New water management system begins operation at US projects

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The US Army Corps of Engineers has developed a new automated information system to support its water control management mission. The new system provides a variety of decision support tools, enabling water control managers to acquire, transform, verify, store, display, analyse, and disseminate data and information efficiently and around the clock.

The US Army Corps of Engineers operates nearly 700 water control projects around the USA, affecting the lives and property of millions of people. These projects include reservoirs, navigation locks and dams, and levee and bypass systems with closure and diversion structures. Many projects serve multiple needs such as flood control, navigation, water supply, hydroelectric power, water quality control, recreation, and environmental enhancement.

Background to the new development

Importance of real-time data

Water control managers who regulate multipurpose projects need access to timely and accurate information on which to base decisions. During a flood event, decisions sometimes have to be made within minutes or hours from the onset of rising river stages. During a drought, decisions can affect water availability for months into the future. Water control managers need continuous real-time data observations from field sites, as well as reliable watershed modelling tools, to provide appropriate responses to changing hydrologic conditions.

Existing system

For the past 25 years, water control management decisions in the Corps have been supported by the 'Water Control Data System', or WCDS. This evolved over a period of about 15 years (1975 to 1990), and comprised dedicated mini-computers, data acquisition and communications hardware.

Although guided by Corps policy, the WCDS was not a centrally planned and developed system. Some data processing programs were developed and fielded throughout the Corps; others were developed and used regionally or in individual offices. From a national viewpoint, it was an assortment of individual systems that were locally maintained, managed and supported. The system was inconsistent in its level of performance and capacity across the Corps. Furthermore, simulation modelling and watershed forecasting efforts were only performed on the most highly developed systems in a few offices.

Need for improvements

The widespread Mississippi flood of 1993 affected the central third of the USA, involving more than 12 States and overlapping several Corps districts. The necessity to collect and store real-time data from this large area, the requirement for computer processing power to prepare timely watershed forecasts, and the unprecedented demand for public information taxed the limits of the WCDS. Non-identical WCDS platforms in adjacent Corps districts further complicated monitoring and response as the flood progressed downstream. As a result, the Corps identified a pressing need to develop a uniform water management system integrating communication networks, standard computer hardware, centrally developed and supported software, and state-of-the-art hydrological and hydraulic models.

Overview of CWMS

In the middle and late 1990s, water control managers from around the Corps convened on numerous occasions to define requirements, and subsequently the design, of a new system. The system was named the 'Corps Water Management System', or CWMS. System development was assigned to the Corps' Hydrologic Engineering Center (HEC) in Davis, California. Development was completed in 2001, and the system is now being deployed at Corps offices with water management responsibilities.

CWMS is a comprehensive system incorporating the acquisition, transformation, verification, storage, display, analysis and dissemination of information to support the Corps' real-time water control mission. The incoming real-time data include hydrological information (river stage, reservoir elevation), meteorological information (observed and forecast precipitation), and other hydro-meteorological information (such as water quality data). Observed data are used to view the current status of the watershed. Watershed modelling programs are used to forecast runoff, reservoir response and operations, river stage, inundated area, and downstream impacts. A number of future precipitation and reservoir operation scenarios can be evaluated before a final release decision is made.

The new system emphasizes the visualization of information in both time and space. The primary CWMS user interface is map-based, providing a spatial reference for data and watershed models. The system is 'live' continuously around the clock and throughout the year, providing support during routine periods, high and low flow periods, and emergencies.

CWMS is designed as a networked client-server system. The server acquires, processes, and stores data, and executes the simulation models. CWMS clients provide system controls as well as data visualization and model interface functions. This design provides a centrally located database for each office to support the sharing of models and modelling results. This architecture allows users to access the system from their individual offices, or from remote locations should their office become inaccessible.

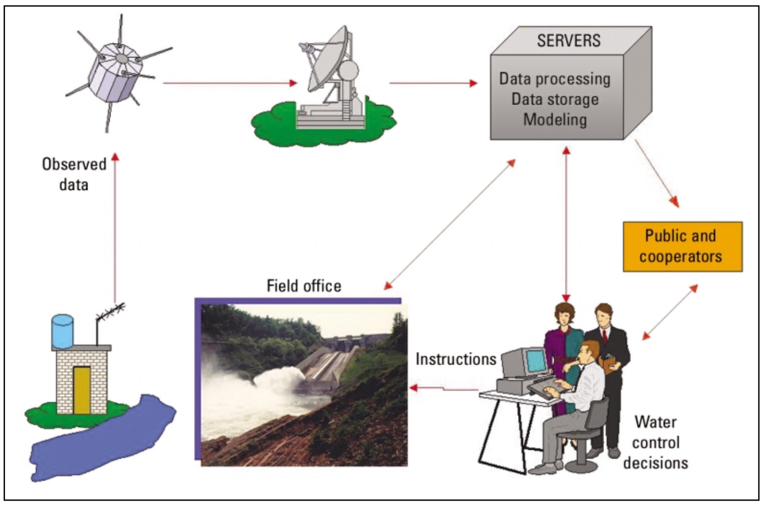


Fig. 1. The water control management decision process.

