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Corps Water Management System (CWMS) – Capabilities and Implementation Status

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14. ABSTRACT
This paper provides an overview of the Corps Water Management System (CWMS) which is an automated information system that supports the U.S. Army Corps of Engineers water control management mission of regulating river flow by more that 700 reservoir and water control structures. CWMS is a nationwide integrated system of hardware and software that enables Corps offices to acquire and manage real-time hydromet and system status data, perform forecasting and decision-support analysis, and provide for user access to virtually any data and information in the system.

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Corps Water Management System - Capabilities and Implementation Status

Darryl W. Davis [1,2]

Abstract

The Corps Water Management System (CWMS) is the automated information system that supports the U.S. Army Corps of Engineers (Corps) water control management mission of regulating river flow by more than 700 reservoir and water control structures. CWMS is a nationwide integrated system of hardware and software that enables Corps offices to acquire and manage real-time hydromet and system status data, perform forecasting and decision-support analysis, and provide for user access to virtually any data and information in the system. The prior system, known as the Water Control Data System (WCDS) has been in service since the late 1970's. Advances in computer and related hardware and software provided the opportunity to upgrade the system and improve execution of the water management mission. The new modernized CWMS includes replacing computer hardware, creation of a corporate water control management database system, and upgrading and development of new modeling and decision support software. The project to modernize CWMS software and database system began in 1997 and has now progressed from software development and testing phase to the deployment phase. Corps-wide deployment began in the summer of 2001 and will be completed in December 2002, progressing region by region within the U.S. CWMS software is comprised of the following components: data acquisition and validation; database; data dissemination; forecasting and decision support modeling; and control and visualization interface.

Background

As part of its Civil Works mission, the US Army Corps of Engineers plans, designs, constructs and operates a variety of water resource projects. Projects include, for example, multi-purpose storage reservoirs, navigation dams and locks, and levee and bypass systems with closure and diversion structures. Corps Emergency Operations often include re-enforcing or temporarily raising levees, sandbagging efforts, and evacuation during flooding. The Corps Water Management System (CWMS) is used to acquire real-time data on watershed conditions, develop forecasts of project inflows and uncontrolled flows below projects, determine project releases, and evaluate impacts of alternative release scenarios. CWMS provides critical information to Corps water managers to make informed decisions under a variety of routine and emergency conditions. Corps' water managers work in close coordination with other Federal (i.e. National Weather Service, US Bureau of Reclamation, Federal Emergency Management Agency), state, and local water and emergency management organizations, to carry out their missions and

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responsibilities. Water management information is also provided to the media and the public.

CWMS was modernized to incorporate state-of-the-art hydrologic modeling techniques, real-time data processing, decision-support tools and network-based information dissemination. The system is now being deployed in each Corps field office with water control management responsibilities - about thirty-five offices. The system was modernized under the rigorous management purview of the Army's Life Cycle Management of Information Systems (LCMIS) process and is now an official Army Automated Information System (AIS).

CWMS Overview

CWMS encompasses steps in the water control management process starting from the receipt of hydromet and watershed data and project status data, through the modeling of system response and decision support analysis, ending with the dissemination of data and decision results. The incoming real-time data include river stage, reservoir elevation, gage precipitation, WSR-88D spatial precipitation, quantitative precipitation forecasts (QPF) and other hydro-meteorological parameters. These data are used to derive the hydrologic response throughout a watershed area, including short-term future reservoir inflows and local uncontrolled downstream flows. The reservoir operation model flows are then processed to provide proposed releases to meet reservoir and downstream operation goals. Then, based on the total expected flows in the river system, river profiles are computed, inundated areas mapped, and flood impacts analyzed. CWMS allows evaluation of any number of operation alternatives before a final forecast scenario and release decision are adopted. For example, various alternative future precipitation amounts may be considered, hydrologic response may be altered, reservoir release rules may be investigated, and alternative bridge obstruction, levee integrity, or other river conditions may be evaluated. When an operation decision is made the results, along with supporting hydromet, watershed, and project status and release data may be disseminated to others via web technology.

The system emphasizes visualization of information in time and space. The primary CWMS user interface is map based to provide clear spatial reference for watershed and modeling information. CorpsView, a Corps developed spatial visualization tool based on commercially available GIS software, provides a direct user interface to GIS products and associated spatial attribute information. The system is 'live' 24/7, continuously providing support during routine high and low flow periods, and during emergencies. CWMS is self-monitoring providing automated status information on components and processes, and alerting to service needs.

CWMS Components

Figure 1 shows the major components of the CWMS (counter clockwise from upper left): Data Acquisition (DA), Database (DB), Modeling (MOD), Control and Visualization Interface (CAVI), Data Dissemination (DD). These components have been developed in network client-server architecture, permitting each component of the system to be hosted on one or more separate hardware platforms. The current server side equipment is Sun Solaris machine(s) and the client (CAVI) side can be fielded on Windows 2000 or Sun Solaris. The major portions of the products are written in Java, with Fortran, and C++ used for certain of the model computations. The CWMS components shown would typically be installed in a local area subnet within each of the thirty-five Corps field offices.

