US Army Corps of Engineers
Hydrologic Engineering Center

Accelerated Corps Water Management System (CWMS) Deployment Campaign

Funded by the American Recovery and Reinvestment Act of 2009 (ARRA)

April 2011

CWMS

PR-79

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
April 2011

2. REPORT TYPE
Project Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Accelerated Corps Water Management System (CWMS) Deployment Campaign

Funded by the American Recovery and Reinvestment Act of 2009 (ARRA)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
David Ford Consulting Engineers, Inc.
CEIWR-HEC

5d. PROJECT NUMBER

5e. TASK NUMBER

5F. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
David Ford Consulting Engineers, Inc.
2015 J Street, Suite 200
Sacramento, CA 95811
(916) 447-8779

8. PERFORMING ORGANIZATION REPORT NUMBER
PR-79

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center (HEC)
609 Second Street
Davis, CA 95616-4687

10. SPONSOR/ MONITOR'S ACRONYM(S)

11. SPONSOR/ MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report provides information on the deployment of the Corps Water Management System (CWMS) to eleven U.S. Army Corps of Engineer Districts. The funding for this effort was received from the American Recovery and Reinvestment Act of 2009 (ARRA). The Hydrologic Engineering Center (HEC) was assigned to manage the funding and the project. Working with three United States contractors that already met the requirements for working with the CWMS software, the deployment began in September 2009 and was finished in a little over a year.

The USACE districts that oversee the watersheds now have more-complete CWMS implementations. CWMS provides the capability at most USACE districts for hydro-meteorological data management, display, and dissemination, watershed runoff forecasting, reservoir operation analysis, flood stage prediction, and flood impact analysis.

This report also includes eleven appendices as separate documents (Appendix 5 has three parts). The appendices are done by watershed and provide more detailed information on the modeling effort for each watershed. Also, each appendix is authored by the BPA contractor responsible for the watershed.

15. SUBJECT TERMS
Corps Water Management System, CWMS, Hydrologic Engineering Center, HEC, American Recovery & Reinvestment Act, ARRA, USACE, technology, water managers, decisions, operating, reservoirs, water control systems, projects, mission, flood risk, navigation, water supply, electric power, water quality, environment, deployment, implementation, Apalachicola River, Chattahoochee River, Flint River, Santa Ana River, Puyallup River, Buffalo Bayou, Red River of the North, BPA, contractors, watersheds, ACF, South Platte River, Fall River, James River (North Dakota), hydrometeorological data, Jackson & James Rivers, dissemination, watershed runoff forecasting, Missouri River Tributaries, analysis, flood stage, flood impact, Willamette River, American River, Juniata River, Cumberland River, Tennessee River, Lower Ohio Rivers, jobs, Raystown Dam, Susquehanna River, lessons

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
U	U	U	UU	98	19b. TELEPHONE NUMBER

Accelerated Corps Water Management System (CWMS) Deployment Campaign

Funded by the American Recovery and Reinvestment Act of 2009 (ARRA)

April 2011

Prepared by:
David Ford Consulting Engineers, Inc.
2015 J Street, Suite 200
Sacramento, CA 95814
(916) 447-8779

Prepared for:
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil

PR-79

All the pictures included in this document were created by one of the three contractors, was obtained from USACE District web sites or Wikipedia sites about the eleven watersheds.

Table of Contents

Table of Contents
(continued)

Page

Table of Contents
(continued)

List of Figures

Figure Number **Page**

List of Tables

Executive Summary

Fueled by American Recovery and Reinvestment Act of 2009 (ARRA) funding, the U.S. Army Corps of Engineers (USACE) tasked contractors in 2009 and 2010 with deploying the Corps Water Management System (CWMS) to eleven USACE districts in about a year - a goal that the contractors completed successfully.

CWMS is advanced technology that can inform water managers' decisions about operating reservoirs and other water control systems. USACE is responsible for managing nearly 700 of the nation's water control projects - a mission that affects the lives and property of millions of Americans. With the best-available technology in CWMS, USACE can expand and enhance its capabilities to manage flood risk, navigation conditions, water supply, electric power production, water quality, and the environment.

Beginning in 2001, the Corps' Hydrologic Engineering Center (HEC) deployed a version of CWMS to the Corps' field offices (Divisions and Districts). However, USACE lacked the funding needed to implement the systems fully. This task remained on USACE's "to-do list".

Nearly eight years later, HEC was assigned to manage $5 million of ARRA funding to accelerate CWMS implementation at select field offices across the country - and create or retain jobs along the way.

Members of the USACEs' CWMS Advisory Group selected eight watersheds for accelerated CWMS deployment. Each member represented a division, and one watershed within each division's boundaries was chosen.

The selected watersheds, spanning twenty states, were the Santa Ana River (CA); Puyallup River (WA); upper Missouri River tributaries (ND, SD, CO); Buffalo Bayou (TX); Red River of the North (MN, ND); Apalachicola, Chattahoochee, and Flint rivers (GA, AL, FL); Cumberland, Tennessee, and lower Ohio rivers (MO, IL, TN, IN, KY, OH, WV, PA); and Jackson and James rivers (VA) watersheds. A map showing dams in the watersheds and the districts where CWMS was deployed is shown in Figure 1.

To execute the deployment, HEC hired three United States contractors. The hydrologic and hydraulic engineering consulting firms were all small businesses that had CWMS expertise and were "on call" for USACE work. USACE can establish on-call relationships with contractors using a contracting mechanism called "blanket purchase agreement" (BPA), which contactors qualify for in advance of receiving specific work orders.

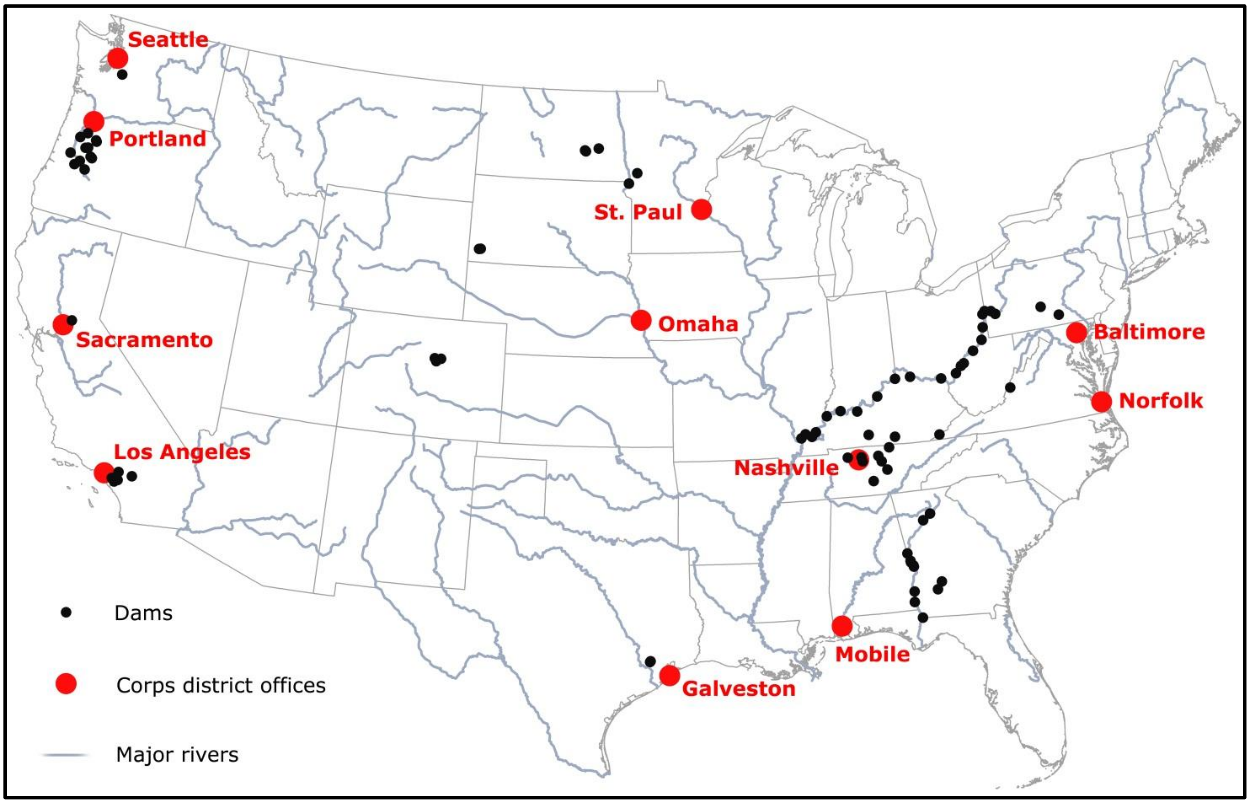


Figure 1. Contractors Deployed CWMS to Eleven USACE District Offices

By selecting contractors that already completed the qualification process and did not require in-depth CWMS training, HEC saved time and pushed the deployment forward from the start.

In September 2009, the Corps issued the BPA work calls to David Ford Consulting Engineers, Inc. (Ford Engineers), Riverside Technology, Inc. (Riverside), and WEST Consultants, Inc. (WEST). The calls tasked the contractors with completing the "shovel-ready" CWMS projects by September 2010. (WEST later received a contract extension for one deployment.)

Riverside and WEST deployed CWMS to three districts each. Ford Engineers deployed CWMS to two districts and helped HEC manage the deployments as the "lead contractor".

The project created or retained five jobs at the firms during the startup period and eight to twenty-five jobs per quarter from October 2009 to September 2010.

The offices that oversee the watersheds now have more-complete CWMS implementations. This provides the capability at most offices for hydro-meteorological data management, display, and dissemination, watershed runoff forecasting, reservoir operation analysis, flood stage prediction, and flood impact analysis.

After costs for the initial eight deployments were established, some ARRA funding remained, as anticipated. HEC then carried out its plan to task the three contractors with deploying CWMS in a limited manner to one additional district each. HEC selected the watersheds based on funds, apparent need, and equity among divisions. The selected watersheds were the Willamette River watershed in Oregon (WEST), American River watershed in California (Ford Engineers), and Juniata River watershed in Pennsylvania (Riverside). The contractors completed the deployments by March 2011.

The project created or retained an additional six jobs from October to December 2010 and more jobs in the following quarter.

