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TRANSFER OF HYDROLOGIC TECHNOLOGY FROM THE UNITED STATES TO THE PEOPLE'S REPUBLIC OF CHINA

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ABSTRACT

The United States of America (USA) and the People's Republic of China (PRC) share many common interests which include the objective to provide improved hydrologic forecasts. Despite major technological advances in hydrologic forecasting, lost lives and property damage due to flood events has been great in both the USA and the PRC. This was recently illustrated by The Great Flood of 1993 in the Mississippi River basin and the 1994 flooding in the Zhu basin. Part of the solution to save life and property and to minimize economic and environmental impacts resulting from such flood events is by achieving improved accuracy and additional lead time in streamflow forecasting. Therefore, exchanges of flood forecasting technologies are key to advancing the state-of-the-art capabilities in both countries. Technologies involved in flood forecasting include hydrometeorological data observations and processing algorithms, hydrometeorological modeling and forecasting systems, telecommunications, and computer hardware and software.

BACKGROUND

The United States Department of Commerce (DOC) and it's National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), has the responsibility to provide river and flood forecasts and warnings for the protection of life and property within the USA. These forecast services also provide for economic and environmental well being through improved water resources management. The NWS strives to continually improve its forecasting capabilities and in recent years the NWS, in partnership with the governments of the PRC and Egypt, is supporting implementation of state-of-the-art flood and water resources forecasting technologies for the Huai River basin in China and the Nile River basin in Egypt. The NWS Office of Hydrology has lead

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responsibility to provide technical assistance to develop the hydrologic forecasting system for these basins.

NOAA has actively collaborated with various Chinese government agencies since 1979 under three separate science and technology protocols. The protocols have addressed important issues in oceanography, hydrology, and atmospheric science and meteorology. The continuation of such technological exchanges are important since catastrophic weather related events have occurred in both the USA and PRC. For example, The Great Flood of 1993 (NWS, 1994) constituted the most costly and devastating flood in the United States during modern times. Damage estimates range between USA $15-20 billion, and human misery and environmental impacts were of catastrophic proportions. The number of fatalities caused by the flood is estimated to be 48 people. Approximately 54,000 people had to be evacuated from flooded areas at some time during the flood, and 50,000 homes with associated property were estimated to be destroyed or seriously damaged. The flood has had enormous ongoing, indirect impacts on hundreds of thousands of people. Similarly, over the centuries China has experienced some of the world's most catastrophic flooding. A particularly damaging flood in 1935 left 890,000 dead and 12.5 million people homeless; in 1982, floods damaged or destroyed more than 400,000 homes. The 1994 floods in the PRC left more than 4,300 people dead and caused an estimated USA $17.4 billion in damages.

Most recently, Madame Ho Jing, Vice Minister of Water Resources (MWR), PRC and Jeffrey Garten, Under Secretary of Commerce, USA, signed a Statement of Intent (SOI) in Beijing on August 30, 1994 regarding flood and water resources forecasting. The SOI "is intended to encourage future cooperation between the USA and PRC in areas pertaining to exchanges of science and technology as they relate to advanced water resources forecasting." Prior to the SOI, a Memorandum of Agreement (MOA) was established between the PRC Ministry of Water Resources and the NWS in which the NWS agreed to furnish technical services for a prototype flood forecasting system for the Huai River Basin in China. The MOA covered the period of April 1, 1994 to January 31, 1995. The project was funded through the World Bank, and the NWS Office of Hydrology is leading development activities to assemble an enhanced hydrologic forecasting system for the Huai River basin. Accompanying the transfer of the NWS river forecasting technology to PRC are commercial computer hardware and software. Through these and continued exchanges of scientific data, technology and personnel, the USA and PRC are making important achievements in the natural sciences in supporting sustainable development by protecting natural, economic and human resources.

