NWSRFS is dependent on the selection of appropriate snowmelt and rainfall-runoff models. A limitation of the SNOW-17 snowmelt model available in NWSRFS is that it is conceptually based. Physically based snowmelt models may improve snowmelt forecasting. Maintaining hydrologic parameters states is time consuming and challenging. The functional requirements define a plan to address the shortcomings of the hydrologic modeling. New methods to improve SNOW-17 must be investigated to simulate physically based snowmelt modeling. Additionally, physically based energy budget snow models should be considered as an alternative to SNOW-17. Procedures must be developed to generate physically based soil moisture fields. Variational assimilation must be included for optimal maintaining of hydrologic parameter states.

1. Evaluate the need to use energy budget snow models versus SNOW-17 models.
2. Investigate methods to improve SNOW-17
3. Develop plan and approach to use SNODAS output to generate run-time modifications to SNOW-17 in operational setting.
4. Generate physically based soil moisture fields.
5. Include variational assimilation of streamflow, precipitation, and potential evapotranspiration into the lumped Sacramento unit hydrograph models for NWSRFS operational implementation.

3.1.1.3.4 Hydraulic Models

The primary hydraulic model in NWSRFS is the dynamic river model FLDWAV. Currently, FLDWAV cannot model the effects of ice on river hydraulics. Additionally, FLDWAV is computationally intensive. In order to run FLDWAV 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). Finally, a major limitation of NWSRFS is the inability to ingest non-NWSRFS hydraulic models. The NWSRFS architecture must be updated to allow for the integration of non-NWSRFS models and easier integration of future model developments. The functional requirements outlined below allow for general enhancements to hydraulic modeling in an effort to improve streamflow forecasting accuracy. These enhancements include the ability to model the effects of ice on streamflow hydraulics. Enhancements to probabilistic hydraulic forecasts are included in the requirements for improvements to FLDWAV as the same model is used in both the OFS and ESP. NWS must leverage, to the maximum extent possible, the hydraulic model development and support capabilities of partner agencies. For this purpose, there is also a general requirement to open the architecture of NWSRFS to allow the use of non-NWSRFS hydraulic models and provide easier integration of future model developments. The preliminary prototype development of this open architecture serves as the foundation for CHPS. CHPS will be fully realized with the WRP.

1. Ice Modeling
    a. Develop time series calculator
    b. Use time series calculator to test ice jam threshold algorithm
    c. Evaluate ice modeling capability in FLDWAV
2. Enhance lock & dam capability in FLDWAV
3. Improve capability to model wind effects
4. Automate FLDWAV calibration procedures
5. Improve efficiency and accuracy of FLDWAV for use within the ensemble system.
6. Implement the Simplified Hydraulic Routing Technique (SHRT) in NWSRFS

7. Evaluate COE suite of hydraulic models and other organization's hydraulic models for their suitability for NWS river forecasting operations.

3.1.1.3.5 Reservoir and River Regulation Models

Reservoir and river regulation models account for and forecast the effect of reservoir operations and other river regulations. Regulation takes place when human activities affect the "natural" discharge. They are most obvious in the form of reservoir regulation but also exist as diversions, bypasses, accretions, return flows and the like. NWSRFS supports different reservoir and river regulation models; SSARESV, RES-SNGL, RES-J and CONSUSE. A limitation of these models is the inability to model river regulations. River regulation presents an extremely complex problem, since water withdrawals and returns to streams may be subject to a web of operations, procedures, consumptive use, and water rights administration rules. Simply, the amount of water removed is often not known. 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 reservoir operations and streamflow regulations will have to be quantified to produce streamflow forecasts and ensembles. NWS must leverage, to the maximum extent possible, the reservoir and river regulation model development and support capabilities of partner agencies. For this purpose NWSRFS architecture must be updated to allow for the integration of non-NWSRFS reservoir and river regulation models and easier integration of future model developments.

1. Enhance existing NWSRFS models to aid with modeling Streamflow Regulation
    a. Provide a RES-J hindcasting capability
    b. Provide a RES-J LOOKUP3 capability to define a value as a function of two other values.
        i. Applied to a reservoir, the value may be parameterized as a withdrawal or a release from a reservoir.
        ii. Applied to a node, the value may be parameterized as a diversion from the node.
    c. Enhance the RES-J LAGK method to allow the use of variable lags.
    d. Add a POWERGEN (power generation) method to the RES-J operation.
        i. Enhance the CONS_USE operation to allow the user to specify where return flows re-enter the stream
        ii. Enhance the CONS_USE operation to allow the user to have the operation compute return flows only, and to do so based on a given diversion time series.
        iii. Enhance the CONS_USE operation to provide the user the option of specifying the time series from which the diversion will be withdrawn.
        iv. Enhance the CONS_USE operation to introduce a Mean Areal Precipitation (MAP) input time series in order to account for the demand satisfied by precipitation.
        v. Enhance the CHANLOSS operation by adding an option to allow the computed loss or gain be a non-linear function of discharge.

vi. Enhance the CHANLOSS operation to compute the resulting stream flow after accounting for loss or gain.

e. Segment Comments –enhance NWSRFS to save comments within the OFS such that punched segments would retain comments for each segment.
f. Multi-valued Time Series Lookup Operation – The Sacramento model includes two multi-value time series containing zone contents and runoff components. The values from these time series may be plotted using PLOT-TS, but the time series cannot otherwise be accessed for manipulation. In some cases, the contents of the zones may provide a useful indicator of basin conditions that could be used to trigger some component of regulation modeling. The LOOKUP3 operation could be enhanced to allow a component of a multi-value time series to be used as the input time series, so that the associated component could be used as a factor in regulation modeling.
g. Integrate NWSRFS Rating Curves – The MAXSTAGE method requires the user to input a rating curve for the downstream node. It is requested that rating curves defined in the system be accessible to this method in place of the rating curve defined in RES-J. This enhancement will allow the model always uses the most up-to-date rating curve data from NWSRFS database.
h. Improve RES-J Operation Speed – The speed of the RES-J operation has been a major concern in several RFCs. It could really use some improvements to improve efficiency. Below are exerts from previous proposal by RTI. "There are some things that could be done to improve the speed of MAXSTAGE simulations. Most users complaining about speed in the past were not using MAXSTAGE, however, since it didn't work until recently. We recommend that we keep an eye on enhancing performance during the upcoming work and identify level of effort and expected gains for a later proposal."