HEC and Ford Engineers, as the lead contractor, prepared this report to summarize the Accelerated CWMS Deployment Campaign and its accomplishments. The WEST, Riverside, and Ford Engineers deployment teams wrote the appendices to this report to describe in detail the deployments at each office.

American Recovery and Reinvestment Act of 2009

President Barack Obama signed the American Recovery and Reinvestment Act of 2009 into law on 17 February 2009. This was an unprecedented effort to jumpstart the United States' economy, create or save millions of jobs, and put a down payment on addressing long-neglected challenges, so the United States can thrive in the 21st century.

The ARRA is an extraordinary response to a crisis unlike any since the Great Depression and includes measures to modernize the United States' infrastructure, enhance energy independence, expand educational opportunities, preserve and improve affordable health care, provide tax relief, and protect those in greatest need.

The ARRA provides $4.6 billion to the USACE's civil works program. USACE will use ARRA funds to meet the intent of the President and Congress to put our fellow citizens to work quickly and to help in the recovery of the nation's economy.

The USACE civil works projects accomplished through ARRA funding will continue to contribute to the nation's safety, economy, environment, and quality of life long past the ARRA funding period. (*Sources: USACE, 2010i; USACE, 2011a*)

United States Army Corps of Engineers

USACE is one of the world's largest public engineering, design, and construction management agencies, leveraging expertise through contracts with civilian companies for all construction and most design work.

USACE is an executive branch agency within the Department of Defense and a Direct Reporting Unit within the Army. USACE manages four program areas that include civil works, military construction, real estate, and research and development. The entire organization employs about 34,550 people, including about 800 military personnel.

The USACE organization consists of a headquarters located in Washington, D.C. (HQUSACE), nine divisions, and 45 districts, of which 38 carry out civil works responsibilities in the United States. Division and district geographic boundaries are mainly aligned with watershed boundaries. USACE also maintains several world-renowned research and development laboratories that contribute to the civil works mission.

Hydrologic Engineering Center

The Hydrologic Engineering Center (HEC) is an organization within the Corps' Institute for Water Resources, and is designated as a center of expertise for USACE in the technical areas of surface and groundwater hydrology, river hydraulics and sediment transport, hydrologic statistics and risk analysis, reservoir system analysis, planning analysis, real-time water control management, and other closely associated technical subjects. HEC supports USACE field offices, headquarters, and laboratories by providing technical methods and guidance, water resources models and associated utilities, training and workshops, accomplishing research and development, and performing technical assistance and special projects. (*Source: HEC, 2010b*)

USACE Water Control Management Mission

USACE operates nearly 700 water control projects in the United States. 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 (Fritz *et al*., 2002). Buford Dam, operated by the Mobile District, is shown in Figure 2.

Figure 2. Buford Dam on the Chattahoochee River in Georgia (*USACE*)

The USACE Engineer Regulation (ER) 1110-2-240, Water Control Management (USACE, 1982), explains the USACE water control management mission.

USACE is responsible for water control management at various United States reservoir projects that USACE owns or operates. This responsibility originates with laws initially authorizing construction of specific projects, laws that apply retroactively to specific projects already constructed, and flood control acts and related legislation that Congress has passed since 1874 that apply generally to all USACE reservoirs.

In addition, USACE is responsible for prescribing flood control and navigation regulations for certain reservoir projects constructed or operated by other Federal, non-Federal, or private agencies. USACE's responsibility for water control management of these projects is authorized by Section 7 of the Flood Control Act of 1944 and related legislation, Federal Energy Regulatory Commission license provisions, agreements between USACE and operating agencies, and the terms of other legislative or administrative provisions.

USACE water control management responsibilities include:

- Developing and maintaining water control plans, manuals, and agreements.
- Implementing the water control plans and manuals of USACE projects.
- Ensuring that applicable non-USACE projects' water control plans are implemented.
- Supervising flood control regulations and operations of USACE and non-USACE projects.
- Providing technical assistance to non-USACE project owners.
- Participating with the U.S. Geological Survey, National Weather Service, and other Federal agencies in the operation, cooperation, and maintenance of the precipitation and river reporting network.
- Acquiring, quality controlling, maintaining, and disseminating water control data.
- Providing project information to USACE entities, stakeholders, and the public.

Corps Water Management System (CWMS)

CWMS is a decision support system that can expand and enhance the information readily available to USACE staff members who must make decisions about operation of Federal water management facilities or who must monitor and approve such decisions made by operation partners.

An example of a modeled watershed in CWMS is shown in Figure 3.

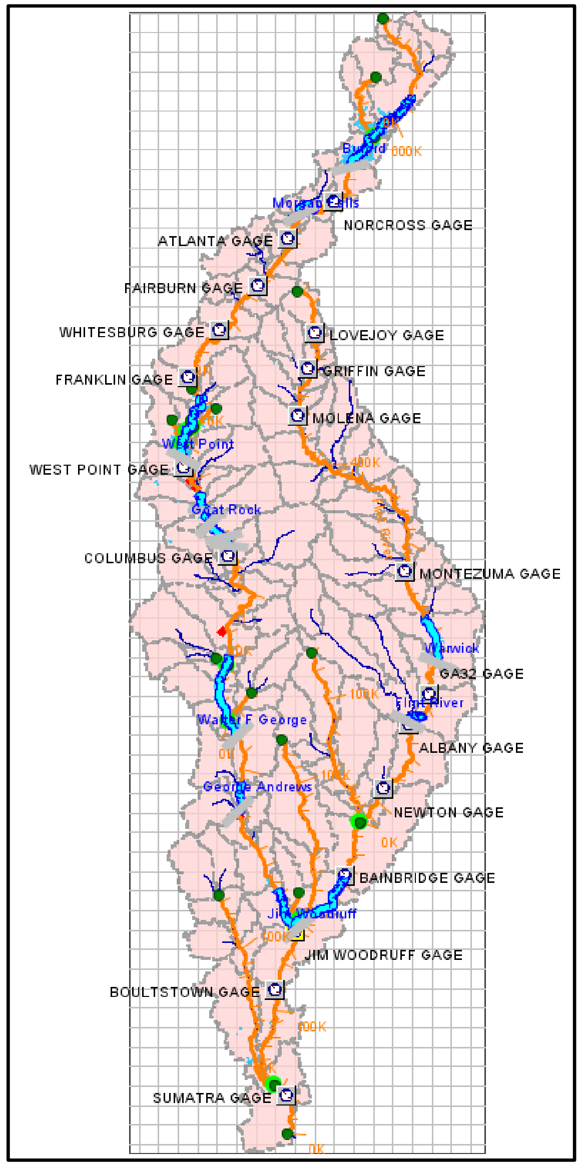


Figure 3. Apalachicola, Chattahoochee, Flint Watershed Modeled in CWMS (*WEST*)

Information Water Managers Need for Decision Making

Water managers in USACE offices nationwide have responsibilities for operation of structures that:

- Manage flood waters.
- Regulate the supply of water for municipal, industrial, and agricultural use.
- Control flows and depths for navigation.
- Regulate waters for environmental protection and enhancement.
- Store and release water for electric power production.

Wise decision making for this operation requires:

- Information about the current state of watersheds, channels, and the water management facilities, including reservoirs, diversions, and other controllable features of the system.
- Information about the likely future state of the watersheds, channels, and management facilities.
- Information about the consequences of management actions that alter future states of the natural and managed systems.

Information Sources

For water managers, information about the current state of the system comes from a network of environmental sensors. These sensors, which are owned and operated by Federal, state, and local government agencies, utility companies, and commercial enterprises, measure:

- Weather conditions, including air temperature, precipitation depths and rates, and evaporation depths and rates.
- Watershed states, including soil moisture conditions and snow accumulation.
- Depth, velocity, flow rate, and other conditions in streams, rivers, canals, and other waterways.
- Water level (from which storage volume may be inferred), rates of release of water through outlets, settings of spillway gates, and other conditions of lakes, reservoirs, and diversions.

A U.S. Geological Survey streamgage is shown in Figure 4.

Data from sensors are transmitted by radio, satellite, telephone, the Internet, and other media to receiving sites, and then to water managers at USACE offices. There, the data are decoded, transformed, examined for quality, and stored in databases. With these data, water managers have near-real-time reports on the current state of the watersheds, channels, and management features.

How the Information is Used

Using the environmental data from the databases as inputs to models of watershed and channel processes, water managers can forecast future availability of water.

Figure 4. U.S. Geological Survey Streamgage

A water manager can predict the runoff from a watershed hours or even days into the future as a consequence of rain falling now or in the past in the watershed. To do so, the water manager uses a mathematical model that simulates infiltration, overland flow, baseflow, channel flow, and other relevant watershed and channel processes. For this runoff forecasting, precipitation forecasted by meteorologists with atmospheric models may also be considered.

With models of water control facilities, water managers can simulate and assess the impact of operation alternatives. For example, a water manager can determine which of two operation alternatives will more likely result in higher downstream water levels due to a large storm. The forecast of future inflow, combined with a mathematical model of the behavior of the reservoir and the downstream channel, makes this possible.

One operation alternative could be to release water now from a rapidly filling reservoir to accommodate future inflows. Another alternative could be to delay release in anticipation that inflows will diminish and large releases will not be required. The manager has, with the analysis tools, capability to compare these operation alternatives in a quantitative manner. Information from the simulation permits the manager to assess the economic, environmental, life safety, and other consequences of the operation alternatives. This information will lead to better-informed decisions.

History of Corps Water Management Decision Support Tools

Consistent with the critical nature of its water control management responsibility, USACE historically has used the best-available technology for managing data about environmental conditions and water control facility performance and modeling watershed, channel, and facility behavior to support decision making.

For example, the software application HEC-1 (HEC, 1998a) and its successor, HEC-HMS, have been used with rainfall observations and precipitation forecasts to predict future inflow to reservoirs. The application HEC-5 (HEC, 1998b), and later, HEC-ResSim, have been used to simulate reservoir operations, thus permitting comparison of operation schedules. And, the application HEC-2 (HEC, 1990). and its successor, HEC-RAS, have allowed water managers to predict downstream flooding levels due to proposed reservoir releases, helping them understand the exposure and consequences that would arise from their decisions.

Beginning in the 1970s, individual USACE offices began developing software primarily designed to meet their local, site-specific needs. HEC subsequently generalized these software programs for USACE-wide application (HEC, 1995b).