Water control management decisions

Fig. 1 shows the typical sequence of data collection, analysis, and decisions within a water control management centre using CWMS.

As shown in the lower left corner of the figure, gauges are provided at key locations and they record observed conditions such as river stages and precipitation. Typically, gauges are equipped with telemetry units which record data hourly and transmit the information to a satellite. The data are then downloaded to CWMS computer servers in the water control management centre. Here the data are processed, stored, and made available for viewing and watershed modelling.

Water control managers use CWMS clients to review data, simulate watershed processes, and make decisions concerning appropriate reservoir regulation strategies to achieve project purposes. Operational instructions are communicated to the dam operators by telephone, email, radio, or other means. The dam operators make the physical changes to gate settings at the water control structures which reflect the instructions.

Components of the system

The CWMS software package can be regarded as a puzzle consisting of five interlocking pieces, as shown in Fig. 2. The four pieces around the perimeter all deal with some aspect of data management. The key middle component, which interacts with all of the data management activities, is watershed modelling. It allows water control managers to use observed real-time data and National Weather Service (NWS) forecast precipitation to simulate future conditions.

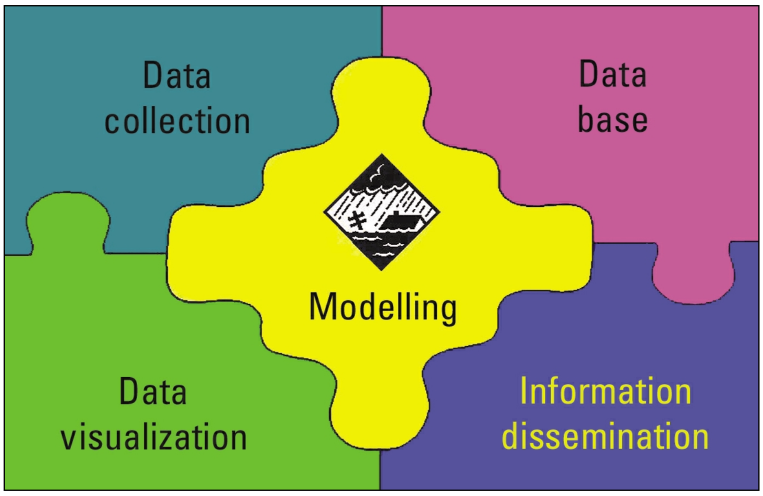


Fig. 2. The components of CWMS.

Data acquisition

CWMS data can be classified as either real-time data or static information. Real-time data include time-series observations, such as river stages, precipitation, reservoir elevations, or pH. Real-time data are gathered continuously from thousands of monitoring sites around the country. This component also provides tools for data validation and transformation.

Static information includes watershed area, reservoir storage capacity, channel geometry, spillway elevation, and other similar data. This is usually gathered from maps, design documents, or one-time field measurements, and is used to calibrate watershed models.

Data storage

Once data have been collected, there is a need to store them efficiently. CWMS uses a relational database (ORACLE) to store the data. This database is capable of organizing and storing vast amounts of data for instant retrieval, either for observing existing trends or for simulating future conditions. In addition, multiple users can access the database at the same time. This concurrent use feature could be especially important during a widespread high water event (such as the 1993 Mississippi flood) when many organizations need to share a common database as floodwaters are progressing downstream.

Data visualization

In a typical water control management centre, managers may need to review hourly data from hundreds of gauges. A concise view of the data and watershed status is essential for making informed and timely decisions. CWMS provides a variety of methods to visualize data and modelling results quickly. These methods normally 'roll up' data into summaries that are shown as graphs, tables, spreadsheets, charts, river profiles, maps, or sometimes a combination of these. Most summaries are linked to a watershed map, so that the user can click on a map icon and immediately view the data associated with that specific location.

Data dissemination

The fourth component of data management addresses dissemination of information and operational decisions to other interested parties. The audience may include: other Corps offices; cooperating Federal, State, and local agencies; other countries; project sponsors, stakeholders and users; and interested organizations and individuals. The posting of relevant information to specially designed web sites is a convenient way to disseminate it to others in a timely fashion.