HYDROLOGIC FORECASTING APPLICATIONS

The forecasting system being implemented in the PRC is the National Weather Service River Forecast System, NWSRFS. The NWSRFS (Fread, et. al., 1991) is a software system (over 350,000 lines of computer code) consisting of many components, including deterministic hydrologic/hydraulic models, which are used to perform all steps necessary to generate streamflow forecasts. The system includes the Calibration System (CS), the Operational Forecast System (OFS), the Extended Streamflow Prediction (ESP) System and the Interactive Forecast Program (IFP). The CS performs the tasks needed to process historical hydrometeorological data and to estimate model parameters for a specific basin. The OFS enables the processing of data and the development of forecasts of hydrologic variables using operations (models/procedures) selected by the forecaster. ESP is the portion of the NWSRFS which enables a hydrologist to make extended probabilistic forecasts of streamflow and other hydrologic variables, such as soil moisture and snow water content. The IFP combines the OFS with a graphical user interface in order to provide forecasters the visual capability to easily and quickly make changes and decisions.

NWSRFS and the Huai River Project

The objective of the recent MOA between the NWS and PRC was to develop a prototype for an interactive flood forecasting system for the Huai River Basin above Zhengyangguan. The completed forecasting system will provide streamflow information that can be used by decision makers to operate flood-control engineering structures (reservoirs, flood-control storage and detention areas, and dikes), guarantee the security of these structures and reduce losses as much as possible. Thus, the system will be the cornerstone of an advanced decision support prototype system for the seven major river basins within China.

The MOA covered Phase I of the project wherein the NWS purchased workstations, installed the latest UNIX operating System on the workstations, installed the NWSRFS Interactive Forecast Program (IFP), coordinated two study tours for MWR Officials, defined parameters and files to operate IFP on the system for the Huai River basin, and assisted with the calibration of hydrologic models, including the addition of a new component to the IFP to allow use of the assimilator (filter) used as part of the Nile Forecasting System. Additionally, the NWS trained PRC hydrologists, assisted MWR in the review of their Master Plan, and assisted MWR in the design and development of a multilevel comprehensive forecasting system operation.

FORECASTING SYSTEM ADVANCEMENTS

The potential for future international technological exchange is heightened as NOAA is now advancing it's hydrologic forecast capability through the Water Resources Forecasting System (WARFS) program structure which builds upon: 1) NOAA's current scientific and operational infrastructure, including the NWSRFS; 2) National Weather Service (NWS) modernization technologies, especially NEXRAD (NEXt Generation Weather RADar - WSR-88D) and AWIPS (Advanced Weather Interactive Processing System); and 3) cooperative and supportive partnerships with other government agencies, universities, and the private sector. WARFS, including Extended Streamflow Prediction (ESP) enhancements, will take advantage of all these program relationships by building on the technological and information framework they provide. ESP enhancements will enable WARFS to provide for analyses of streamflow traces within specified future time windows, objectively account for meteorological/ climatological forecasts in the streamflow trace analysis, provide for a variety of probabilistic analyses of the traces, and package probabilistic streamflow forecast products with extended lead times (up to several months). Thereby, WARFS will provide