In the mid-1980s, USACE began to integrate existing water control data management hardware and software into a USACE-wide system known as the, "Water Control Data System" (WCDS). The individual software applications such as HEC-1, HEC-2, and HEC-5 continued to be enhanced. In WCDS, these applications were able to exchange data with one another using another software application called, "HEC-DSS" (HEC, 1995a).

With environmental data and modeling results stored in an HEC-DSS database, WCDS facilitated fully integrated analysis—from the tip of a raingage bucket to impacts from reservoir releases.

CWMS Components

CWMS includes a:

- **Data acquisition component.** This permits water managers to gather and use real-time data from a wide variety of sources. For example, for the CWMS installation at the Galveston District, streamflow data are acquired from the U.S. Geological Survey, rainfall data come from the Harris County Flood Control District, and rainfall forecasts come from the National Weather Service. All these data are processed and transformed to a consistent format for use in CWMS.

- **Data management component.** A separate data warehouse that uses the USACE corporate Oracle® data management system which securely stores incoming data from sensors after those data are processed.

- **Data reporting and visualizing component.** Water managers may need to review hourly data from hundreds of gages as they make decisions (Fritz *et al*., 2002). CWMS provides methods for this, including summaries presented as graphs, tables, spreadsheets, charts, river profiles, maps, or sometimes a combination of these. Within CWMS, the summaries are linked to a watershed map, so that the user can click on an icon and immediately view the data associated with that location.

- **Data analysis component.** The analysis applications of CWMS are described briefly in Table 1. These are similar to the applications included in WCDS. However, the CWMS applications meet modern computer software standards, include easy-to-use graphical user interfaces, and execute within operating systems selected by USACE.

Table 1. Description of CWMS Analysis Applications

Application	Role in CWMS
HEC-HMS	Simulates watershed response to precipitation. Inputs include observed or forecasted rain or snowfall, temperature, snowpack, and other environmental conditions. Outputs include flows throughout the watershed, including inflows to reservoirs.
HEC-ResSim	Simulates behavior of reservoirs and linking channels, following user-specified rules for reservoir release decision making. Inputs include flows into reservoirs and unregulated flows downstream of reservoirs. Outputs include reservoir releases, downstream regulated flows, and reservoir storage conditions.
HEC-RAS	Simulates, in one-dimension, behavior of channels and adjacent floodplains. This permits evaluation of inundation as water surface elevations corresponding to flows computed by HEC-HMS or HEC-ResSim. Inputs include flows, and outputs include water surface elevations.
HEC-FIA	Assesses consequences of computed flow or water surface elevations in the system. Inputs include flows or water surface elevations at critical locations. Outputs include economic, life loss, or other measures of impact, or optionally, information on actions to be taken in response to flows or elevations that will be experienced.

Each of the CWMS analysis components is maintained as a separate application, thus permitting configuration, calibration, and maintenance of one component without disruption of others. Data and other inputs are passed to each application with the HEC-DSS data exchange application.

Figure 5 illustrates how the CWMS analysis components are linked to provide water managers the information needed to support their decision making.

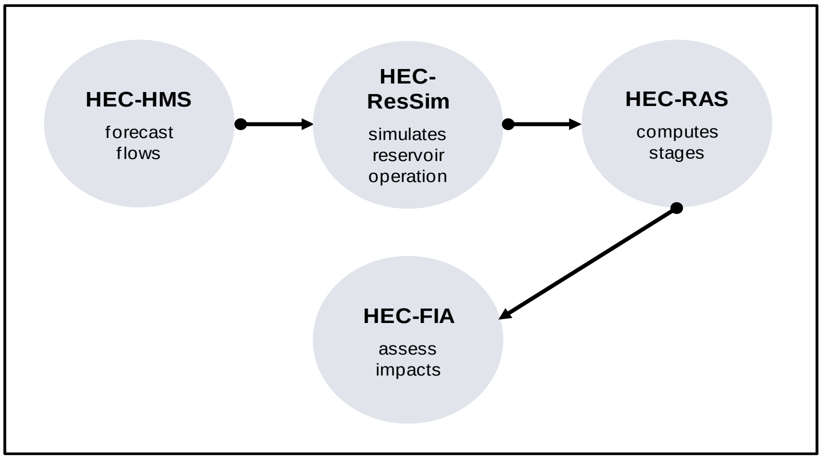


Figure 5. Relationship of CWMS Analysis Applications

Execution of the application programs and display of the results is controlled by the CWMS user with the Control And Visualization Interface (CAVI). An example of the CAVI displaying information is displayed in Figure 6.

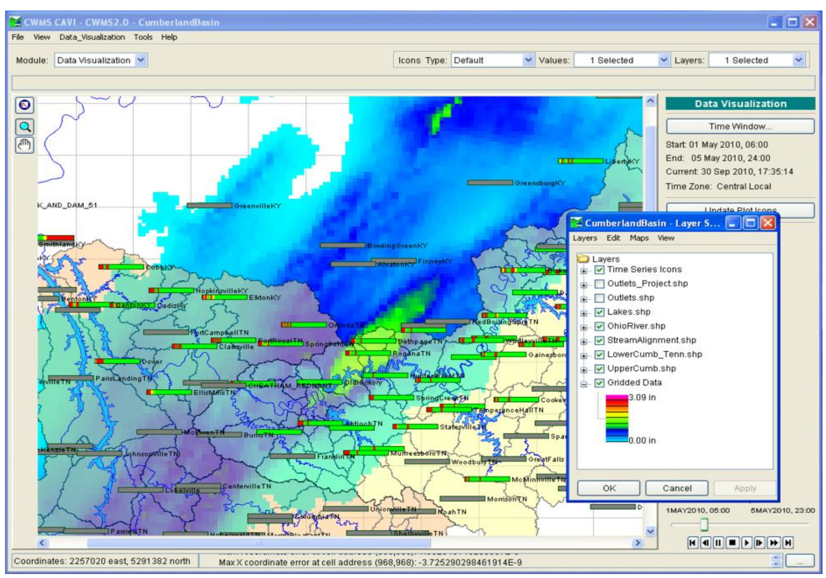


Figure 6. CAVI Example - Cumberland Basin. Data Visualization of Precipitation (*Riverside*)

CWMS is designed to run on USACE servers in district and division offices nationwide. Individual users access these servers remotely with secure desktop or laptop personal computers (PCs).

- **Data and information dissemination component.** This component of CWMS ensures that those who need to know the current state of a water control system and likely future states have ready access to the data. This is accomplished using modern information sharing technology, including specially designed websites for display.

CWMS Achievements

With a common data management scheme, a common set of analysis applications, and a consistent user interface, CWMS provides water managers with a reliable source of information for decision making. Other advantages of CWMS include:

- Use of locally developed applications is minimized, thus reducing the cost of maintaining and updating the decision support system as improvements are made. Water managers, for example, no longer need to worry about the retirement of key staff members who developed unique programs or customized spreadsheet models. CWMS applications are maintained and updated by HEC staff, with direction from a CWMS management group.

- The user base is USACE-wide. Water managers from one district or division can share knowledge of CWMS and responsibility for its use with water managers in another. This leads to more efficient use of the decision support system, great assurance of continuity of operations should a site experience an outage, and less reliance on one or two key people in an office.

- The pool of architect-engineer (AE) contractors upon which the USACE can call for assistance is broader. As the models included in CWMS are well known, expertise outside USACE is great. Virtually every district has access to local AE contractors who have expertise and experience in configuring and using the modeling programs used in CWMS. This promotes more flexibility and greater efficiency as USACE calls upon private enterprise to help with its mission.

- A variety of publications about CWMS are available from HEC (HEC, 2010b).

CWMS Deployment Steps

These are the basic steps to deploy CWMS:

1. Install the complete CWMS application, including the Oracle® database software, analysis applications, data feeds, and user interface (CAVI).

2. Configure the data feeds to acquire real-time data for the watersheds for which decisions are required. (This will vary from district to district and watershed to watershed.)

3. Develop models, and configure and calibrate them.

4. Integrate the models within CWMS, making modifications and adjustments as needed.

5. Connect the models to the data feeds and configure the CAVI.

Status of CWMS in USACE before Accelerated CWMS Deployment

Beginning in September 2001, HEC deployed a version of CWMS to USACE offices with a water control management mission. HQUSACE designated CWMS as the target decision support system for water control management, so that USACE could accomplish its mission in a more efficient and consistent manner. However, USACE lacked the funding needed to implement CWMS fully - to analyze watersheds, build models, set up data management and display systems, integrate and test components, and coordinate with partner agencies.

Thus, the districts and divisions continued to use various analysis tools that they assembled to meet their local needs, such as spreadsheet models and predecessors to the current CWMS models. Some offices integrated analysis tools into WCDS. Others used partial implementations of CWMS. Districts and divisions with partial CWMS implementations developed the CWMS components piece by piece, using funding from various studies. This process was slow moving and did not allow the offices to develop components optimized to work in parallel within CWMS for real-time water control management.

The status of CWMS deployment at the eleven selected offices before this project, shown in Table 2, was a reflection of CWMS deployment at many offices nationwide - districts and divisions had pieces of CWMS but not complete and fully functioning CWMS configurations.

Without funds, the USACE timeline for full implementation could not be achieved.

In addition, HEC was developing a new version of CWMS, Version 2.0, which was released in 2010 during this project. So, districts and divisions with CWMS components would eventually need to integrate those components into CWMS 2.0.

Table 2. Status of CWMS Deployment at the Eleven USACE Districts before Accelerated CWMS Deployment

Watershed	District	CWMS Models	CWMS Configuration	Data Streams	CWMS 2.0 Installed
Santa Ana	Los Angeles				
Missouri	Omaha				
ACF[1]	Mobile				
Jackson & James Rivers	Norfolk				
Puyallup	Seattle				
Cumberland[2]	Nashville (& LRD[3])				
Red	St. Paul				
Buffalo	Galveston				
Willamette	Portland				
Juniata	Baltimore				
American	Sacramento				

[1] Apalachicola, Chattahoochee, Flint Rivers watershed (ACF).
[2] Cumberland, Tennessee, and Lower Ohio Rivers watershed (Cumberland).
[3] LRD is the Great Lakes and Ohio River Division. Riverside deployed the Cumberland, Tennessee, and Lower Ohio Rivers CWMS watersheds to both the Nashville District and the Division.