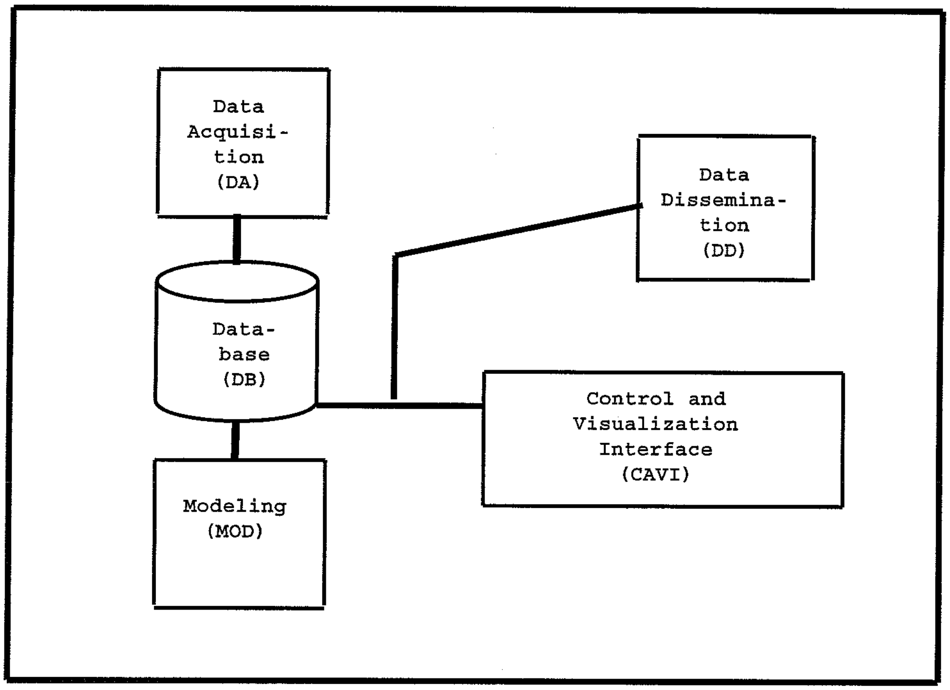


Figure 1. CWMS schematic and components.

Data Acquisition. The Data Acquisition (DA) component is responsible for ingesting data from any of the supported data sources. Currently, the primary data streams processed in the Corps are GOES Data Collection Platform (DCP) and National Weather Service SHEF. These and other formatted data may be processed as it is received via FTP or other file transfers, or via point-to-point network socket connections. Either type data is written directly to permanent storage and is then operated upon by the data acquisition software. Two levels of data screening may be performed. "On-the-fly" screening uses only simple magnitude and range checks. The second level of screening can perform tests that consider the rate-of-change of variables, comparison with neighboring stations, and other statistical tests. The DA component is also responsible for the derivation of secondary parameters. Typical derivations include: reservoir pool elevation to reservoir storage, river stage to flow, and accumulative precipitation to incremental precipitation. All data is stored in the database during its processing by the DA components. The data acquisition display is user configurable to depict data status via color bars positioned on a background map. These bars are time-scaled and reflect the data quality assigned during screening (e.g. green - OK, yellow - questionable, red - rejected). Graphic/tabular editing screens are available to correct data with quality problems.

Database. The Database (DB) component provides permanent data storage for the system. It is responsible for the management of all data received from the data streams and all data generated as derive and modeling operations are performed. The record database is an Oracle relational database designed for standard application in all Corps water management CWMS installations. The Database Interface (DBI) controls all data written to or read from the database. The DBI provides a single image view of data that is used in the many components of CWMS. All data in the database is stored in Coordinated Universal Time (UTC) in System International (SI) units. Activities requesting data from the DBI receive the information in US Customary or SI units. In all cases time remains in UTC and the application is responsible for displaying the time correctly in the users selected time zone. The consistent use of UTC resolves issues where data crosses time zones and the problematic semi-annual shifting between standard and daylight time. **Figure 2** shows thumbnail plots of river status for several locations with the Milesburg plot enlarged. This display is a live depiction of data as it flows in and is stored in the database.