2. Develop time series calculator capability
3. Open architecture to allow the use of non-NWSRFS reservoir and river regulation models and easier implementation of new model developments
    a. Provide access to USACE/HEC Reservoir Simulation Model in NWSRFS

3.1.1.3.6 Architecture

With the advancements of AHPS it has been long understood that the architecture of NWSRFS must also be advanced to accommodate these efforts. AHPS supports the preliminary definition and prototype development of a new software architecture and infrastructure which will serve as the foundation of CHPS. CHPS will be fully realized with the WRP. Currently, there are three ongoing "proof of concept" projects advancing the proposed architecture. The first project replaces the NWSRFS MAT data preprocessor with a data services and an algorithm services concept with a Workflow Management System. The second project delivers the enhanced frozen ground algorithm using the evolving CHPS architecture. The third project addresses the standardization of data management and delivery through coordinating an XML data exchange with USGS, Army Corps of Engineers, and others.

1. Continue the definition and development of a new software architecture and infrastructure to support NWS hydrologic operations.

a. Create a CHPS software architecture shell (Data Services and Algorithm Services connections) for an example NWSRFS data pre-processor, the MAT.
    i. Replace existing MAT science algorithms
    ii. Unify MAT computations across NWSRFS
    iii. Eliminate the use PPPDB and PPDB fs5file input databases in favor of the IHFS Database for input.
b. Deliver enhanced Frozen Ground Algorithm as part of the AWIPS national baseline, using OHD's evolving CHPS architecture.
c. Create and expand the Hydrology XML Consortium (HydroXC)
    i. Establish HydroXC
    ii. Interview and survey all the RFCs about their XML work and future vision
    iii. Define an XML interface between FLDWAV and FLDVIEW
    iv. Re-engage consortium members with new data modeling exercises and workshops

3.1.1.3.7 Product Generation and Graphical Dissemination

Product generation and graphical dissemination must be enhanced to provide low-flow and drought products and provide ability for RFC/WFO collaboration on forecast products before public dissemination.

1. Provide enhancements to the HydroGen application
2. Improve XSETS to allow graphical viewing and editing of current and past hydrographs
3. Provide ability for RFC/WFO collaboration on forecast products before public dissemination.

3.1.1.3.8 Data Archive

The operational capability is to support and maintain a national archive database. This database is used to support the verification of lumped model forecasts, support calibration activities for hydrologic and hydraulic models and preserve a history of lumped model hydrologic forecasts. This data archive for operational forecast is largely in place with the outstanding requirement to provide tools to keep the River Forecast Center (RFC) Archive system (RAX) in sync with the Integrated Hydrologic Forecast System (IHFS) database.

1. Provide tools to keep the River Forecast Center (RFC) Archive system (RAX) in sync with the Integrated Hydrologic Forecast System (IHFS) database.

3.1.1.3.9 Enhance the existing deterministic verification system

The final step in streamflow forecasting is to provide the forecast and verification information needed by customers to make their necessary risk based decisions. NWSRFS must provide detailed analytic verification data and tools to forecasters, researchers and developers to improve operational forecasting and provide a rational justification for research and development efforts.

The functional requirements outlined below show steps for improving the operational deterministic verification system.

1. Add additional metrics, including corresponding graphics, and additional archiving capabilities to the existing verification software. Metrics to be added include the correlation coefficient, forecast variance, observed variance, Gilbert score, and average lead time to detection
2. Add persistence calculations to verification software
3. Add ability to compute metrics for all physical elements to verification software
4. Add ability to compute confidence intervals for metrics to verification software.
5. Identify a path for proper error analysis of deterministic forecasts. This includes work on the operations concept, requirements development, and operational development plan for the “raw model” forecasts.
    a. Add ability to generate “raw model” forecasts to RFS
    b. Integrate “raw model” forecast information into the verification system metrics.
6. Investigate new methods to assess trends in the verification data.
    a. Propose performance metrics; provide capability to disseminate performance metrics, other results and data; and provide real-time access.

3.1.1.3.10 Operational Calibration and Implementation

The operational concept of lumped model forecasting services relies on the RFCs implementation of operational calibration. Operational calibration increases forecast accuracy and provides the framework to produce long-term probabilistic forecast information. Operational calibration for a single forecast location requires developing calibration input data, select appropriate model operations, estimating initial model parameters and states, tuning model parameters, developing calibration documentation and quality information, and implementing calibration results into operational systems including ESP.

Historical data is fundamental in performing operational calibration. This historical data includes hydrometeorological inputs (precipitation, temperature, potential evapotranspiration), streamflow data (stage data, rating curves, diversion data), regulation data (diversions, reservoir operations) and hydraulic data (cross-sections, dam data). NWSRFS currently supports calibration for most basins, however this activity remains a time consuming process. A significant component of AHPS is to support the current methods of operational calibration while supporting efforts to improve the calibration process. Each year support must be provided to assist RFCs in their operational calibration and implementation efforts through the use of contractors.

1. Provide support to assist RFCs with operational calibration and implementation

3.1.2 Distributed Model Forecasting

3.1.2.1 Operational Concept of Distributed Model Forecasting

Short- to long-term forecast services aim to improve forecast accuracy with easier to use products. Improving forecast accuracy will be accomplished with distributed hydrologic modeling where appropriate and improved calibration procedures.