Legend

CWMS models

Does not have an HEC-HMS, HEC-ResSim, HEC-RAS, or HEC-FIA model.
Has at least 1 of the 4 models.
Uses at least 1 of the 4 models for real-time forecasting.
Has all 4 models and uses all 4 for real-time forecasting.

CWMS configuration

Does not have a CWMS configuration.
Has a CWMS configuration.
Has a CWMS configuration and uses it for real-time forecasting.
Has a CWMS configuration integrated with all 4 models and uses it for real-time forecasting.

Data streams

No CWMS data streams established.
At least 1 CWMS data stream established.
Uses at least 1 CWMS data stream for real-time forecasting.
All required CWMS data streams established and used for real-time forecasting.

CWMS version 2.0 installed

Not installed.
Installed.

Benefit of Accelerating CWMS Deployment

The USACE offices selected for this project had critical need for CWMS to enhance and expand their water control management capabilities. Receiving CWMS sooner ensured that the offices could use the best-available technology sooner to address their needs.

The Seattle District, for example, will use the HEC-ResSim model built for the Puyallup watershed to support review of reservoir operation. This is a high priority because during a recent flood event, normal operation resulted in unexpected damages to a city, apparently, because of physical changes in the channel. The district seeks to reduce flood risk to the city without increasing risk to other locations.

The St. Paul District will use the HEC-HMS model from the Red River deployment to forecast inflow to Lake Ashtabula. The district needed an additional source of inflow forecasts to enhance flood control management of the Sheyenne River. The need was so immediate that during this project, Ford Engineers used the HEC-HMS model, before it was integrated into CWMS, to forecast inflow at the district's request. Ford Engineers had to assemble the required gridded input data by hand using real-time data and meteorological forecasts from the Web.

The average time required to forecast inflow was about two hours. Using the CWMS configuration, the district will be able to produce a similar forecast in much less time - about thirty minutes.

The Buffalo Bayou deployment also highlights the benefit of accelerated deployment. Prior to this project, the Galveston District had a Buffalo Bayou CWMS configuration. The CWMS configuration included HEC-ResSim, HEC-HMS, HEC-RAS, and HEC-FIA models. However, CWMS did not run through all the programs because the data transfer links were not complete, and each of the models required significant changes and updates to be useable in CWMS.

The district relied on experienced water managers to make reservoir release decisions using National Weather Service West Gulf River Forecast Center flow forecasts.

CWMS deployment was needed because once the experienced water managers retire; key skills and knowledge will be lost. CWMS will allow other staff to use a quantitative, comprehensive system to make informed release decisions.

Furthermore, the estimated flood damages prevented by Addicks and Barker reservoirs in the Buffalo Bayou watershed have been increasing as larger events have occurred in recent years, so the importance of efficient operation is even greater.

Selection Process for Accelerated CWMS Deployment

Watershed Nomination

HEC invited USACE divisions and districts to nominate watersheds for accelerated CWMS deployment. A nomination form asked the offices to describe:

- The watershed, including location, size, number of reservoirs, and special issues.
- The importance of deploying CWMS for the candidate watershed.
- What priority CWMS deployment for the watershed was relative to other watersheds in the division.
- The ability of the USACE office to use CWMS on a continual basis.
- What CWMS components the office already had and what components the office needed.
- An estimate of how much a complete implementation would cost and how much each component would cost.

HEC received about forty nominations from eight divisions: North Atlantic, South Atlantic, Great Lakes and Ohio River, Mississippi Valley, Southwestern, South Pacific, and Northwestern, which is split into the Missouri River Basin Water Management Division (Missouri Basin) and the Columbia Basin Water Management Division (Columbia Basin). A map of the divisions is shown in Figure 7.

Figure 7. Map of USACE Divisions

Initial Watershed Selection

HEC and the lead contractor reviewed the candidate watersheds and information provided on the nomination forms. Ultimately, the eight watersheds that the divisions ranked number one in priority were selected. The selected watersheds are listed in Table 3.

Table 3. Initial Eight Watersheds Selected for Accelerated CWMS Deployment

Deployment Team	Watershed	Location	Division	District
DAVID FORD CONSULTING ENGINEERS	Buffalo Bayou	Texas	Southwestern	Galveston
DAVID FORD CONSULTING ENGINEERS	Red River	Minnesota, North Dakota	Mississippi Valley	St. Paul
WEST CONSULTANTS, INC.	Santa Ana River	California	South Pacific	Los Angeles
WEST CONSULTANTS, INC.	Apalachicola, Chattahoochee, Flint Rivers	Georgia, Alabama, Florida	South Atlantic	Mobile
WEST CONSULTANTS, INC.	Upper Missouri River tributaries (South Platte, Fall, James Rivers)[1]	Colorado, South Dakota, North Dakota	Northwestern, Missouri Basin	Omaha
RIVERSIDE global science solutions	Cumberland, Tennessee, Lower Ohio Rivers[2]	Missouri, Illinois, Tennessee, Indiana, Kentucky, Ohio, West Virginia, Pennsylvania	Great Lakes & Ohio River	Nashville
RIVERSIDE global science solutions	Jackson & James Rivers	Virginia	North Atlantic	Norfolk
RIVERSIDE global science solutions	Puyallup River	Washington	Northwestern, Columbia Basin	Seattle

[1] The nomination ranked No. 1 by the Northwestern Division, Missouri Basin, was for HEC-HMS models only. This nomination and the division's fifth-ranked nomination for another set of HEC-HMS models were selected. In sum, the Missouri River tributaries deployment included HEC-HMS models for the Fall River, James River, and South Platte River watersheds and an HEC-ResSim model for the South Platte River watershed.

[2] Riverside deployed CWMS to both the Nashville District and the Great Lakes and Ohio River Division.

The eight selections best satisfied the following criteria:

- The USACE office had a critical need for CWMS implementation.
- The division ranked CWMS deployment for the watershed as high priority among the division's watersheds.

- The USACE office had the capability to use CWMS on a continual basis.
- The watersheds represented different USACE divisions.
- The overall cost of deploying CWMS for the eight watersheds could be accommodated by the project budget.
- It was feasible to complete the work required. For example, enough data existed to develop the CWMS models.

Additional Watershed Selection

After HEC determined the amount of funding that would remain after costs for the eight deployments were determined, HEC selected three additional watersheds, listed in Table 4, for partial CWMS deployment. Based on the districts' priorities and as the budget allowed, the districts would receive functional CWMS configurations with select CWMS models.

Table 4. Additional Three Watersheds Selected for Accelerated CWMS Deployment

Deployment Team	Watershed	Location	Division	District
DAVID FORD CONSULTING ENGINEERS	American River	California	South Pacific	Sacramento
WEST CONSULTANTS, INC.	Willamette River	Oregon	Northwestern, Columbia Basin	Portland
RIVERSIDE global science solutions	Juniata River	Pennsylvania	North Atlantic	Baltimore

Project Management and Organization

HEC and the lead contractor wrote an overall project management plan before the deployments began to define the project objectives, deliverables, success criteria, managerial process, organization, and execution (HEC, 2009). The following sections describe the structure of the project as defined in the project management plan.

Project Delivery Team

The contractors formed a deployment team for each of their deployments, led by a deployment site manager. The deployment teams executed the work.

The contracting officer for the project was from the Sacramento District. The contracting officer's technical representative was from HEC. HEC and the lead contractor managed the project overall. Each USACE office designated a technical representative to coordinate with contractors' deployment teams.

In summary, responsibilities were as follows:

- The contracting officer and contracting officer's representative were accountable for contracts associated with the project. They were consulted regarding any changes in work products, schedules, and costs. They were informed of progress.

- The contracting officer's technical representative was the engineer in charge of final technical decisions made throughout the project. The engineer in charge was consulted regarding any technical issues that could not otherwise be resolved by the project manager, lead contractor, or technical representatives. In the event of any disputes regarding scopes of work, work products, and so on, the engineer in charge resolved the disputes. Also, the engineer in charge was informed of progress continuously.

- The project manager was the government's day-to-day manager of the project. The project manager was accountable for the success of the project, was informed of the status of work and was consulted as difficulties arose with project execution. The project manager reviewed contractors' work products.

- The lead contractor was accountable to the project manager for the success of the project and, in this role, facilitated work by the contractors. The lead contractor made recommendations throughout the project to the project manager regarding performance work statements. The lead contractor monitored the deployment teams' progress and reviewed their work products. The lead contractor briefed the project manager weekly on progress overall. The project manager briefed others as necessary.

- The technical representative was the Corps employee at each district or division who was responsible for assisting the contractor with deployment there.

- The deployment site manager was an employee of the contractor who was responsible for deployment to an office.

- The contractors communicated directly with technical representatives and worked cooperatively with them throughout the duration of this project. Communications with district and division staff members, particularly if those resulted in any important decision making for the project, were documented and provided to the lead contractor for the record.

Lead members of the project delivery team are listed in Table 5 through Table 8.

Table 5. Individuals who Served Managerial Roles for the Accelerated CWMS Deployment

Role	Name	Affiliation
Contracting officer	Niki Haas	Sacramento District
Contracting officer's representative	Diane Cuming	HEC
Contracting officer's technical representative	Christopher Dunn	HEC
Project manager	William Charley	HEC
Lead contractor's manager	David Ford	Ford Engineers

Table 6. Riverside Deployment Site Managers and USACE Technical Representatives

Watershed/Corps Office	Deployment Site Manager	USACE Technical Representative
Puyallup/Seattle District	Amy Volckens	Joel Fenolio
Jackson & James/Norfolk District	Phil Burkhalter	R. Owen Reece, Jr.
Cumberland, Tennessee, Lower Ohio Nashville District/Great Lakes & Ohio River Division	Shaun Carney	Deborah Lee (District) Robert Sneed (Division)
Juniata/Baltimore District	Sandra Bratlie	Thomas Ressin

Table 7. WEST Deployment Site Managers and USACE Technical Representatives

Watershed/Corps Office	Deployment Site Manager	USACE Technical Representative
Apalachicola, Chattahoochee, Flint/Mobile District	Henry Hu	Randall Harvey
Santa Ana/Los Angeles District	Jake Gusman	Greg Peacock
Missouri/Omaha District	David Smith	Timothy Temeyer
Willamette/Portland District	Chris Goodell	Laurie Rice

Table 8. Ford Engineers Deployment Site Managers and USACE Technical Representative

Watershed/Corps Office	Deployment Site Manager	USACE Technical Representative
Buffalo Bayou/Galveston District	Teresa Bowen	Mike Sterling
Red/St. Paul District	Teresa Bowen	Elizabeth Nelsen
American/Sacramento District	Teresa Bowen	Angela Carmi

Deployment Strategy

CWMS deployment is a time-consuming, complex process that requires hydrologic and hydraulic engineering expertise.