Modeling. The modeling component is responsible for the specification of model alternatives, the execution of model runs, and the display and interpretation of analysis results. The model suite includes precipitation input preparation, hydrologic response modeling, reservoir operation modeling, steady and unsteady flow river profile analysis, inundated area determination, and flood impact analysis. The models that are implemented in CWMS include the HEC suite of NexGen programs (USACE 2001a), with the addition of GIS processing and viewing via Environmental Systems Research Institute products of ArcInfo and ArcView (ESRI 2001). The model functions are: HEC-HMS (USACE 2001b) - precipitation runoff; HEC-ResSim (USACE 2002b) - reservoir system; HEC-RAS (USACE 2001c)- river profile analysis; HEC-FIA (USACE 2002a)- flood impact (damage); and ArcInfo/ArcView - inundation boundary computation,

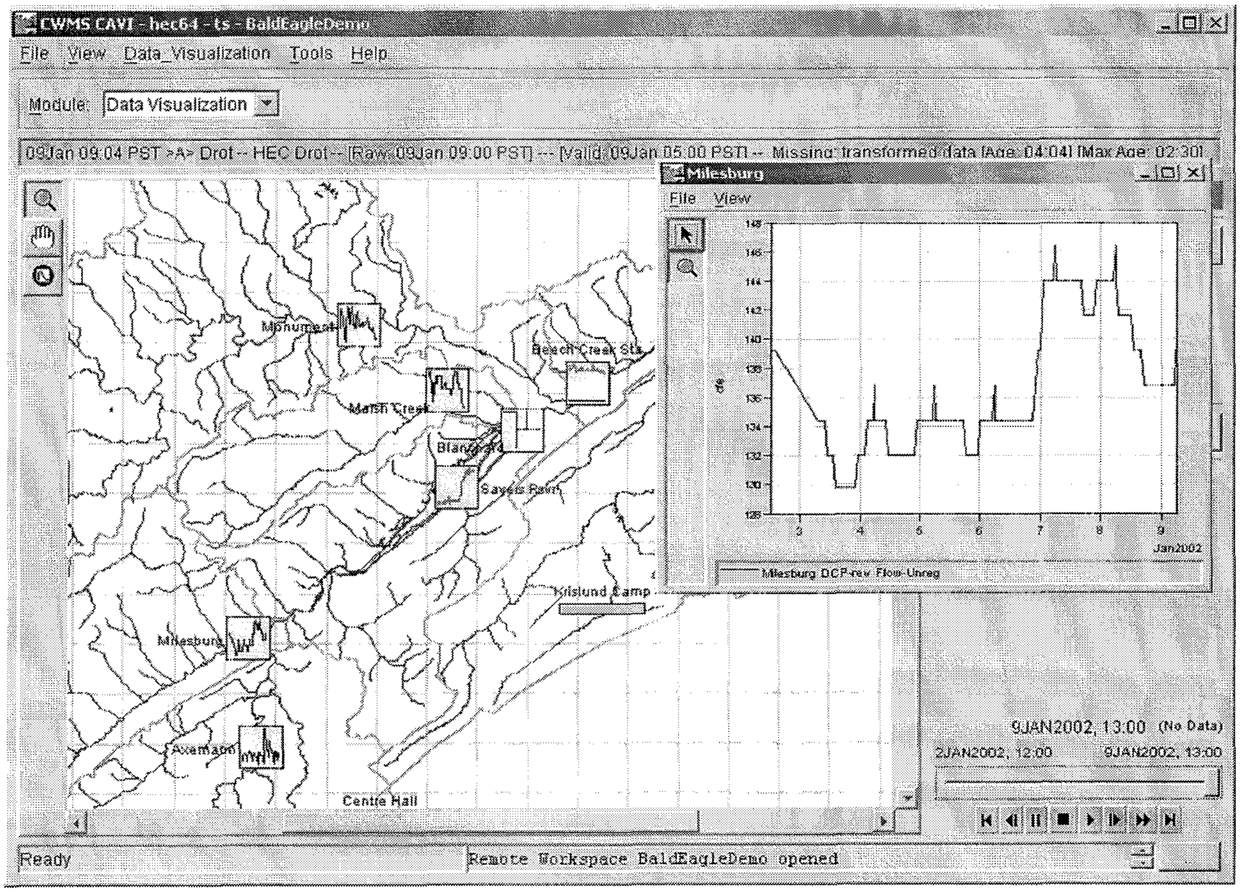


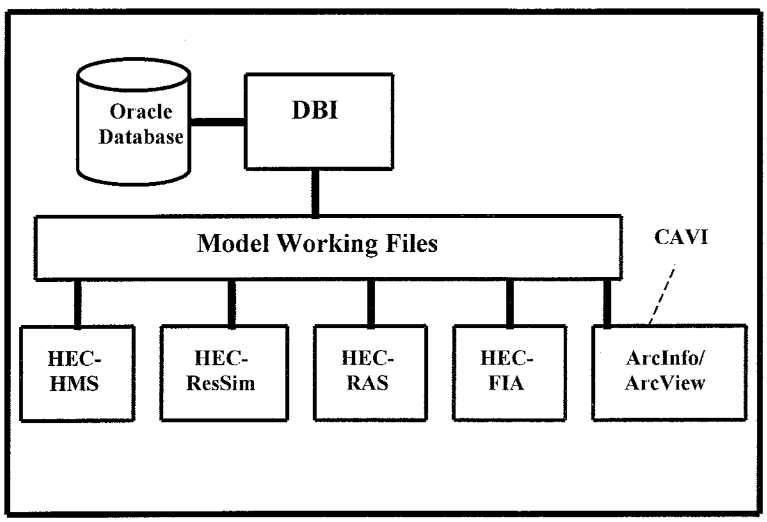
Figure 2. Live thumbnail plots from database.

and GIS information viewing. Access for set up, seamless model execution as an integrated suite, and viewing is via the CAVI. The integration schema permits other supplementary models (than those presently implemented) to be substituted or added so that they would function in a similar transparent and seamless manner.