Watershed models

CWMS provides an integrated suite of modelling programs which represent the hydrological and hydraulic aspects of the watershed. The installed modelling programs include HEC-HMS (Hydrologic Modelling System), HEC-ResSim (Reservoir Evaluation System), HEC-RAS (River Analysis System) and HEC-FIA (Flow Impact Analysis).

HEC-HMS simulates watershed hydrology using observed and predicted precipitation to compute runoff. Runoff is combined with base flow to generate flow hydrographs at various points within the watershed.

HEC-ResSim simulates the operation of a reservoir or a system of reservoirs. The program uses inflow to the reservoir (computed by HMS), the physical characteristics of the reservoir (dam height, storage capacity and outlet capacity) and operational guidelines to simulate reservoir operations. The product is a forecast operation scenario which includes lake elevation, reservoir releases and spillway flow.

HEC-RAS computes river stages and water surface profiles using the uncontrolled flows computed by HMS, or the controlled releases computed by ResSim. RAS uses the hydraulic characteristics of the stream channel including cross-section geometry, stream bank roughness coefficients and information on bridges, culverts or other structures in the river.

FIA uses the results from RAS, along with basic economic information, to assess the impact of an event scenario. FIA computes agricultural and urban damage in terms of the financial cost of the damage, the area flooded, the number of people affected, or the number of structures inundated. FIA also computes the damage prevented (or benefits provided) by reservoir and levee projects.

These modelling programs are unique in that they have been developed for a wide variety of applications and provide a basic framework for developing watershed models. It is up to the user to develop and calibrate models for a particular watershed.

Watershed modelling with CWMS

Watershed models, when combined with weather predictions, allow water control managers to prepare forecasts of hydrological conditions in the watershed. The managers then use the results to help make reservoir regulation decisions with the knowledge of how those decisions will affect both in-lake and downstream areas.

Control and visualization interface

Access to the CWMS components is accomplished through the Control and Visualization Interface (CAVI). The CAVI is the interface which integrates the individual pieces of CWMS into one package. It includes mechanisms to evaluate the quality of incoming data, visualize information in time and space, facilitate modelling parameter adjustments, control and execute simulation models, and compare the results of different scenarios. The CAVI functions are grouped into modules corresponding to various water management tasks. These modules include Data Acquisition, Data Visualization, and Model Interface.

Data Acquisition Module

The Data Acquisition Module provides a means to review visually the status and quality of data being received from the real-time gauges. Valid and current data are critical to running models in real-time. Fig. 3 shows a typical screen from the Data Acquisition Module. The colour bars are spatially located to represent the location of key gauges and indicate the variation through time of the quality of the data. Each bar in Fig. 3 represents a seven-day time period. At an interval specified by the user, CWMS will screen the incoming data for a gauge and indicate the status using various colours. Green indicates that data are being received and have been verified. Yellow indicates that data are being received but the values are questionable. Red indicates that data for the gauge are missing or rejected.