Deployment is not simply a software installation exercise - it requires coordination, analysis, judgment, creative problem solving, and the ability to communicate processes and results.

To deploy CWMS for this project, the contractors completed these basic steps:

- **Met with Corps water managers to assess the situation.** The contractors traveled to the Corps offices to meet with water managers. They discussed what CWMS components the offices already had, what the deployment objectives were, and what would be required to achieve the objectives. The Corps issued contracts under the BPAs, or "BPA calls", for the three contractors' assessments.

- **Developed a cost proposal and work plan.** Based on information from the assessments, the contractors estimated how much effort the deployments would take. The contractors submitted their cost proposals to HEC and described the needed tasks.

- **Received BPA call to deploy CWMS.** The Corps and contractors settled on the work costs and plans. In September 2009, the Corps issued eight BPA calls, one for each deployment, giving the contractors the go-ahead to start the work. The BPA calls included the performance work statements. A performance work statement defines the scope of work, including the objectives, deliverables, and schedule for performance.

- **Collected and reviewed existing models and studies.** The contractors gathered existing models, study data, and water control manuals. The contractors reviewed these to determine a starting point for development.

- **Wrote a hydrologic engineering management plan (HEMP).** The CWMS deployments required agency coordination, identification of data sources, model development, model integration, installation, testing, internal quality assurance/quality control (QA/QC), documentation, agency review, revision, and technology transfer.

  The contractors coordinated these tasks by writing a HEMP for each deployment. The HEMPs identified and scheduled deployment activities and described technical details. For each task, the HEMPs defined what the deliverables and completion criteria were. The HEMPs also described the contractors' internal QA/QC procedures, the agency review and revision process, and what the contractors needed from the government to complete the tasks.

  The contractors developed the HEMPs according to the performance work statements and Corps guidelines in:

  - Engineer Manual 1110-2-1417, *Flood-Runoff Analysis* (USACE, 1994a)
  - Engineer Pamphlet 1110-2-9, *Hydrologic Engineering Studies Design* (USACE, 1994c)
  - Engineer Pamphlet 1110-2-10, *Hydrologic Engineering Analysis Concepts for Cost-Shared Flood Damage Reduction Studies* (USACE, 1994b)

- **Identified required data and information.** CWMS models need real-time meteorological, hydrologic, and system data. CWMS provides these data to the models through automated data streams from its database. The contractors identified the specific data streams needed. The contractors then communicated with the Corps offices to find out which data streams the offices already established and if those data were in the proper format. The contractors assisted the offices with filling data gaps by researching where the data streams could be obtained or by determining substitutes. The contractors also helped the offices make data requests to other agencies and figured out how data could be properly formatted.

- **Developed models.** Using the models, data, and manuals collected, the contractors developed the models for this project to meet the Corps offices' deployment objectives. As prescribed by HEC, the contractors developed the models in 30%-, 60%-, and 100%-complete phases. Development included identifying points in the modeled watersheds where data should be input and computations made, coordinating the location of these points between individual models so that input could be passed from one model to the other, determining naming conventions for the points, calibrating the models to historical data, using other historical events to verify the accuracy of the models, and recommending parameters and initial conditions for the models.

  Development also involved translating data and guidelines into CWMS input. This required some judgment, which was guided by Corps regulations, Corps water managers, and the contractors' engineering knowledge and experience.

  The contractors communicated with the Corps offices, HEC, and the lead contractor throughout the development process to ensure that the offices' needs would be met and the modeling strategies were sound. This included biweekly conference calls with HEC and the lead contractor, in which all contractors gave progress updates, identified problems, and found solutions.

- **Documented the work.** The contractors documented what existing models and data they began with; how they built, calibrated, and verified models for this deployment; the models' results; analysis of the results; sources of information used; rationale for key decisions; any model limitations; and unresolved issues.

- **Reviewed work internally.** The contractors did internal quality assurance/quality control (QA/QC) review, as described by their HEMPs, ensuring a high-quality product for submission to the Corps.

- **Submitted work for agency review and revised work.** The contractors submitted their models and documentation to HEC at the 30%-, 60%-, and 100%-complete phases. HEC and the lead contractor reviewed the work. Contractors responded to review comments and revised their work as necessary. The contractors worked with HEC, and, at times, the lead contractor, to troubleshoot issues with the models or bugs in the software.

- **Integrated models into a CWMS configuration and installed and tested CWMS.** Once the models were finalized, the contractors integrated them into CWMS. The contractors set up the models to feed into each other and to be controlled using a single interface, the CAVI. The contractors also set up CWMS to receive real-time data. They installed the CWMS configuration, which they developed on a PC, onto the Corps offices' CWMS servers. The contractors tested the ability of CWMS to simulate large events with accuracy, or "stress tested" the watersheds. They also tested any data feeds that were established. (The Corps offices were responsible for establishing the data feeds.) The contractors documented the details and results of the integration and stress testing and submitted the CWMS computer files and documentation to HEC for review.

- **Transferred technology.** Once the models and integration were complete and worked as expected, the contractors traveled to the Corps offices to "transfer the technology". Technology transfer included presentations about how the models were developed and training of Corps staff members to use and modify the models and CWMS configuration.

- **Wrote final project report appendices.** The contractors wrote comprehensive, detailed reports about each deployment. These are appended to this report.

Typically, each deployment contract divided the work into nineteen tasks. Splitting up the work allowed contractors to invoice on a regular basis to support employment throughout the project. In addition, HEC, the lead contractor, and the Corps offices had the opportunity to review the work in progress. This allowed them to ensure that the deliverables met their expectations and raise any concerns while contractors still had time to revise the work.

Progress Monitoring and Reporting

The lead contractor kept a schedule of activities for each deployment. The lead contractor monitored the schedule, reporting progress and delays to the HEC project manager weekly. With the assistance of the lead contractor, the HEC project manager discussed with the deployment site managers issues and delays and how they should be resolved.

HEC and the lead contractor also held the biweekly conference calls with all deployment site managers to stay informed of progress and give contractors the opportunity to notify HEC of issues. When it was beneficial to share the discussion of those issues with the group of contractors, HEC did so over the conference call. Other contractors shared their insight as appropriate.

The contractors submitted monthly status reports to document their progress on each task and any concerns they had.

Continuous monitoring and reporting on progress ensured the project's timely completion. Table 9 shows the general project schedule for the initial eight deployments.

Table 9. General Project Schedule for the Initial Eight Deployments

2009	**February to August**	Nominate watersheds Select watersheds Assess work required	Write project management plan Attend orientation workshop for contractors
	September	Issue deployment contracts Begin deployment work	Write hydrologic engineering management plans Research data sources
	October	Write hydrologic engineering management plans	Research data sources
	November	Submit hydrologic engineering management plans Review and revise	Submit data sources task Participate in biweekly conference calls
	December	Develop 30% models Review and revise	Participate in biweekly conference calls
2010	**January**	Submit 30% models Review and revise	Participate in biweekly conference calls
	February	Develop 60% models Review and revise	Participate in biweekly conference calls
	March	Develop 60% models Review and revise	Participate in biweekly conference calls
	April	Develop 60% models Review and revise	Participate in biweekly conference calls
	May	Submit 60% models Review and revise	Participate in biweekly conference calls
	June	Develop 100% models Review and revise	Participate in biweekly conference calls
	July	Develop 100% models Review and revise	Participate in biweekly conference calls
	August	Submit 100% models Review and revise	Participate in biweekly conference calls
	September	Review and revise Integrate models Conduct stress tests	Participate in biweekly conference calls Transfer technology Write final reports
	October	Review and revise	Tie up loose ends

Review Process

Prior to submitting their deliverables to HEC, the contractors reviewed them internally. Contractors included quality control plans in their HEMPs. For 100%-complete models and other deliverables, contractors certified that they followed their quality control plans.

After internal review, contractors submitted their models and documentation to HEC. HEC and the lead contractor reviewed the deliverables to ensure that they:

- Were of high quality.
- Met professional standards
- Were technically sound.
- Followed Corps guidance.
- Met criteria stated in the performance work statements and HEMPs.

HEC and the lead contractor entered comments into the USACE online review system, Document Review and Checking System (DrChecks) (ProjNet, 2011). DrChecks provided a forum for dialogue between the reviewers and contractors. The contractors could concur, nonconcur, or provide information in response to the reviewers' comments and provide text to elaborate. The contractors revised their work as necessary.

The reviewers then "backchecked" the responses, deciding whether the issues had been adequately addressed. If so, the reviewers closed the comment. If not, the reviewers nonconcurred, leaving the comment open and explaining why they disagreed or were unsatisfied with the response.

The process of response and backcheck continued until all comments on the deliverables were closed. When the deliverables were complete and all comments were closed, HEC notified the contractor that the task was complete. An example comment is shown in Figure 8.

HEC and the lead contractor set the review process on an aggressive schedule, typically fourteen days for review and ten days for response and revision. This ensured that the deployments moved forward fast enough to meet the project schedule.

p. 42: Please clarify how you estimated n values from satellite imagery. The standard of practice is to observe the channel properties from a bit closer vantage point to estimate n values.
Submitted By: David Ford

Evaluation **Concurred**
In the absence of better information, we used satellite imagery to estimate the roughness of the overbanks for the Rabbit River, Mustinka River, and Big Slough. The Manning's n value for these streams' overbanks of 0.05 is consistent with scattered brush and heavy weeds. The main channel Manning's n values for the Rabbit River, Mustinka River, and Big Slough are consistent with main channel Manning's n values for the streams with existing HEC-RAS models.

Submitted By: Adam Schneider

Backcheck Recommendation **Open Comment**
Non-concur. My question is this: Can you see the overbank land use, etc., well enough in a satellite image to estimate Manning's n values? Please elaborate.