Figure 3 shows the models as integrated in CWMS, and **Figure 4** is the CAVI dialogue for specifying a forecast alternative. At a user specified forecast time, data pertinent to a watershed area is extracted from the database and placed in a modeling sub-database. This sub-database is then the source and destination for all model runs and all the alternatives that are evaluated. At completion of the analysis the final operation alternative results are posted back to the Oracle database for dissemination. The sub-database, the related model parameters, and specific model output and log files can be saved to off-line storage to serve as a complete record of the analysis performed to support the decision process. **Figure 6** (included later) is an example of the model interface for the test watershed in Bald Eagle Creek, Pennsylvania. The depiction is a zoomed window displaying the model layer for reservoir analysis. Other model layers of watershed basins/flow, flood impact, and stage can be displayed separately or as multiple overlays depending on user preference.

Hydrologic modeling. The hydrologic response of the watershed is modeled using spatially distributed precipitation. HEC-HMS accepts gridded precipitation from both radar and point precipitation gage sources. Digital Elevation Model (DEM) data is used to develop model basin boundaries and parameters. Runoff excess from each grid cell is determined and is routed using the Modified Clark procedure to provide runoff at the sub-basin outlet. Sub-basin hydrographs are then routed down through the channel network to develop flow into reservoirs, and local flow at downstream locations. The HMS model is set up and calibrated for a base forecast condition outside of the CWMS environment and inserted into the CWMS system - a one time (or occasional) set up. Within CWMS, selected model adjustments are permitted in the forecast mode, for example, general wetness condition (loss rates) by watershed region, and this capability is operated via the CAVI. **Figure 5** depicts the HEC-HMS model layout.

Reservoir modeling. The analysis of reservoir operations is performed using HEC-ResSim. This newly developed reservoir simulation program determines project releases based on a set of user supplied operation rules. A reservoir model is defined over a stream alignment,



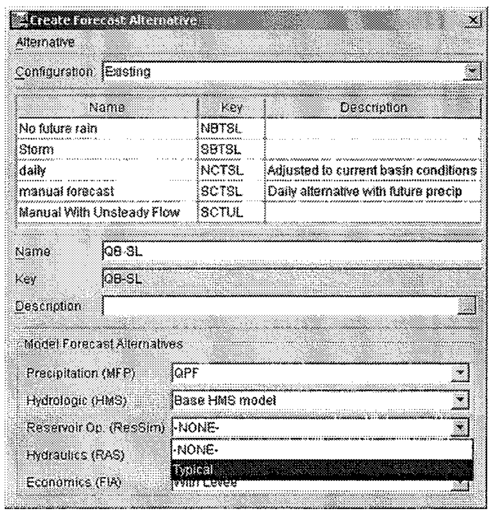


Figure 3. CWMS models integration schematic.

Figure 4. Forecast setup dialogue.