3.1.2.2 Current Capabilities of Distributed Model Forecasting

Distributed modeling has been advanced from scientific concept to near operational. The Distributed Modeling Inter-comparison Project (DMIP) was completed and an entire journal dedicated to the projects findings has been published (Journal of Hydrology, Volume 298, October 2004). The Hydrology Lab Research Distributed Hydrologic Model (HL-RDHM) has been developed and prototyped with distributed modeling capabilities. Proven distributed modeling capabilities of HL-RDHM have been advanced to the operational Distributed Hydraulic Modeling (DHM) of the NWSRFS. DHM is currently being prototyped and tested at WGRFC and ABRFC. DHM is expected to be fully operational in AWIPS Operational Build 7.

3.1.2.3 Requirements to Provide Distributed Model Forecasting Services

Distributed modeling must be advanced to include snow models and ease implementation efforts to work operationally. Calibration procedures must be advanced to support data preparation and hydrologic model parameter estimation at the distributed modeling scale. The operational architecture must be advanced to support the demands of a distributed model forecasts. Product generation and dissemination must be streamlined and automated to assist forecasters with the voluminous information produced by distributed modeling.

3.1.2.3.1 Hydrometeorological and Climatological Inputs

Hydrometeorological inputs drive the hydrologic forecasting process. An accurate representation of the hydrometeorological conditions is necessary for hydrologic forecasting. To support distributed modeling, hydrometeorological inputs must be processed at the appropriate distributed modeling temporal and spatial scale.

1. Create hydrometeorological inputs at the appropriate distributed modeling scale.

3.1.2.3.2 Hydrologic Forecasting

The functional requirements outlined below derive a plan to address the shortcomings of the calibration and hydrologic forecasting system. The calibration system enhancements include adapting all calibration procedures to the distributed modeling element scale. The deterministic hydrologic forecasting system enhancements include the steps necessary to implement distributed modeling operational. These steps include lessons learned from the Distributed Modeling Inter-comparison Project (DMIP) and the goals of DMIP II. Additional steps revolve around moving the research distributed model into operations and necessary enhancements to make distributed modeling a viable operational hydrologic modeling system. The CONUS HL-Research Distributed Hydrologic Model tests are required to support the NOAA Water Resources

Program via the development of prototype products such as gridded soil moisture, soil temperature, surface runoff, and other water balance components. The CONUS tests are also required to support NOAA's contribution to the National Integrated Drought Information System (NIDIS). Furthermore, CONUS HL-RDHM executions promote an efficient research-to-operations pathway by; supporting ongoing OHD internal and external research into parameterization, calibration and other areas; identifying basins that will potentially benefit from distributed model application and providing these recommendations to RFCs; identifying 'problem' areas that require improvements to HL-RDHM components; providing an efficient evaluation mechanism for CONUS and regional -scale products such as NOHRSC SNODAS model outputs, NSSL/OHD Q2 precipitation fields, and OHD/NASA Marshal Space Flight Center gridded PE estimates.

1. Calibration System Procedures applicable to the distributed modeling scale
    a. Develop Simplified Line Search (SLS) automatic calibration procedures
    b. Research and development on usage of SSURGO data to derive a priori model parameters in an effort to improve current SAC-SMA parameter estimation for distributed modeling
    c. Evaluate a parameter regionalization approach for SAC-SMA and SNOW-17 using lumped calibrated parameters, including the use of new sources of validation data such as soil moisture.
    d. Evaluate adjusting parameters based on climate indices.
    e. Develop Adjoint Based Optimizer (AB-OPT) for unit-hydrograph and SAC-SMA parameters for NWSRFS operational implementation.
2. Hydrologic Forecasting
    a. Distributed Model Inter-comparison Project (DMIP)
        i. DMIP I (complete)
            1. Determine if distributed models provide increased simulation accuracy compared to lumped models. (complete)
            2. Determine what level of model complexity is required to realize improvement in basin outlet simulation. (complete)
            3. Determine what level of effort is required for distributed model calibration. Determine what improvements are realized compared to non-calibrated and calibrated lumped models. (complete)
            4. Determine the potential for distributed models set up for basin outlet simulations to generate meaningful hydrographs at interior locations for flash flood forecasting. (complete)
            5. Determine what characteristics identify a basin as one likely to benefit from distributed modeling versus lumped modeling for basin outlet simulations. Determine if these characteristics can be quantified. (complete)
            6. Determine how research models behave with forcing data used for operational forecasting. (complete)
            7. Determine what is the nature and effect of rainfall spatial variability in the DMIP basins. (complete)
        ii. DMIP II
            1. Confirm the results from DMIP 1 with a longer validation period

2. Expand model comparisons to a Western U.S. basin with significant snow effects. (Compare energy based models with performance of distributed SNOW-17 model)
3. Expand analysis to include new sources of validation data, particularly use of soil moisture data.
4. Improve our understanding of uncertainty, in particular the contributions of different model components (inputs, soil moisture accounting, and routing) to overall uncertainty.
5. Expand comparison to consider forecast mode in addition to simulation mode.

b. Hydrology Lab - Research Distributed Hydrologic Modeling (HL-RDHM)
    i. Initial Development of HL-RDHM: distributed model capabilities using 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. (Complete). The operational capability of this prototype is the Distributed Hydrologic Modeling (DHM) and will be available in OB7.
    ii. Enhance HL-RDHM by including distributed frozen ground modeling capabilities
    iii. Enhance HL-RDHM by including distributed snow modeling capabilities including SNOW-17.
    iv. Enhance HL-RDHM by including additional routing techniques.
    v. Enhance HL-RDHM to include alternative distributed rainfall-runoff techniques.
    vi. Enhance HL-RDHM to include variational streamflow assimilation.
    vii. Create robust parameterization techniques appropriate for the scale of distributed modeling.
    viii. Increase spatial resolution of DHM to agree with improved radar spatial resolution
    ix. Increase temporal resolution of DHM to agree with improved radar temporal resolution.

c. CONUS Research Model System tests
    i. Evaluation of initial CONUS model for water balance
    ii. Develop a strategy for validation: gridded simulations versus point observed data for soil moisture
    iii. Data collection: NRCS SCAN, Illinois data for further testing
    iv. Test against other soil moisture observations
    v. Support OHRFC and CBRFC with RFC-domain runs of HL distributed model
    vi. Evaluate initial SAC-SMA and SNOW-17 parameters
    vii. Create plans for developing CONUS 4km gridded climatologies for water balance variables.
    viii. Add other forcings.

ix. Support NIDIS prototype project in Arizona

3.1.2.3.3 Architecture

Many of the architecture functions required to advance distributed modeling are also required for probabilistic forecasts. For brevity all architecture requirements have been summarized in Section 3.2.3.6 Architecture.