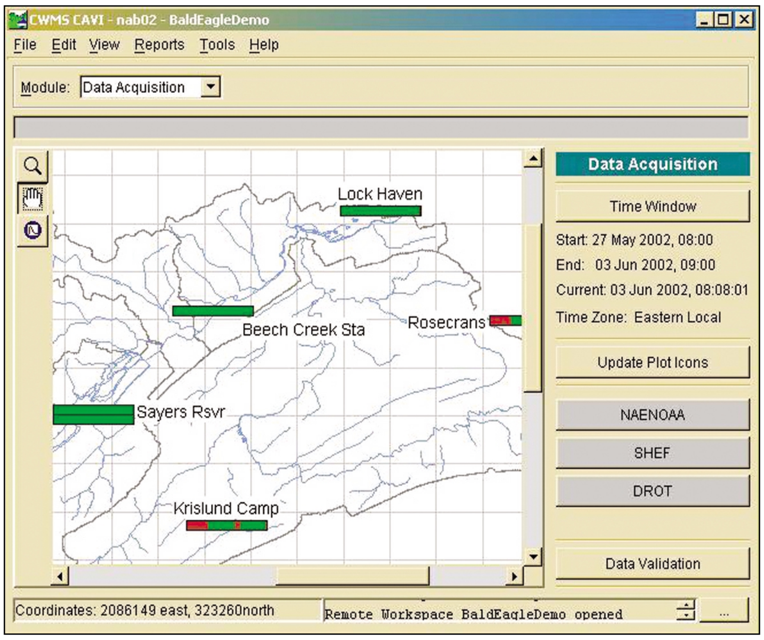
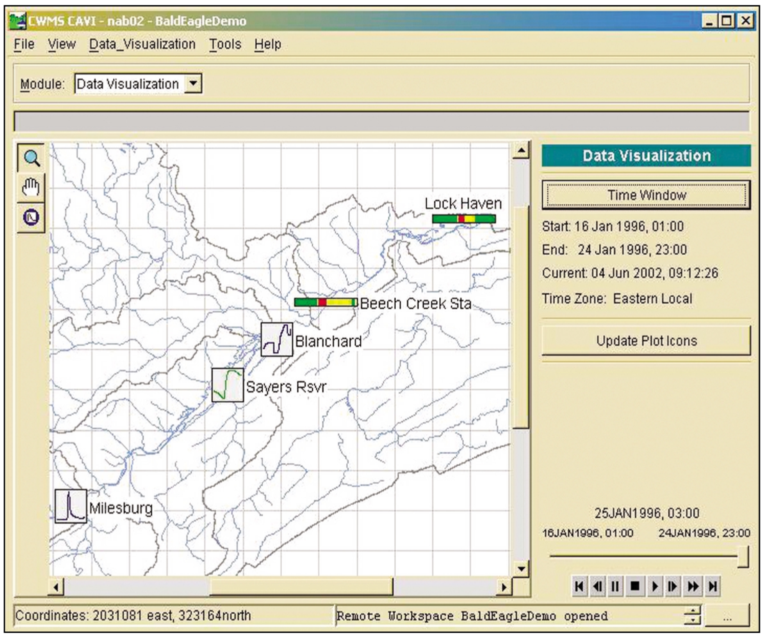


Fig. 3. The data acquisition module.

Data Visualization Module

The Data Visualization Module is the CWMS tool which allows the water control manager to evaluate visually the current hydro-meteorological state of the watershed. Fig. 4 shows a typical screen from the Data Visualization Module. Spatially located icons representing specific data at gauge locations are shown in two forms: thumbnail plots and threshold colour bars. Thumbnail plots are miniature plots of data for a location, and threshold colour bars act as alerts and are set up to change colour based on certain threshold values. In Fig. 4, the green portion of a threshold colour bar indicates a normal river stage, yellow indicates that a cautionary stage has been reached, and red indicates that the flood stage has been exceeded. Again, each bar represents a seven-day time period. Full sized plots or tabulations of data are also accessible through these icons.

Fig. 4. The data visualization module.



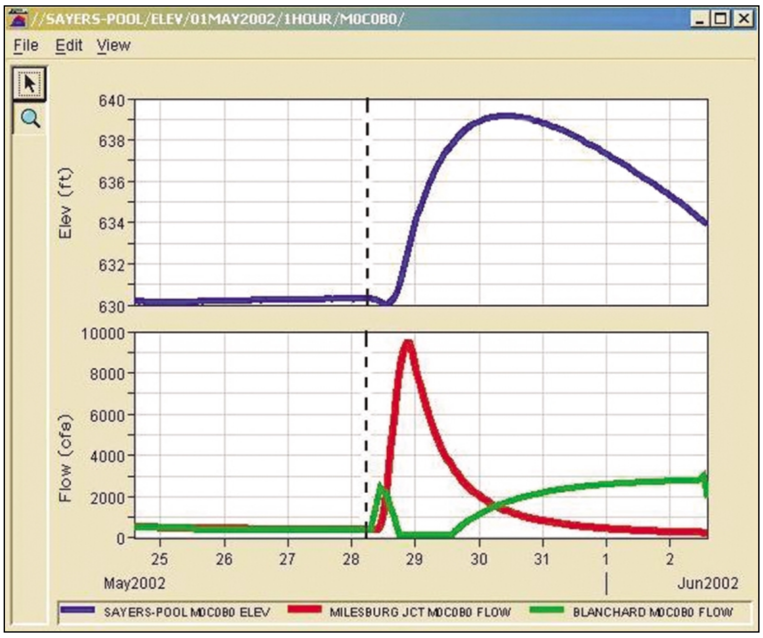


Fig. 5. Sample plot of model simulation results.

Model Interface Module

The Model Interface Module provides the means for creating and running a comprehensive watershed simulation scenario. A real-time simulation uses observed data up to the present time and forecast precipitation. The integrated models use those data to forecast the watershed's response to the anticipated precipitation. Different real-time parameter settings, such as reservoir gate openings and different future precipitation amounts, can be applied to produce various scenarios, and the results and impacts can be compared graphically and through reports.