Submitted By: David Ford

Evaluation **Concurred**
Please see the attached file as an example of the imagery we used to estimate Manning's n values for the Rabbit River, Mustinka River, and Big Slough. The image resolution for this area is quite good. We obtained the images to make these estimates through Google Earth. Because Google Earth uses a combination of both satellite imagery and aerial photography, I changed the text in the memo to say "Google Earth" rather than "satellite imagery." (Attachment: SatelliteImagery1.jpg)

Submitted By: Adam Schneider

Backcheck Recommendation **Close Comment**
OK.

Submitted By: David Ford

Current Comment Status: **Comment Closed**

Figure 8. Example Model Review Dialogue on DrChecks and Visual Aid Accompanying Contractor Response

Measures of Success

The products of the Accelerated CWMS Deployment Campaign demonstrate its success. The contractors deployed functional CWMS configurations to eleven districts, and this work created and retained jobs.

Jobs Created or Retained

The contractors estimated the number of jobs that the project created or retained per quarter, according to White House Office of Management and Budget (OMB) guidelines (OMB, 2010).

The project created or retained six to twenty-five jobs per quarter over five quarters, from 1 October 2009, to 31 December 2010. The pre-deployment activities created or retained five jobs from 17 February 2009, to 30 September 2009. Estimates for the first quarter of 2011 will be available later on www.Recovery.gov.

Table 10 shows the number of jobs created or retained per quarter for each contract included in the project, according to contractors' reports (Recovery Accountability and Transparency Board, 2010).

Table 10. Number of Jobs Created or Retained by the Accelerated CWMS Deployment Campaign

Contractor	Objective	Start up[1]	Q4 2009	Q1 2010	Q2 2010	Q3 2010	Q4 2010
WEST	Site assessments	0	-	-	-	-	-
WEST	ACF deployment	0	0	3	4	4	1.5
WEST	Missouri deployment	1	1.25	1.25	1.5	2.5	0.25
WEST	Santa Ana deployment	0	0	2.5	1.5	2	0.25
Riverside	Site assessments	1	1.4	-	-	-	-
Riverside	Cumberland deployment	-	1.4	2.49	4.3	4.4	0.5
Riverside	J&J deployment	-	0.87	0.84	0	2.4	0.7
Riverside	Puyallup deployment	-	0.79	1.05	1.25	4.4	0.5
Ford	Site assessments	1	-	-	-	-	-
Ford	Lead contractor	1	1	1	1	1.5	0.63
Ford	Buffalo deployment	0.5	0.5	0.5	0.8	0.72	0.27
Ford	Red deployment	0.5	0.5	1.4	1.82	1.68	0.18
WEST	Willamette deployment	-	-	0.5	1	1	0.50
Riverside	Juniata deployment	-	-	0.42	0.5	0	0.76
Ford	American deployment	-	-	0.4	0.4	0.44	0.33
Total jobs per quarter		5	7.71	15.35	18.07	25.04	6.37

[1] The start-up period was from 17 February 2009 to 30 September 2009.

Types of jobs needed for the CWMS deployment were project managers, hydrologic and hydraulic engineers, computer systems analysts, quality control specialists, technical reviewers, technical writers, and general support staff.

CWMS Deployed

Table 11 shows the deployment status at the conclusion of the project. The sections that follow describe objectives for each deployment and confirm that the contractors completed them.

Table 11. Status of CWMS Deployment at the Eleven USACE Districts after Accelerated CWMS Deployment

Watershed	District	CWMS Models	CWMS Configuration	Data Streams[1]	CWMS 2.0 Installed
Santa Ana	Los Angeles				
Missouri	Omaha[2]				
ACF	Mobile				
Jackson & James Rivers	Norfolk				
Puyallup	Seattle[2]				
Cumberland	Nashville (& LRD[3])				
Red	St. Paul[2]				
Buffalo	Galveston				
Willamette	Portland				
Juniata	Baltimore[2]				
American	Sacramento				

[1] It was the Corps offices' responsibility to establish CWMS data streams.
[2] The HEC-HMS model in CWMS requires the snowmelt function. The snowmelt function was not available in CWMS during the project. When it is available, Corps offices can update the CWMS interface.
[3] LRD is the Great Lakes and Ohio River. Riverside deployed the Cumberland, Tennessee, and Lower Ohio Rivers CWMS to both the Nashville District and the division

Legend

CWMS models

- Does not have an HEC-HMS, HEC-ResSim, HEC-RAS, or HEC-FIA model.
- Has at least 1 of the 4 models.
- Can use at least 1 of the 4 models for real-time forecasting.
- Has all 4 models and can use all 4 for real-time forecasting.

CWMS configuration

- Does not have a CWMS configuration.
- Has a CWMS configuration.
- Has a CWMS configuration that can be used for real-time forecasting.
- Has a CWMS configuration integrated with all 4 models and can use it for real-time forecasting.

Data streams

- No CWMS data streams established.
- At least 1 CWMS data stream established.
- Can use at least 1 CWMS data stream for real-time forecasting.
- All required CWMS data streams established and can be used for real-time forecasting.

CWMS version 2.0 installed

- Not installed.
- Installed.

Buffalo Bayou Deployment

State: Texas (Figure 9)
USACE Division: Southwestern
USACE District: Galveston
Major Water Control Projects: Addicks Dam on South Mayde Creek; Barker Dam on Buffalo Bayou
Contractor: Ford Engineers

Importance

The CWMS deployment will help the Galveston District manage Addicks and Barker dams, which will reduce flood risk to Houston. Houston is the fourth most populous city in the United States, with a population estimated at 2.3 million in 2009.

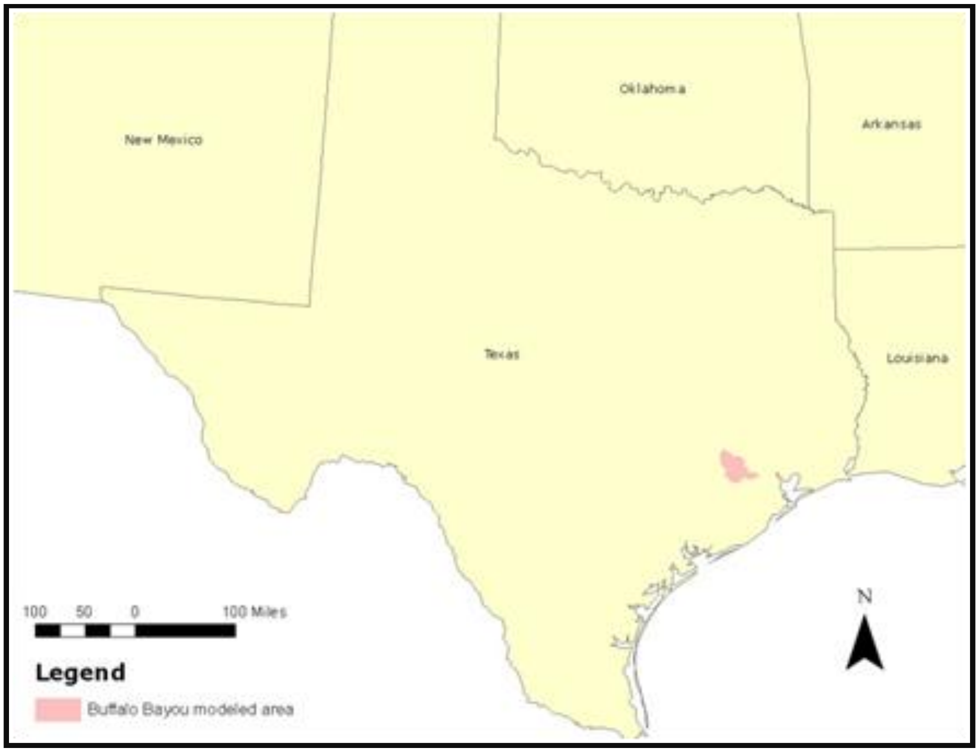


Figure 9. Location of Buffalo Bayou

The Houston area has flooded periodically throughout its history, and Harris County, the primary location of Addicks and Barker reservoirs, has been the storm center of at least twelve major storms since 1853.

The Corps designated Addicks and Barker dams as "extremely high risk". The designation is based on two structural areas of concern and the potential catastrophic impact to Houston in the event of dam failure (though the dams are not in imminent danger of failure). As part of the effort to mitigate risk, the designation moves the dams to the front of the line for funding for repairs and studies, including this CWMS deployment. *(Sources: US Census Bureau 2009 estimate; City of Houston, 2015; Appendix VI; USACE, 2011e.)*

Deployment Objectives and Results

- Used information from three existing HEC-HMS models to create a new, calibrated HEC-HMS model of the Buffalo Bayou watershed that includes Cypress Creek. Converted the steady HEC-RAS model into an unsteady model. Updated all reservoir elevations in the HEC-ResSim model from National Geodetic Vertical Datum of 1929 to North American Vertical Datum of 1988.

- Prepared inundation maps at one-foot contour intervals within Addicks and Barker reservoirs and of the downstream floodplain, so the extent of flooding can be readily viewed in Google Earth®.

- Integrated all models and ran a forecast. Installed CWMS and the Buffalo Bayou watershed for the Galveston District.

- Trained Galveston District staff members on using CWMS.

- Enhanced and expanded the Galveston District's real-time water control management capabilities.

Red River of the North Deployment

Importance

The-CWMS deployment will help the St. Paul District manage water control projects in the Red River of the North watershed, which provide flood control, water supply, low-flow augmentation, and pollution abatement benefits.