3.1.2.3.4 Product Generation and Dissemination

With distributed modeling, products and information may be available at the distributed modeling element in addition to the traditional forecast location. The operational requirement is to develop, generate, and deliver useful information to all customers derived from streamflow forecasts at the distributed modeling element scale.

3.1.2.3.5 Data Archive

The operational capability is to support and maintain a national archive database. This database may be used to support the verification of forecasts at the distributed modeling element scale, support calibration activities for hydrologic and hydraulic distributed models and preserve a history of distributed modeling forecasts. The functional requirements described below describe the steps needed to develop this national archive.

1. Determine data needed to support a verification program of distributed modeling forecast products, support calibration activities and preserve a history of distributed modeling forecasts.
2. Develop national archive and database procedures to collect the data needed.

3.1.2.3.6 Verification

The operational capability is to provide detailed analytic verification data and tools to forecasters, researchers and developers to improve operational forecasting and provide a rational justification for research and development efforts. The end goal is to provide the forecast and verification information needed by customers to make their necessary risk based decisions.

The functional requirements outlined below show steps for improving the operational deterministic verification system and for distributed modeling forecasts.

1. Research metrics to be used for grid forecast verification.
2. Provide verification of distributed modeling forecast products; provide capability to disseminate verification metrics, other results and data; and provide real-time access

3.2 Probabilistic Forecasting

3.2.1 Operational Concept of Probabilistic Forecasting

Short-to long-term forecast services aim to provide longer forecast horizons and uncertainty information with easier to use products. Providing longer forecast horizons and uncertainty information will be accomplished with enhancements to the Ensemble Streamflow Prediction (ESP) system. The enhancements to the ESP system aim to provide a seamless, consistent and reliable probabilistic forecast for all time horizons (hours to seasons) which effectively accounts for all sources of uncertainty.

The short-to long-term forecast system will be seen to the forecaster as a collection of well understood tools that allow the forecaster too effectively and knowledgably deliver probabilistic forecasts. To the customer, the short-to long-term forecast service will provide streamflow and streamflow related forecast, uncertainty, and verification information for all time horizons at the appropriate forecast locations to allow customers to make appropriate risk based decisions.

3.2.2 Current Capabilities of Probabilistic Forecasting

Currently, with the NWSRFS Ensemble Streamflow Prediction System, RFCs have the tools necessary to provide long-term probabilistic forecasts at most headwater basins and downstream basins with simple hydraulic conditions. Parts of the short-to long-term forecasting system exist for demonstration purposes only. Five RFCs are currently investigating methods to quantify the uncertainty of the short- to long-term hydrometeorological inputs to the hydrologic forecasting model. CNRFC, MARFC and ABRFC are investigating the use of a single-value QPF (and where appropriate QTF) together with a joint distribution of historical forecast and observations to estimate a distribution of probable precipitation (temperature) values for the given QPF (QTF). CBRFC is investigating the use of medium range global ensemble forecasts with appropriate downscaling properties as direct input into the ensemble forecasting system. The NERFC is investigating the direct use of the meteorological model, MM5, ensembles. The prototype ensemble forecasting system includes an operational post-processor which attempts to quantify the hydrologic sources of uncertainty by combining all sources together.

3.2.3 Requirements to Provide Probabilistic Forecasting Services

Significant efforts must be made to fully understand and implement models that quantify all hydrometeorological, hydrologic, and hydraulic sources of uncertainty. Although this plan documents known requirements and research to operations activities, a full operations concept and research and development plan for the many facets of short- to long-term ensemble forecasting must be developed. The operational architecture must be advanced to support the demands of a short- to long-term probabilistic forecast system. Product generation and dissemination must be streamlined and automated to assist forecasters with the voluminous information produced by probabilistic forecasts. Advancements must be made to understand, develop and create an operational probabilistic verification system.

1. Develop operations concept and research and development plan for short- to long-

term ensemble forecasting.

3.2.3.1Hydrometeorological and Climatological Inputs

Probabilistic forecasting requires the quantification of uncertainty associated with all components of the forecasting system. Among the most influential and difficult to quantify are the hydrologic forcing inputs including precipitation, temperature, potential evapotranspiration and freezing heights for all forecast time horizons. The full operational capability is the incorporation of bias- and spread- corrected hydrologic forcing input ensembles from global and regional models using adequate downscaling processes.

The current probabilistic forecasting system integrates hydrometeorological forecasts/climate outlooks from National Centers for Environmental Prediction Climate Prediction Center (NCEP/CPC) to adjust the historical temperature, precipitation and other 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 hydrometeorological forecasts, for which the uncertainty needs to be quantified.

The functional requirements outlined below define a plan to address the shortcomings of the probabilistic hydrometeorological inputs. The functional requirements for the probabilistic hydrometeorological inputs are shown 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 next stage, the system will incorporate the skill of available hydrometeorological 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 variable predictability of individual storm events as well as the skill relationship evident through time and space aggregation must be understood and preserved. For example, some storm systems are inherently more predictable than others. Harnessing this predictability (or lack of it) is extremely important. For example, the skill in predicting a 1 hour precipitation accumulation four days in advance is nearly zero however there is skill in predicting the 24 hour amount. The 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 ensemble generation procedures described in the above phases above are a function of the time horizon of the available forecast data. Methods must be developed to ensure smooth transitions between the different ensemble generation procedures.