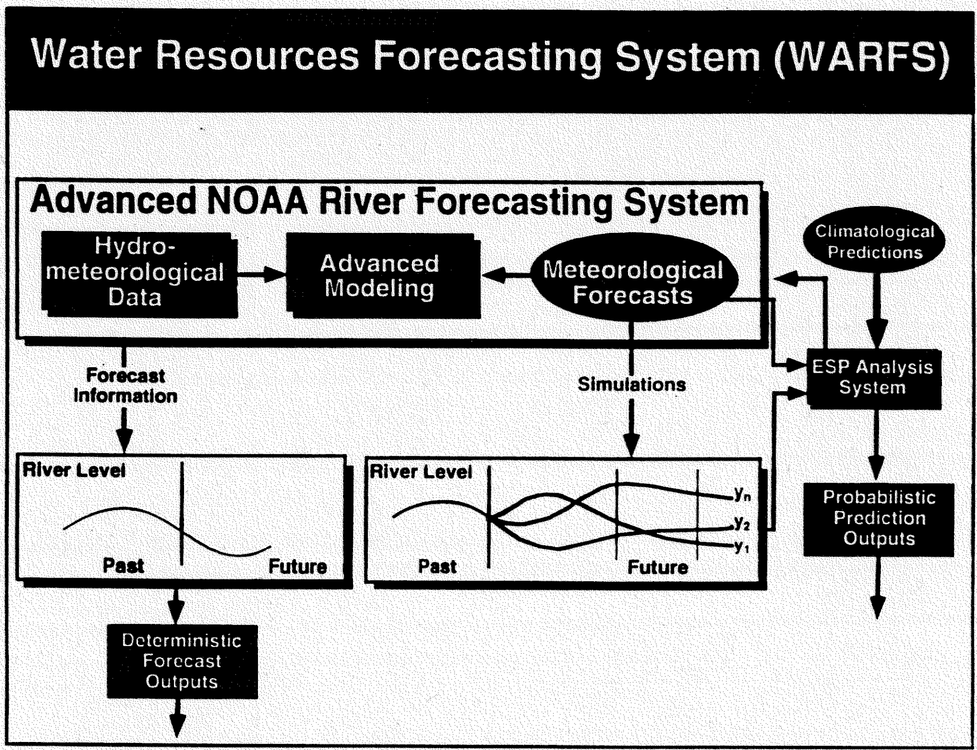

Figure 1. Schematic of the Water Resources Forecasting System (WARFS) integrated real-time modeling and data management/analysis system.

river forecasts which not only account for precipitation already on the ground but which also will probabilistically account for estimates of future precipitation. This advanced prediction system will greatly improve a nation's capability to take timely and effective actions that will significantly mitigate the impact of major flood and drought situations. The advanced system will also provide probabilistic products to water resource managers for the evaluation of water availability and allocation for water supply, navigation, hydropower, ecosystems and agriculture.

WARFS is an integrated real-time modeling and data management/analysis system which includes provisions for the use of historical hydrologic/hydrometeorologic data and meteorological/climatological forecasts for input to Extended Streamflow Prediction (ESP) simulations (Figure 1). As indicated above, implementation of WARFS services builds upon the NWSRFS and NWS modernization technologies and is divided into three interdependent functional requirement areas: Integrated Data Management and Analysis, Advanced Hydrologic/Hydraulic Modeling, and Advanced Product Packaging/Dissemination. ESP is the portion of NWSRFS which produces probabilistic forecasts out to several months. WARFS probabilistic forecasts not only will greatly improve the capability of emergency managers and water facility managers to take timely and effective actions to mitigate the impact of major flood and drought situations, they also will provide better support for overall water resources management (e.g. better management of competing water demands between irrigation, fisheries, and hydropower). For example, the application of ESP on the Nile

River has increased forecast lead time of the annual flood from two weeks to over three months with acceptable accuracy.

Integrated Data Management

The NOAA Hydrologic Data System (NHDS) will provide the nucleus of capabilities required by WARFS to handle the integration of real-time/historical station and gridded data, and model generated (forecast) outputs. The data sets will be large, having sizes comparable with up to 50 years at temporal resolutions of hourly to daily for gridded (50,000 - 150,000 grid points at resolutions as small as 2 km) estimates of surface hydrometeorological variables. Gridded data will include precipitation, temperature, snow water equivalent, and evapotranspiration. Time series data also will include point estimates for parameters such as river flow, river level, and reservoir discharge. The NHDS will access, assimilate, analyze and maintain the required data and information. The information maintained by the NHDS spans the time domain from historical to real-time, and spans the quality domain from observed, or raw data, to high quality derived products. The data handled by the NHDS will be acquired from a variety of sources which also provide data which span the quality and time domains. Characteristics of current and potential operational and archive data sources are now being identified, and plans and techniques for acquisition of these data by the NHDS are being developed.

The data volumes and analysis techniques contemplated for WARFS require the use of specialized computer-based techniques for both data management and computational effectiveness. In addition, these large data volumes will require the use of relatively automated approaches with minimal manual intervention. The advanced mathematical/ statistical analyses to be performed upon the data involve the production of high quality estimates of fields and time series of hydrometeorological physical and derived elements using multivariate analysis techniques.

Advanced Hydrologic/Hydraulic Modeling

As depicted in Figure 1, the advanced modeling module of WARFS applies hydrometeorological data in order to produce deterministic streamflow forecast products. As Figure 1 also illustrates, these same advanced models may be coupled with historical hydrometeorological data and meteorological/climatological forecasts/predictions to produce multiple simulations of future river flows. Additionally, analyses may be performed upon the simulations in order to produce long-term probabilistic predictions of streamflow. ESP is at the heart of WARFS capabilities allowing for probabilistic predictions and, when hydrometeorological coupling capabilities are included, provides objective probabilistic predictions of greater accuracy, and more information for decision makers to arrive at "optimum" water management and flood control measures.