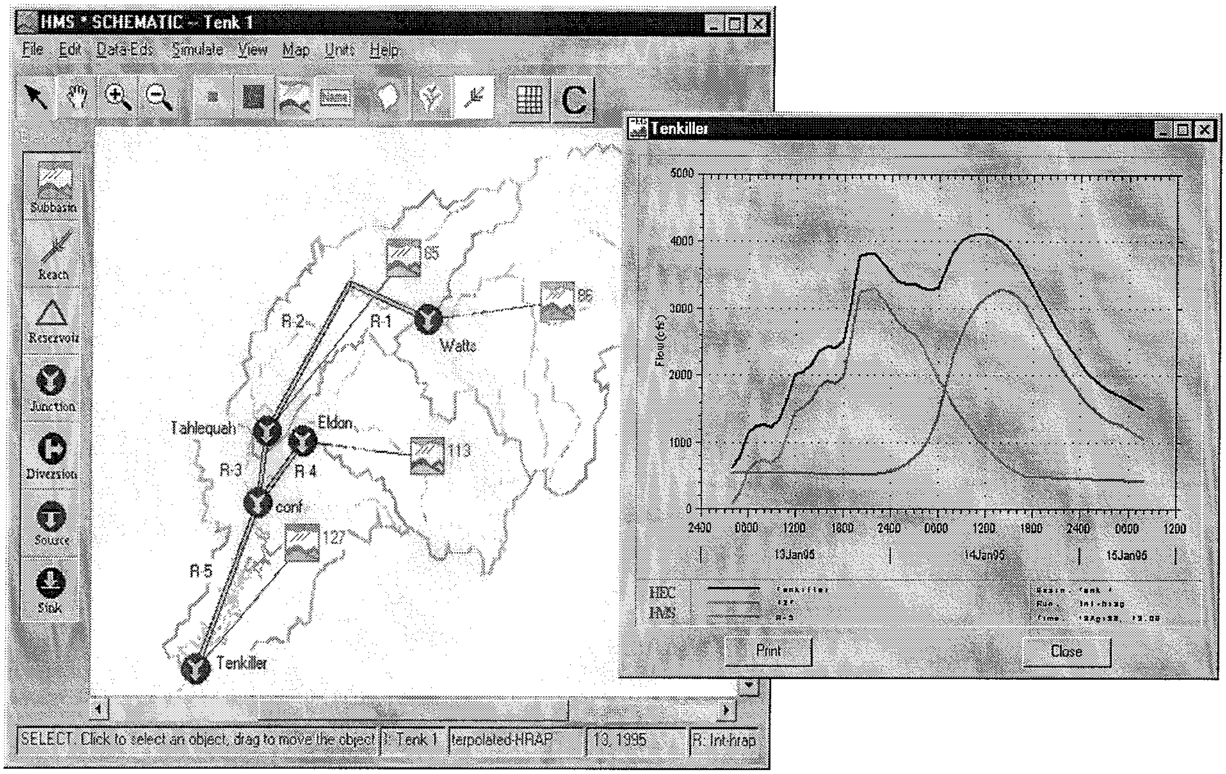


Figure 5. Typical HEC-HMS model schematic and results.

which shows the river network underlying the system model. Model objects representing reservoirs and channel reaches, are drawn by selecting an object tool from the tool list and locating the upstream and downstream ends of the object on the stream alignment. Operational data are defined and stored separately for each reservoir. Each reservoir "owns" one or more sets of data that define the operational storage zones and associated release rules. Rules can be defined to control individual outlets within the outlet works or groups of outlets. Rules are also available to control operation for downstream goals or constraints.

This rule-based approach allows good flexibility in describing desired behavior for individual reservoirs operating for multiple local and downstream goals, as well as when reservoirs must operate as a system. The reservoir model uses inflows generated from the hydrologic model runs. Initial pool elevation, its corresponding reservoir storage and known project releases must be available to properly initialize the model. In cases where different rules lead to a conflict in determining releases, a rule priority is used to resolve the conflict. The determined releases are then combined with local uncontrolled flows from the hydrologic model to provide total flows throughout the watershed. **Figure 6** depicts the reservoir layer in the model interface of the CAVI. Note that the display panel with an array of display choices is activated by selecting the control point of interest on the stream alignment shown in the reservoir layer.

River Profile modeling. The total river flow for each of the alternatives is used to determine the water surface profiles before, through, and downstream of the reservoirs. The HEC-RAS model is capable of generating both steady and unsteady flow profiles. Each of these determinations is based on a stream model that includes in-line structures and cross-section