1. Create seamless (1 hr – 365 days) precipitation and temperature ensembles free of climatological noise that include long term climate adjustments.
2. Incorporate the skill of the short-term precipitation (QPF) and temperature (QTF) hydrometeorological forecasts into the ensembles generated with removed noise.

3. Incorporate the skill of the HPC 1-5 day, 6-10 day and 8-14 day hydrometeorological forecasts into the ensembles when QPF/QTF is not available.
4. Develop methods and procedures to quantify the skill relationship seen in the temporal, spatial, and storm type aggregation of forecasts.
5. Create ensembles for the other hydrologic forcing inputs (potential evapotranspiration, freezing heights…)
6. Incorporate the bias and spread corrected hydrologic forcing input ensembles from global and regional climate models using adequate downscaling processes (e.g., frozen GFS)
7. Develop procedures to ensure smooth transitions between the different ensemble generation procedures.

3.2.3.2 Hydrologic Forecasting

Enhancements are needed within the hydrologic forecasting system in order to quantify all sources of hydrologic forecast uncertainty including initial conditions, model parameter, and model structure uncertainty for all forecast time horizons. Real-time data assimilation is necessary in the probabilistic forecasting system to maintain model states and improve probabilistic forecasting. NWSRFS currently supports a post-processor as a means to lump hydrologic forecasting uncertainty. The post-processor must first be used to understand the different sources of hydrologic uncertainty, then upgraded to account specifically for each source of hydrologic uncertainty including initial conditions, model parameter and model structure uncertainty. Additionally, the uncertainty resulting from the calibration system and the probabilistic forecasting system using different sources of data and different processing routines to compute hydrometeorological and hydrologic inputs must be quantified.

The functional requirements outlined below define a plan to address the shortcomings of the probabilistic hydrologic forecasting system. The first requirement is to include real-time data assimilation in the probabilistic hydrologic forecasting system. Other requirements include using the existing lumped hydrologic uncertainty model to understand the significant sources of hydrologic uncertainty. Final requirements include steps to determine individual sources of hydrologic uncertainty such as initial conditions, model parameter, model structure uncertainty, and the uncertainty resulting from the calibration system and the probabilistic forecasting system using different sources of data and different processing routines.

1. Incorporate real-time data assimilation of hydrologic and hydrometeorological data into operational ensemble prediction.
    a. Develop operations concept and research and development plan for data assimilation
    b. Develop prototype ensemble data assimilation for RFC short-term ensemble prediction.
2. Lumped Hydrologic Uncertainty
    a. Evaluate ensemble post-processor
        i. Quantify the significance of the different sources of hydrologic uncertainties (initial condition, calibrated parameter, and structure errors).

   ii. Quantify how well the current post-processor accounts for the uncertainties.
  b. Recommend improvements to current post processing system
3. Explicitly determine the uncertainties resulting from the difference between the calibration, real time and forecast forcings.
4. Explicitly Determine the Uncertainty of the Initial Conditions
5. Explicitly Determine the Model Parameters Uncertainty
6. Explicitly Determine the Model Structure Uncertainty

3.2.3.3Reservoir and River Regulation Models

The operational requirement for reservoir and river regulation models is to quantify the uncertainty from reservoir operations and river regulations, and quantify the uncertainty of the initial conditions, parameters and model structure of the models used to simulate and forecast reservoir operations and river regulations.

NWSRFS supports different reservoir and river regulation models; SSARESV, RES-SNGL, RES-J and CONSUSE. A limitation of these models is the inability to quantify the uncertainty of the initial conditions, parameters and model structure used to simulate and forecast reservoir operations and river regulations. The functional requirements outlined below aim to quantify this uncertainty.

1. Explicitly quantify uncertainty in reservoir and river regulation models.

3.2.3.4Hydraulic Models

The operational requirement for hydraulic models is to quantify the uncertainty of the initial conditions, parameters and model structure of the hydraulic models used to simulate and forecast flow. Hydraulic models must produce river stage and flow forecasts and uncertainty information at un-gaged points to support probabilistic forecast mapping.

NWSRFS supports the hydraulic model FLDWAV. A limitation of these models is the inability to quantify the uncertainty of the initial conditions, parameters and model structure. The functional requirements outlined below aim to quantify this uncertainty.

1. Explicitly quantify the hydraulic parameter uncertainty.
   a. Derive and test probabilistic channel parameters

3.2.3.5Architecture

To ensure processing integrity and faster science infusion, an architecture management function needs to be developed and implemented for NWSRFS. A primary 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. The preliminary prototype development of this architecture management function serves as the foundation for CHPS. CHPS will be fully realized with the WRP. Use cases will be developed to help discover the complete operational requirements which 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.

The functional requirements outlined below describe specific steps to standardize the data management and delivery; develop an architecture management component to control and unite the developments and enhancements to ensemble forecasting and distributed modeling; provide appropriate GUIs to support a seamless system for ensemble forecasting including calibration, ensemble generation, product dissemination and verification; and provide an open architecture to allow the use of non-NWSRFS models and allow for easier implementation of new model developments.

1. Standardize data management and delivery
2. Develop an architecture management component to control and unite the developments and enhancements of the different ensemble system components to provide a seamless ensemble forecasting system including a migration path for legacy applications.
3. Provide appropriate GUIs to support a seamless system for ensemble forecasting including calibration, ensemble generation, product dissemination and verification.
4. Provide an open architecture to allow the use of non-NWSRFS models and allow for easier implementation of new model developments.

3.2.3.6 Product Generation and Dissemination

The operational requirement is to develop, generate, and deliver useful information to all customers. This information will be derived from the streamflow and streamflow-related ensemble forecasts produced by the ESP system for all time horizons.