Sample products

The model results can be viewed using several methods. The first of these, as shown in Fig. 5, is a plot of the forecast data. The dashed vertical line represents the time at which the forecast was made. Data to the left of that line represent observed data. Data to the right of the line represent the forecast data, or the response of the basin to precipitation. Fig. 5 shows the reservoir inflow and outflow in the bottom portion and the reservoir lake elevation at the top.

Fig. 6. Flood inundation mapping.

CWMS also uses Geographical Information Systems (GIS) tools to carry out analyses and enhance graphical displays. Aerial photography, digital maps and other GIS data allow the geo-referencing of critical features in the watershed. Results of the model simulations can be used to map inundated areas, such as the example shown in Fig. 6. The inundated area can then be combined with other GIS data to identify critical locations which would be affected by the event, such as schools, roads, and hospitals.

A further enhancement to the inundated area map is the Impact Action Table. Critical river stages at key locations, associated impacts, and suggested responses or actions are entered into the FIA model. As a simulation is being executed, dates and times for reaching the critical stages can be predicted. This information can then be made available to field personnel, who can take advance measures such as installing closures, erecting road barriers, or evacuating campgrounds.

Requirements and applications

System requirements

When fully deployed, CWMS will be a powerful system, providing a variety of analytical tools to assist water control managers with real-time decisions. Initially, however, CWMS can be demanding to implement. It requires users to gather, store, process, and disseminate watershed information as well as to develop and maintain an electronic network for managing large amounts of data. CWMS will require:

• a wide network of field observation points for collecting and reporting real-time data;
• extensive static information about watersheds and projects;
• engineering and modelling expertise to develop, calibrate, and verify hydrological/hydraulic models so they accurately reproduce watershed conditions;
• precise hydrographic and topographic maps for plotting inundated areas;
• a fast reliable computer network to link the multiple CWMS components and make them available for concurrent use; and,
• system administrators to maintain the software and hardware.

All of these items will require up-front time and money to implement. Some will require specially trained personnel. The initial investment in CWMS may be substantial, but the benefits to be derived will far outweigh the costs.

Potential applications

First and foremost, CMWS is designed to be a decision support system for real-time water control managers within the Corps of Engineers. It can be applied whenever decisions are needed with respect to the storage and release of water (day-to-day routine operations, flood events, drought periods, or emergency situations).

CWMS also has potential applications in related water resource fields. A few of these applications are described below:

• *Emergency planning and response*. Impact action tables can be used to identify the effects of high (or low) river stages, the appropriate emergency responses, and estimates of times and dates when the impacts are expected to occur. Data in the tables may provide valuable, even life-saving, advance information for flood plain residents.

• *Flood plain studies*. CWMS inundation maps can be used to identify flood plains, hazardous river crossings, safe evacuation routes, flood-free safety shelters, and the flood susceptibility of public utilities.
• *Project planning*. CWMS can be used to examine the arrangement, location, and sizing of new projects as well as changes to the size and regulation of existing projects. Proposed projects can be 'tested' electronically, using historic or synthetic flow records, before a commitment is made to actual construction.
• *Project performance evaluation*. CWMS can be used to analyse project performance after a high water event, to report damage prevented, and to generate data for post flood reports. The system can also be used to test alternative regulation scenarios to determine if improved project performance might be possible.

These are just a few of the potential applications; there are certainly many others. Although CWMS has been developed specifically for regulating Corps of Engineers projects, its inherent flexibility will permit its application to both small and large watersheds anywhere in the world.

Conclusion

The initial development phase of CWMS was completed in February 2001. Beginning in September 2001, HEC began a phased deployment process to the 42 Corps field offices with water control management responsibilities. Deployment to all offices is scheduled for completion by December this year. Following this initial installation of CWMS hardware and software, each office will begin the task of developing watershed models for all the basins in its district. Complete implementation may take several years, depending on the size and complexity of watersheds. HEC recently initiated a 'betterments' phase to maintain, refine, and improve CWMS capabilities. This phase will continue throughout the CWMS life cycle.

The new CWMS package provides a uniform system for real-time water control management. It provides state-of-the-art tools for collecting, analysing, and modelling real-time data. It also has potential applications in several related water resource fields. CWMS is currently being deployed to all Corps offices having water management responsibilities; its full implementation will take several years.

The system is designed to be flexible, allowing it to be applied to watersheds of any size anywhere. CWMS has been designed using modular components, so that it can be deployed in a step-by-step fashion as time and resources permit. In summary, the new system provides a foundation or framework for a successful water control management system. ◊

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