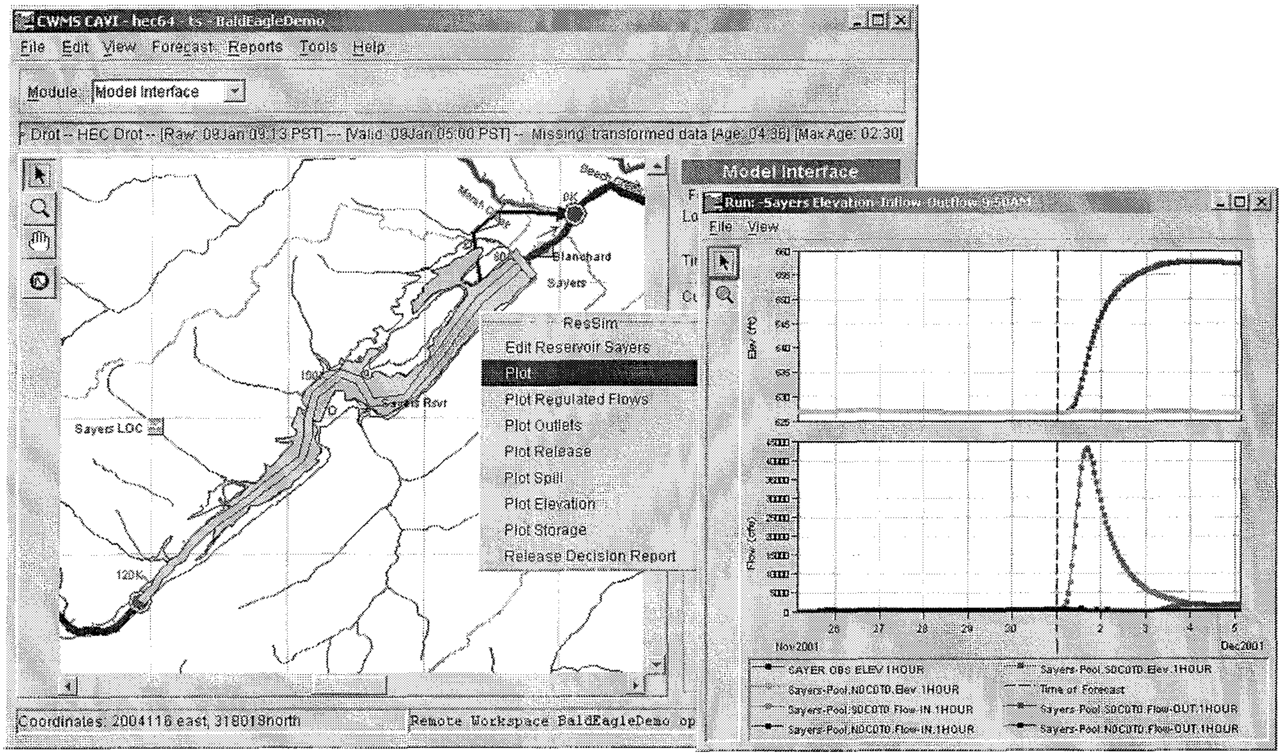


Figure 6. HEC-ResSim reservoir layer and sample display.

geometry. Geo-spatial tools may be used to assist in generating the necessary cross-sections from triangular irregular network (TIN) files. Because this operation can be performed with spatially registered cross-sections, the resulting water surface profiles can be used to map inundated areas. **Figure 7** shows output displays from the river profile analysis with HEC-RAS. The inset is a quasi- 3D representation of the stream; this display can be animated to show the rise and fall of the profile during passage of a forecast flood event.

Flood Impact Analysis. Based on the information available from the preceding model steps the impacts of flows and stages may be evaluated. This evaluation is based on relationships between flow and/or stage and various evaluation functions, such as damage, area/properties impacted, and emergency response table. The damage functions may reflect urban, suburban, and agricultural conditions. Impacts are evaluated for any number of impact areas as defined by the user. Impact results may be aggregated by county, state, congressional district, or other desired spatial entity. The relationships used for computing impact analysis in real-time are separately prepared in a one time, or occasional, set up step. A number of GIS-based and other utilities are available to assist in function development. **Figure 8** is the CAVI display for the flood impact layer of the model interface. Selecting the impact area of interest brings up a number of displays and tabulations for selection by the user.

Data Dissemination. Internet Web and other automated technology is used to provide information from the CWMS to interested parties. Data received from the data acquisition components, derived data, and final project operation data are available for dissemination to

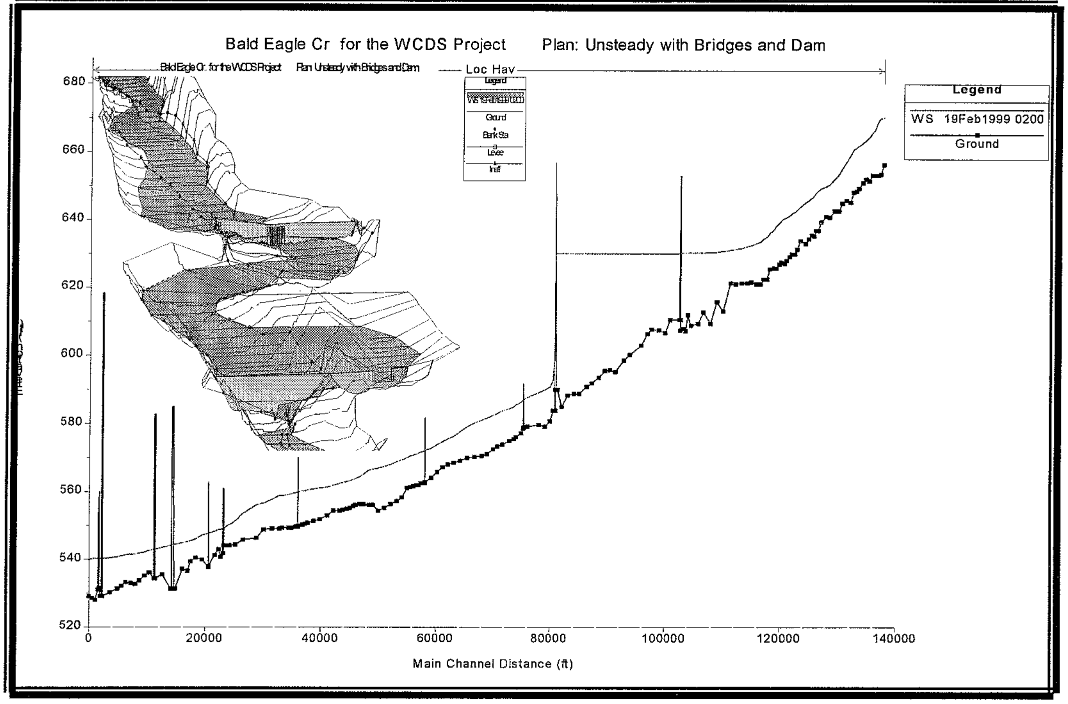


Figure 7. River profile example displays.