The Ensemble Streamflow Prediction Analysis and Display Program (ESPADP) were initially developed to provide interactive analysis and display of ESP time series data. Recent customer survey feedback identified that the current probabilistic products are not meeting customer needs. Determining and satisfying customer needs for probabilistic information is critical to the success of the AHPS program. Probabilistic forecasts 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. 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. User interfaces must satisfy the diverse need of our diverse customers including general customers, emergency managers and water managers and may be satisfied with different levels of information.

As probabilistic information is required at increasing number of river forecast locations, the volume of data will be overwhelming to forecasters. Real-time functionality is required to assess and verify that the ensemble forecasts are reliable. Additionally, the ensemble forecasting system must become more streamlined and automated with appropriate GUIs to assist the forecaster with product generation, validation and dissemination. 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. Finally, other delivery mechanisms should be investigated and tested to see if there are more appropriate mechanisms to deliver information to end users.

The functional requirements outlined below provide steps to improve the ensemble product generation and dissemination. These steps include determining what probabilistic information is relevant to customers; providing the forecaster the real-time ability to assess and verify the reliability of ensemble products; developing appropriate GUIs and tools to assist the forecaster with ensemble product generation, validation, and dissemination; provide more public access to ensemble products; and finally ascertaining if other delivery mechanisms are appropriate.

1. Provide low-flow and drought probabilistic products
    a. Non-exceedance Probability Plot (complete)
    b. Non-exceedance Histogram (complete)
    c. Provide low flow/stage reference value in ESPADP plots (complete)
2. Determine what probabilistic information is relevant to users (emergency managers, water managers and general customers)
    a. Develop procedures to determine what probabilistic information is relevant to users and the most appropriate ways to communicate the information.
    b. Use developed procedures to determine what probabilistic information is relevant to users and the most appropriate ways to communicate the information.
    c. Write a report describing the most relevant probabilistic information for users and the most appropriate ways to communicate the information.
    d. Implement findings into appropriate GUIs to assist in the ensemble product generation and dissemination.
3. Provide ability to assess and verify ensemble products reliability in real time.
4. Develop appropriate GUI to assist in the ensemble product generation, validation and dissemination.
5. Incorporate more public access to probabilistic products.
6. Provide hydrologic information to other delivery mechanisms (PDAs or other future mobile technologies) from a centralized location as appropriate.

3.2.3.7 Data Archive

The operational requirement is to support and maintain a national archive database. This database may be used to support the verification of probabilistic forecasts, support calibration activities for hydrologic and hydraulic models and preserve a history of probabilistic forecasts.

The functional requirements described below describe the steps needed to develop this national archive.

1. Determine data needed to support a verification program of probabilistic products, support calibration activities and preserve a history of probabilistic forecasts.
2. Create a national archive and database procedures to collect the data needed.

3.2.3.8 Verification

The operational requirement is to provide detailed analytic verification data and tools to forecasters, researchers and developers to improve operational forecasting and provide a rational justification for research and development efforts. The ensemble verification system aims at evaluating the quality of ensemble forecasts and hindcasts generated by the operational forecasting software and an ensemble hindcaster, respectively, for hydrometeorological variables (e.g., precipitation and temperature) and for hydrologic variables (e.g., streamflow) to validate the ensemble science and to verify all the probabilistic products. The end goal is to provide the forecast and verification information needed by customers to make their necessary risk based decisions.

The key component of the system will be the verification application, which will evaluate the quality of the ensemble forecasts and hindcasts via the Verification Algorithms and produce reliable and supportable verification statistics. The functional requirements outlined below show steps for developing a probabilistic verification system.

1. Provide an ensemble hindcaster capability to allow forecasters and scientists to validate ensemble science, establish a performance envelope of existing and new ensemble capabilities, improve reliability of ensemble forecasts, and assess benefit-cost effectiveness of newly proposed solutions.
2. Develop methods and procedures to verify probabilistic forecasts; provide capability to disseminate verification metrics, other results and data; and provide real-time access to verification metrics
3. Develop a national performance metric and performance goals to show improvements to probabilistic forecasting.
4. Create an Ensemble Verification Program (EVP) combining the functionality of JProbVS and Ens_verify to verify precipitation and temperature ensembles.
5. Add ability to compute metrics from stored ESPADP tables and observed time series in EVP.
6. Link EVP to the Interactive Verification Program (IVP) to take advantage of all the IVP calculations
7. Add graphics of discrimination, reliability, rank histograms, for fixed locations, time and lead time to EVP.

3.3 Short- to Long-Term Forecast Services Training

Currently training is provided through NWS Training Center and COMET. As science and technologies advance, training must also advance to keep forecasters knowledgeable of current capabilities. Training should be expanded and updated to include the new science development and service implementation capabilities of AHPS.

Universities and private industry can provide the training to support basic hydrologic understanding. A spectrum of approaches and training entities (COMET, NWSTC, WDTB, OHD, etc) will provide training to support the hydrology forecast program's implementation of new science and NWS specific technology. This will ensure that those involved in the operation and support of the program have a sound understanding of system enhancements and upgrades.

The training outlined below describes the training needed to support the hydrologic forecasting program. This includes training in basic hydrologic sciences, hydraulic modeling, and advanced hydrologic sciences.

1. Basic Hydrologic Science - Provide a basic hydrologic science course for RFC forecasters and WFO Hydrologic Program Managers. The course content should include the scientific background to understand and use hydrologic forecasting models. Specific subject matter should include data processing and quality control, hydrologic and hydraulic modeling, and GIS and flood plain mapping.
    a. Deliver "Hydrologic Cycle" Module
    b. Deliver "Unit Hydrograph Theory" Module
    c. Deliver "Streamflow Routing" Module
    d. Deliver "Runoff Processes" Module
    e. Deliver "Flood Frequency Analysis" Module
    f. Deliver "Snowmelt Processes" Module
    g. Deliver "Flash Flood Processes" Module
    h. Deliver "River Ice" Module
    i. Deliver "Long Term Flood Case Study – Rainfall Induced" Module
2. Hydraulic Modeling and Calibration - Provide a hydraulic modeling and calibration course for RFC personnel. The course content should include the necessary skills required to perform hydraulic modeling and calibration.
3. Advanced Hydrologic Sciences - Provide an advanced hydrologic science course for RFC Development and Operations Hydrologists (DOHs), select RFC forecasters and WFO Service Hydrologists. The course content should include the necessary scientific background to understand and implement advances in hydrologic forecasting models. Specific subject matter should include distributed hydrologic modeling, ensemble hydrologic forecasting and precipitation processing.