The existing ESP procedure, within NWSRFS, assumes that meteorological events which occurred in the past are representative of events which may occur in the future. A separate streamflow time series is simulated for each year of historical data using the current soil moisture and streamflow conditions as the starting point for each simulation. Before an ESP analysis is performed upon these potential future streamflow trace ensembles, the forecaster can subjectively weight the years of simulated streamflow based on the similarity between the climatological conditions of each historical year and the current year. Since subjective weighting is difficult and often unreliable, a forecaster usually assigns an equal weight for each simulated year. However, this approach disregards the relative importance of the recent past, present, and predicted future meteorological and climatological states. Therefore, a hydrometeorological coupling procedure for the ESP ensemble analyses should be developed in order to objectively assign weights to each simulation.

Meteorological/climatological forecasts would be the most useful if detailed quantitative precipitation forecasts (QPFs) could be directly input to streamflow prediction models. Unfortunately, current QPF models and procedures do not consistently provide sufficiently accurate values for direct input to hydrologic models (NWS, 1994). Although current QPF products provide generalized guidance information indicating rainfall amounts and locations of rainfall areas, they generally do not provide the necessary spatial and temporal detail and accuracy required for assigning QPF values to individual watersheds, especially for time windows beyond 12 to 24 hours.

In the absence of the required precision in precipitation forecasts, particularly beyond 24 hours, enhanced ESP ensemble analyses approaches will be developed to objectively extract the skill contained in the meteorological forecasts through coupling of the historical time series of precipitation with the precipitation forecasts for the current year. One approach to such coupling involves the development of objective techniques for the assignment of weights to the individual traces included in the ensembles analysis based on multiple streamflow simulations using 25 or more years of historical records. Probabilistic streamflow forecasts can then be developed using mathematical/statistical analyses upon the traces obtained for each year of data. These analyses can be performed for different forecast periods and additional hydrologic variables of interest.

Advanced Product Packaging/Dissemination

The advanced hydrometeorological modeling provided by WARFS will greatly improve NOAA's capability to provide more timely and accurate forecasts. NOAA will provide advanced forecast products through WARFS which meet multiple objectives, and varying user needs, including the following: 1) support forecast service requirements of government and quasi-government water and emergency managers; 2) satisfy needs for forecast services at near-, mid-, and long-term time scales for a wide variety of water use situations nationwide; 3) provide critical information on forecast reliability; 4) improve hydrologic forecast sensitivity to weather and climatic forecasts; and, 5) provide water resources forecasts to non-government intermediaries, who in turn serve specific industries.

CURRENT AND POTENTIAL IMPLEMENTATION ACTIVITIES

WARFS implementation activities have begun within the upper Mississippi River basin at the NWS North Central River Forecast Center, located in Minneapolis, Minnesota. As an increase in USA resources become available, WARFS implementation activities can be expedited within the Mississippi Basin and early implementation can proceed in one or more additional basins in the United States, e.g. the Columbia River Basin in the Northwest which is of critical economic and environmental importance to the USA. As these technologies are advanced, they may be shared with other countries through memoranda of agreement or through other technological exchange mechanisms as appropriate.

SUMMARY

The National Weather Service River Forecasting System (NWSRFS) includes commercial computer workstations and software, and hydrometeorological software, developed over a period of two decades by NWS scientists to forecast floods and droughts along rivers in the United States. Its sophisticated computer models incorporate past weather and hydrological data with a system of hydrologic/hydraulic models that accurately predict flows along the river. These same, or similar, technologies should allow China's water resource managers to make critical decisions to protect lives and property in the flood plain. Once such capabilities are in place on the Huai River, further implementation activities can be expanded into additional China river basins, such as the Yangtze.

The Department of Commerce and NOAA, in partnership with other major cooperators, are now advancing their forecasting technologies in the USA through the development and implementation of the Water Resources Forecasting System (WARFS). WARFS extended forecast lead times (up to several months) will allow for: more effective mitigation of extreme events (e.g. floods and droughts), improved operations of water resource facilities (e.g. irrigation and hydropower facilities), and enhanced ecosystem management (e.g. fisheries and wetlands management). As these advanced technologies are developed, DOC/NOAA/NWS can exchange them with PRC and other governments in order to help meet sustainable development needs. These exchanges may be executed through memoranda of agreements or through other technological exchange mechanisms as appropriate.

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