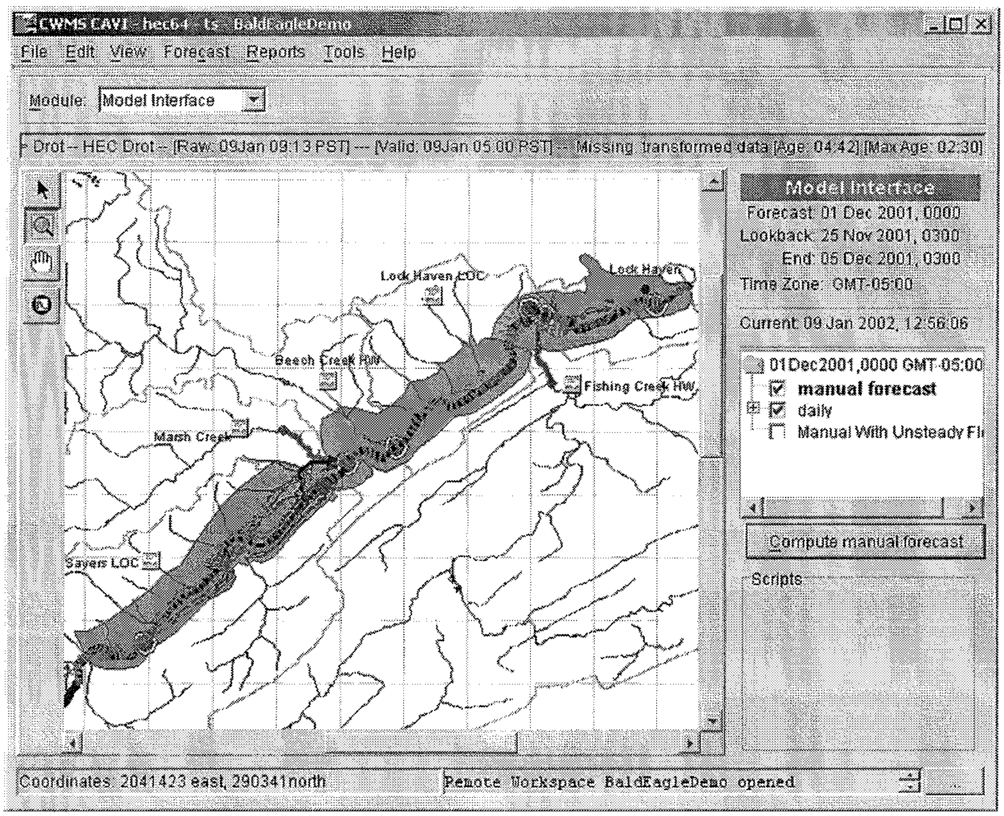
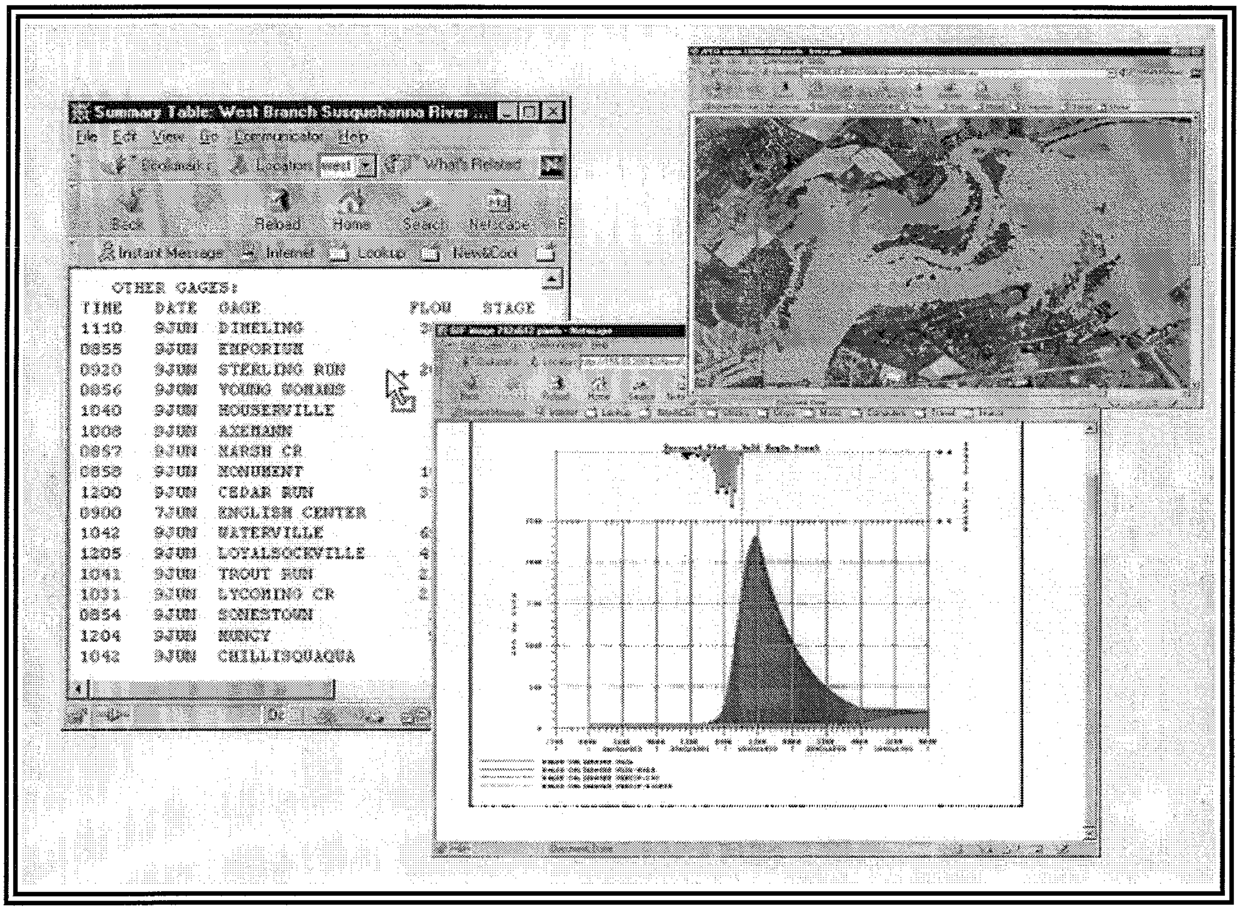