States: Minnesota, North Dakota (Figure 10)
USACE Division: Mississippi Valley
USACE District: St. Paul
Major Water Control Projects: Baldhill Dam on the Sheyenne River; Orwell Dam on the Otter Tail River; Lake Traverse Project on the Bois de Sioux River
Contractor: Ford Engineers

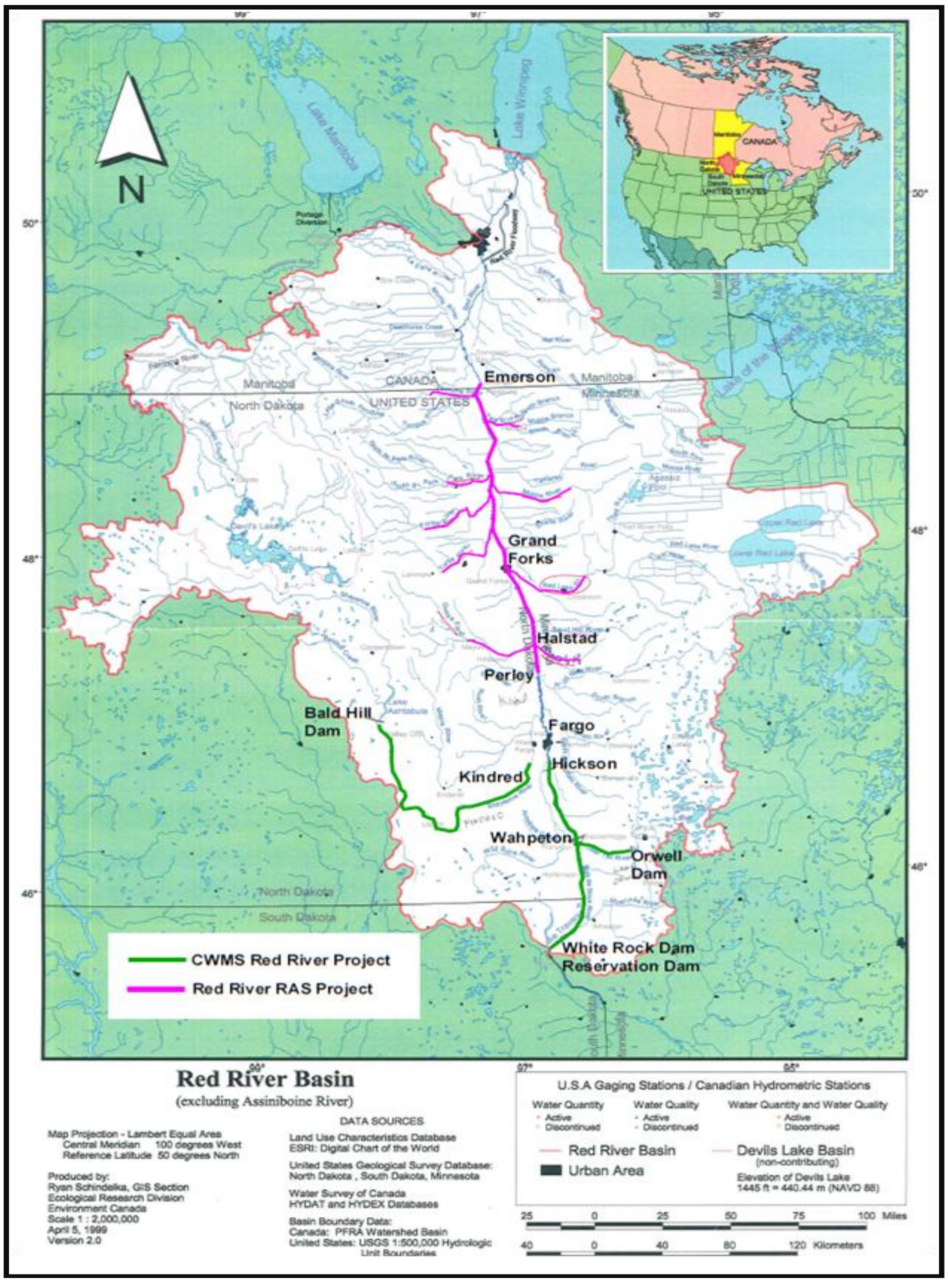
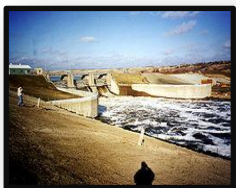


Figure 10. Location of Red River of the North Basin (*Environment Canada, 5 April 1999*)

Operation objectives include reducing flood risk to the major population centers of Fargo, ND-Moorhead, MN; Grand Forks, ND-East Grand Forks, MN; and Wahpeton, ND-Breckenridge, MN. The Red River and its tributaries cause costly local flooding every year. Average annual flood damages in the Fargo-Moorhead metropolitan area are currently estimated at over $190 million. (*Sources: USACE, 2010; USACE, 1994d; USACE, 1992; Appendix VII*)

Deployment Objectives and Results



- Developed an HEC-HMS model (that includes snowmelt) for inflows into Baldhill Dam on the Sheyenne River and for local flows (including snowmelt) downstream of Baldhill to Kindred[1].
- Developed an HEC-ResSim model of the Sheyenne from Baldhill Dam to Kindred with computation points at Valley City and Lisbon.
- Developed an HEC-HMS model (that includes snowmelt) for inflows into the Lake Traverse project and Orwell Dam and for local flows downstream of Lake Traverse and Orwell Dam to Wahpeton[1].

- Developed an HEC-ResSim model of Lake Traverse on the Bois de Sioux and Orwell Dam on the Otter Tail River to Wahpeton on the Red River.
- Developed and/or updated, calibrated, and validated HEC-RAS models from Lake Traverse on the Bois de Sioux and from Orwell on the Otter Tail to Wahpeton on the Red River.

- Developed and calibrated an HEC-RAS model on the Sheyenne from Baldhill Dam to Kindred.
- Developed two HEC-FIA models, one model for the Red River watershed and the other model for the Sheyenne River watershed.
- Deployed the Red River watershed configuration and Sheyenne River watershed configuration for St. Paul District.
- Trained St. Paul District staff members on CWMS use.
- Enhanced and expanded the St. Paul District's real-time water control management capabilities.

[1] The HEC-HMS model in CWMS requires the snowmelt function. The snowmelt function was not available in CWMS during the deployment. Corps offices can update the CWMS interface once HEC implements the function. Beyond this, the contractor met the objective.

Santa Ana River Deployment

Importance

State: California (Figure 11)
USACE Division: South Pacific
USACE District: Los Angeles
Major Water Control Projects: Seven Oaks Dam and Prado Dam on the Santa Ana River; San Antonio Dam on San Antonio Creek; Carbon Canyon Dam on Carbon Canyon Creek; Villa Park Dam on Santiago Creek
Contractor: WEST

The CWMS deployment will help the Los Angeles District manage water control projects in the Santa Ana River watershed, which provide flood control and water conservation benefits. Operation objectives include reducing flood risk for more than two million people living within the floodplains, which contain approximately 110,000 acres of heavily urbanized area including the cities of Anaheim, Santa Ana, Huntington Beach, Garden Grove, and Fullerton.

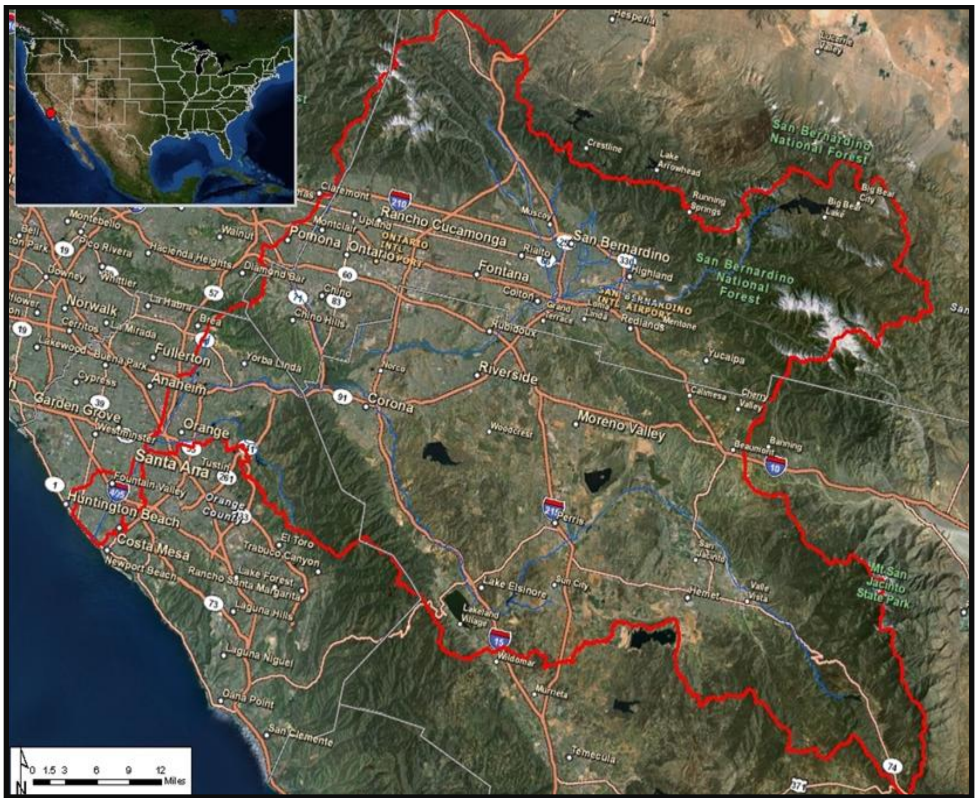


Figure 11. Location of Santa Ma River Watershed (*WEST*)

The watershed, which is the largest stream system in Southern California, is prone to flash flooding due to the high potential for intense rainfall in the mountain areas and downstream urbanization. Thus, rapid flood forecasting by the district, which CWMS can support, is essential for reservoir operations and to reduce the potential flooding in the basin. (*Sources: USACE, 2011d; USACE, 2009p; Orange County, 2011; Appendix VI.*)

Deployment Objectives and Results

- Provided improved forecasted inflows for reservoirs in the Santa Ana River watershed to assist the district in making reservoir release decisions.
- Developed an HEC-HMS model, HEC-ResSim model, HEC-RAS model, and HEC-FIA model compatible with CWMS.
- Completed stress tests.
- Deployed Santa Ana watershed cofiguration to the Los Angeles District.
- Trained district staff on CWMS use.
- Enhanced and expanded the Los Angeles District's real-time water control management capabilities.

Apalachicola, Chattahoochee, Flint Rivers Deployment

States: Alabama, Florida, Georgia (Figure 12)
USACE Division: South Atlantic
USACE District: Mobile
Major Water Control Projects: Buford Dam; Morgan Falls Dam; West Point Dam; Bartletts Ferry Dam; Goat Rock Dam; Oliver Dam, North Highlands Dam; Walter F. George Lock and Dam; and George Andrews Lock and Dam; all on the Chattahoochee River. Warwick and Flint River dams on the Flint River. Jim Woodruff Lock and Dam on the Apalachicola River.
Contractor: WEST

Importance

The CWMS deployment will help the Mobile District manage water control projects in the Apalachicola, Chattahoochee, Flint rivers watershed, which provide flood control, hydropower, navigation, water supply, water quality, fish and wildlife management, and recreation benefits.