4 Flood Forecast Mapping and Graphical Dissemination Services

4.1 Operational Concept of Flood Forecast Mapping and Graphical Dissemination

Flood Forecast Mapping and Graphical Dissemination Services are 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. A further service is to provide customers with the capability to create their own information sets.

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 page map depicting flood inundation areas to real-time flood-forecast maps produced from advanced hydrologic and hydraulic models with high resolution GIS and hydrometeorological data sets to include more detail on the location and magnitude of an event.

4.2 Current Capabilities of Flood Forecasting Mapping and Graphical Dissemination

Currently RFC graphical dissemination services are limited to depictions of observations and forecasts and probabilistic products at a limited number of forecast locations. A few demonstration sites in Pennsylvania, North Carolina and Florida are testing the concept of real-time flood forecast mapping services. These maps are produced from data generated by hydrologic forecast models and dynamic routing hydraulic model.

4.3 Requirements to Provide Flood Forecast Mapping and Graphical Dissemination

The requirements to provide flood forecast mapping and graphical products will vary depending on the needs of the given location. Flood mapping services may include graphical E-19s depicting stages for minor, moderate and major flooding; a library of static maps developed at one foot intervals from a one-dimensional, slope area method hydraulic model; real time maps generated from a simplified routing model or steady state hydraulic model; and real time maps generated from a dynamic routing hydraulic model.

4.3.1 Graphical E-19s depicting stages for minor, moderate and major flooding

The operational requirement is to provide graphical E-19 maps depicting stages for minor, moderate and major flooding.

Graphical E-19 maps are produced from digital elevation model data and E-19 information of minor, moderate and major flooding. Currently this effort is being prototyped in North Carolina. The requirements include a proof of concept in a variety of different terrain, coordination with FEMA and outside contractors, and steps needed for national implementation.

1. Proof of concept pilot efforts in North Carolina, Pennsylvania, Kansas, Michigan, Arizona and California.
2. Working with FEMA to incorporate vendor development of Graphical E-19s into local Floodplain Map Modernization contracts.
3. Write national guidelines for WFOs and RFCs to accomplish implementation of Graphical E-19s.
4. Write technical requirements for FEMA vendors who are developing Graphical E-19s as part of their contracts.
5. National implementation of Graphical E-19 maps through local development and vendor contracts.

4.3.2 Library of static maps

The operational requirement is to provide a library of static maps depicting one-foot intervals from a one-dimensional, slope area method hydraulic model.

The library of static maps would be produced from digital elevation model data and water surface profiles derived from a one-dimensional, slope area method hydraulic model. The requirements include a proof of concept in a variety of different terrain and national implementation.

1. Proof of concept pilot efforts in a range of areas.
2. Develop a national database inventory of high resolution elevation data and status of FEMA Cooperating Technical Partners Flood Insurance Map Modernization projects at NWS river forecast point locations.
3. Write national guidelines for WFOs and RFCs to accomplish implementation of a library of static maps.
4. National implementation of a library of static maps through local development and vendor contracts.

4.3.3 Real time maps generated from a simplified routing model

The operational requirement is to provide real time maps of flood forecast information from simplified routing models or steady state hydraulic models.

Real-time flood-forecast maps may be produced from water surface profile data from any hydraulic routing model. NWS uses the Simple Hydraulic Routing Technique (SHRT) model. Also, dam break flood-forecast maps can be generated using output from the Simplified Dam Break (SMPDBK) model.

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.

1. Produce surface water profiles from the Simplified Hydraulic Routing Technique (SHRT)
2. Produce surface water profiles from the Simplified Dam Break (SMPDBK) model.
3. Develop techniques to merge OHD's surface water profiles from simplified routing models or steady state hydraulic models to NOS flood inundation maps.
    a. Capability to produce integrated flood inundation maps
    b. Capability to produce salinity forecast
    c. Capability to produce temperature/velocity forecasts
4. Implement the hardware/software infrastructure necessary to produce flood inundation maps from a simplified routing model or a steady state model integrated in the AWIPS structure.
5. Provide a flood-forecast mapping application to visually display real time water surface profiles generated from a simplified routing model or a steady state model.
6. Provide a generic data interface between FLDVIEW and other flood mapping tools using XML.

4.3.4 Real time maps generated from a dynamic routing hydraulic model.

The operational requirement is to provide real time maps of flood forecast information from dynamic routing hydraulic models.

Real-time flood-forecast maps may be generated using water surface profiles from any hydraulic routing model. NWSRFS supports the use of the dynamic routing model FLDWAV. 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.

The requirements outlined below including testing and evaluating FLDWAV/FLDVIEW at various locations, implementing FLDVIEW into AWIPS baseline operations, steps and procedures to automate some of the data needs for flood inundation mapping and finally to enhance the flood inundation mapping with geographic data layers.

1. Implement the hardware/software infrastructure necessary to produce flood inundation maps from a dynamic routing hydraulic model integrated in the AWIPS structure.
2. Provide a flood-forecast mapping application to visually display real time water surface profiles generated from a dynamic routing hydraulic model (FLDWAV).
    a. Standard map view (x-y orientation)
    b. A cross-section, with the x-axis along the centerline of the stream
    c. A cross section that traverses the floodplain from one side to the other.
        i. Evaluate accuracy of the flood maps generated using FLDWAV/FLDVIEW in Pennsylvania due to Hurricane Ivan.
        ii. Evaluate the accuracy of the maps in the Tar River Basin.
3. Provide a generic data interface between FLDVIEW and other flood mapping tools using XML.
4. Merge river hydraulic flood maps with coastal maps.
5. Automate the procedure of 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, creating cross-section elevation profiles (FLDXS)

4.3.5 Dissemination

Perhaps the most meaningful part of the flood forecasting services is disseminating this information to our customers. The dissemination requirements must first determine what products to disseminate, evaluate procedures for dissemination, and ultimately provide our customers the tools to create their own information sets.