Figure 8. Flood impact layer of model interface.

other Corps offices, cooperating Federal, state and local agencies, and other public and private interests. A close working relationship exists between the Corps of Engineers and the National Weather Service (NWS). Information that the Corps of Engineers disseminates is solely associated with its mission to operate water projects, and to perform emergency flood fight activities. Public dissemination of flood alerts, flood warnings, and other weather information is the responsibility of the NWS. **Figure 9** is a depiction of a sample Web-accessible display automatically generated via selecting a 'posting' option from the CAVI.

Deployment and Implementation

CWMS is an official Army AIS that has progressed through the various LCMIS milestones, recently achieving Milestone Decision III (approval to deploy) in August 2001. Deployment of the system began in July 2001 and is proceeding systematically across the Nation Corps region by Corps region. Deployment will be concluded in December 2002. For each Corps office with water control management responsibilities (about thirty-five offices), deployment consists of installing and testing the CWMS server, client, database, and Commercial (COTS) software; activating the live data feeds and processing; installing and activating the Oracle database;



configuring, preparing data, and calibrating the forecasting and decision support models; creating

Figure 9. Sample Web posting of forecast results.

proper administration and security processes for the system, and achieving on-site user training and operation. Successful deployment results in fully operational CWMS for at least one meaningful watershed within the office's geographic area. Full implementation, that is extension of the coverage to the office's remaining geographic area and water control projects, is expected to occur over the 3 to 5 years following deployment. At the time of preparation of this paper, deployment had been accomplished for approximately half of the Corps offices.

Acknowledgments

Planning, design, development, testing, and deployment of CWMS has been a model of teamwork among HEC staff and the extended community of other participants across the Corps and in the private sector. HEC is the responsible 'materiel developer' under the HQUSACE program manager; Corps field office teams developed the system requirements; HEC staff led the software development with assistance by a private contractor; selected field offices served as test sites throughout the development process; and a senior water management group provided oversight. Principal HEC staff with leadership roles in CWMS development include, besides the author: Art Pabst - Technical Director; Dan Barcellos - database system; Bill Charley - CAVI and models team leader; Carl Franke - data acquisition and data dissemination; Matt McPherson - data validation/transformation; Tom Evans - runoff forecasting and deployment coordinator; Gary Brunner - river profile modeling; Joan Klipsch - reservoir system modeling; and Penni Baker - flood impact modeling. The GIS-related activities team member is Tim Pangburn, USACE Remote Sensing and GIS Center. John DeGeorge and his team at RMA Associates, Fairfield, CA contributed substantially to software development for the DBI, flood impact and reservoir models, and overall system integration.

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