1. Evaluate existing dissemination processes
2. Determine products for dissemination
3. Develop a GIS-based display system to present a variety of hydrologic information to meet the needs of local, regional, and national users.
    a. Evaluate prototype ArcIMS system design
        i. Incorporate Graphical E-19s with CRH ArcIMS mapping project
        ii. Convert FLDIMS MapGuide templates for all areas to ArcIMS
    b. Develop Flood Internet Mapping Service (FLDIMS) to overlay flood inundation shape files over geographic data layers showing aerial photographs, roads, structures, and other relevant information.
    c. Incorporate census data in this system to enhance hydrologic outlooks, watches, and warnings.
    d. Incorporate low flow database information in graphical format utilizing ArcIMS.
    e. Provide graphical dissemination of ESPADP digital data, NDFD shapefiles, NWS Doppler radar shapefiles, precipitation data, water supply information, water quality information, and climate data.
4. Provide customer with tools to make their own information sets.

4.3.6 Flood Forecast Mapping and Graphical Dissemination Services Training

Universities and private industry can provide the training to support basic hydrologic understanding. A spectrum of approaches and training entities (COMET, NWSTC, WDTB, OHD, etc) will provide training to support the hydrology forecast program's implementation of new science and NWS specific technology. This will ensure that those involved in the operation and support of the program have a sound understanding of system enhancements and upgrades.

The training outlined below describes the training needed to support flood mapping and graphical dissemination services. This includes training in GIS.

1. GIS Users Workshop - Provide a basic Geographic Information Systems course for RFC forecasters and WFO Hydrologic Program Managers. The course content should include the background to understand and use Geographic Information Systems with regard to hydrology.

5 Logistical Verification

Hydrologic program managers might use forecast verification to show program value and program improvements as well as make important decisions on scientific and resource investment. For these users, a verification system that includes measurements of non-skill attributes or logistical measures of the hydrologic forecast service are required. The purpose for collecting the logistical information is to answer questions like the following. What new types of forecasts have been developed? Is the number of forecast locations increasing or decreasing? Have computational improvements reduced the effort to issue a forecast? Have methodological improvements reduced the time it takes to prepare a basin for forecasting? To answer these types of questions the collection of the following logistical measures are required:

1. Characterizing point forecasts by service type, frequency and location.
2. Characterizing areal forecasts by service type, frequency and location.
3. Daily queries of the number of issued forecasts by type and location.
4. Quantifying the person effort required to set up a basin for forecasting; including data gathering, calibration, model setup and implementation efforts.
5. Quantifying the person effort required to issue each type of forecast; including manual quality control of input data, forecaster run-time modifications and forecaster review and analysis.
6. Quantifying the timeliness of issued forecasts.

The end goal requirement is to standardize and automate the collection of these logistical verification measures and provide a national database of those measures to those who manage the hydrology program. Query tools should be provided, such that managers may query the national database of logistical measures and create meaningful assessments.

6 Outreach

Through the Office of Climate, Water and Weather Services (OCWWS) Hydrologic Services Division (HSD) and the regional headquarters, outreach efforts ensure partners and customers understand clearly and can benefit fully from new AHPS products and services. The objective is to accomplish outreach with National, regional and local partners with local emphasis on locations where AHPS is being or will soon be implemented.

The requirement is to develop clear and consistent AHPS outreach materials for use by National, regional and local personnel. This task supports the development of national and local brochures and supports local outreach activities including workshops. This effort also includes activities such as focus group studies and customer satisfaction surveys to ensure that AHPS is meeting customer needs.

1. Develop, produce and distribute Turn Around, Don’t Drown (TADD) national brochure.
2. Develop, produce and distribute Floods the Awesome Power national brochure
3. Support the development, production and distribution of local outreach brochures.
4. Support local outreach activities including Customer Regional Workshops and educational outreach.
5. Conduct focus group studies to understand customers needs for and usage of probabilistic streamflow forecasts.
6. Conduct biennial Customer Satisfaction Index surveys of AHPS/Hydrologic Services.

7 Web Page Deployment

The national web presence for AHPS short- to long-term forecast products is at its infancy and must be expanded to accommodate graphical hydrographs for all forecast locations. The operational objectives are to develop, generate, and deliver useful streamflow and streamflow related information to all customers through the national AHPS web page. The national AHPS web page should provide a standard look and feel for the presentation of AHPS hydrologic and forecast information by all NWS weather offices. Additionally, a single national database that aggregates information on hydrologic observation and service locations used by WFOs and RFCs should be provided. The current web presence for AHPS is in its infancy and must be enhanced and expanded. The functional requirements outlined below will improve product generation and dissemination and provide a national web presence for AHPS. These steps include enhancing web pages by adding new AHPS forecast locations and updating maps, implementing HydroGen into AWIPS, implementing the first phase of the AHPS Products and Information Team recommendations, and implementing a National River Location Database.

1. Enhance Web pages by adding new AHPS forecast locations and updating maps
2. Implement HydroGen into AWIPS
3. Implement the first phase of the AHPS Products and Information Team recommendations.
    a. Data basing of AHPS web products configuration information
    b. Integrate customer feedback into enhanced river hydrograph
    c. Develop NWS strategy for consistent precipitation graphics.
4. Implement National River Location Database (NRLDB)
    a. Link with local WFO IHFS database to support national database of E-19 information.
    b. Enhance NRLBB to include services information.
    c. Enhance NRLBB to include observational and forecast information to support AHPS web pages.
    d. Enhance NRLBB to incorporate graphics files.