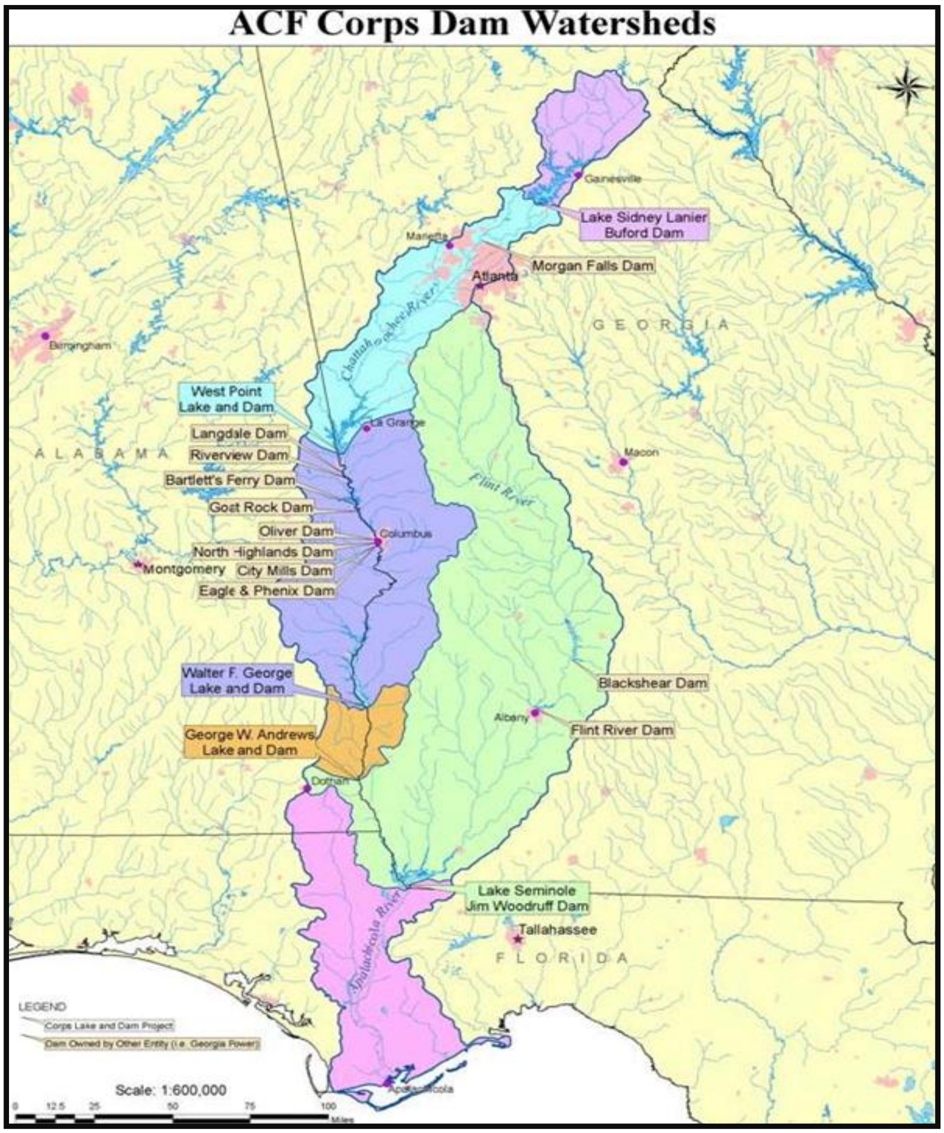


Figure 12. Location of Apalachicola, Chattahoochee, Flint Rivers Watershed and Location of Dams *(USACE)*

Operation objectives include reducing flood risk to metropolitan Atlanta, GA - an area with more than 5.6 million people.

During the 15-23 September 2009 event, the Chattahoochee River rose to its highest levels since Buford Dam was built. A state of disaster was declared for several counties in Georgia, many of them in the Atlanta area. The flood caused at least $500 million in damages and was blamed for at least ten deaths.

Operations also mitigate flooding in West Point, a town in Troup County, Georgia. The population is about 3,382. The Chattahoochee River flows through the city, and floods can affect parts of the city along both banks.

The operation of Buford Dam and West Point Dam for flood control is affected by many factors, such as weather forecasts and runoff amounts and timing both upstream and downstream of the reservoirs. The Mobile District did not have a comprehensive watershed modeling system for short-term decision support of real-time water control operations. Deploying CWMS would provide the Mobile District enhanced capability for managing real-time operation on a short-term basis. (*Sources: Appendix IV; USAGE, 2011b; Georgia Power, 2010.*)

Deployment Objectives and Results

- Developed a meteorological forecast processor, an HEC-HMS model, an HEC-ResSim model, HEC-RAS models for three important reaches, and HEC-FIA models for important impact areas that are all compatible with CWMS.
- Integrated the models into CWMS.
- Completed stress tests.

- Deployed the ACF watershed configuration to the Mobile District's server.
- Trained Mobile District staff on CWMS use.
- Enhanced and expanded the Mobile District's real-time water control management capabilities.

Missouri River Tributaries Deployment

South Platte River

Importance

The CWMS deployment will help the Omaha District manage water control projects in the South Platte River watershed, which provide flood control benefits. Operation objectives include reducing flood risk to the Denver region. Denver is the most populous city in Colorado with more than 600,000 people, according to 2009 estimates.

States:
Colorado (Figure 13), South Dakota (Figure 14), North Dakota (Figure 15)

USACE Divisions:
Northwestern; Missouri River

USACE District:
Omaha

Major Water Control Projects:
South Platte River watershed - Chatfield Dam on the South Platte River; Cherry Creek Dam on Cherry Creek; and, Bear Creek Dam at the confluence of Bear and Turkey Creeks. Fall River watershed - Cold Brook Dam on Cold Brook; and, Cottonwood Dam on Cottonwood Creek. James River watershed - Jamestown Dam on the James River; Pipestem Dam on Pipestem Creek.

Contractor:
WEST

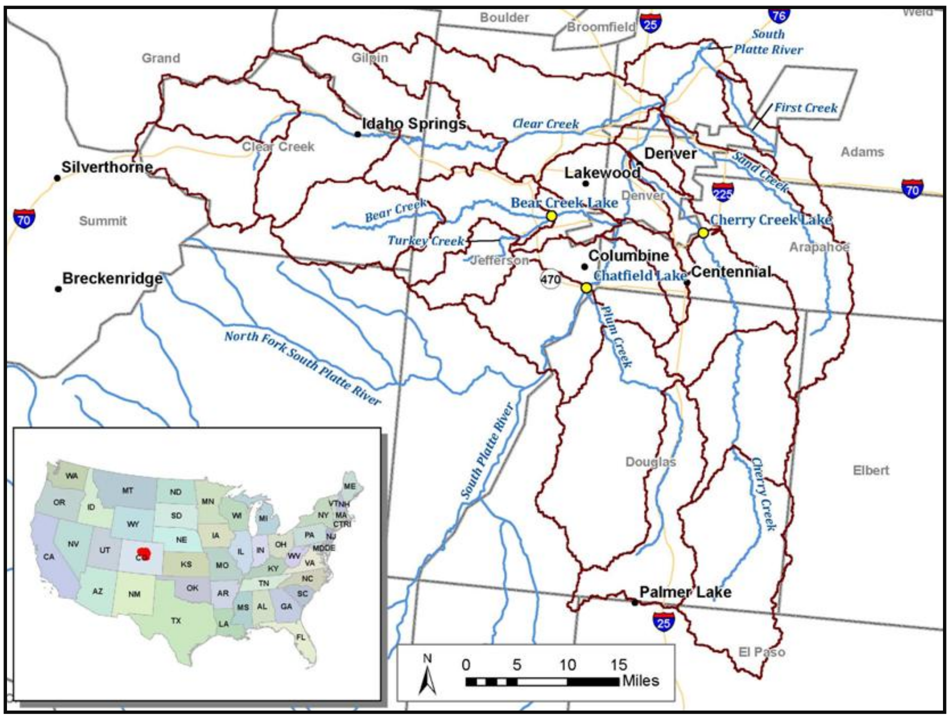


Figure 13. South Platte River Basin *(WEST)*

A large portion of the South Platte River flows within the city of Denver, so flooding of the city is a major concern. Major floods hit the area hard and often between 1864 and 1965. *(Sources: USACE, 20101; U.S. Census Bureau 2009 estimate; Appendix V - Part B.)*

Deployment Objectives and Results

- Provided the ability to forecast inflow volumes to Chatfield, Cherry Creek, and Bear Creek reservoirs (with focus on the Plum and Cherry Creek basins) following periods of heavy rainfall to assist the district in making reservoir release decisions.

- Developed an HEC-HMS model and an HEC-ResSim model compatible with CWMS.
- Integrated the models into CWMS.
- Completed stress tests.
- Deployed the South Platte River watershed configuration to the Omaha District.
- Trained the Omaha District's staff on CWMS use.
- Enhanced and expanded the Omaha District's real-time water control management capabilities.

Fall River Basin

Importance

The CWMS deployment will help the Omaha District manage Cold Brook and Cottonwood darns, which provide flood control benefits. Operation objectives include reducing flood risk in the City of Hot Springs, which has a population of about 4,000, according to 2009 estimates. In past years, the Fall River was subject to flash flooding, causing damage to Hot Springs and nearby rural areas. (*Sources: USACE, 2010b; Appendix V - Part A; U.S. Census Bureau 2009 estimate*.)

Deployment Objectives and Results

- Provided the ability to forecast inflow volumes to Cold Brook and Cottonwood reservoirs following periods of heavy rainfall to assist the Omaha District in making reservoir release decisions.
- Developed an HEC-HMS model and an HEC-ResSim model compatible with CWMS.
- Integrated the models into CWMS.
- Completed stress tests.
- Deployed the Fall River watershed configuration to the Omaha District.

- Trained the Omaha District's staff on CWMS use.
- Enhanced and expanded the Omaha District's real-time water control management capabilities.

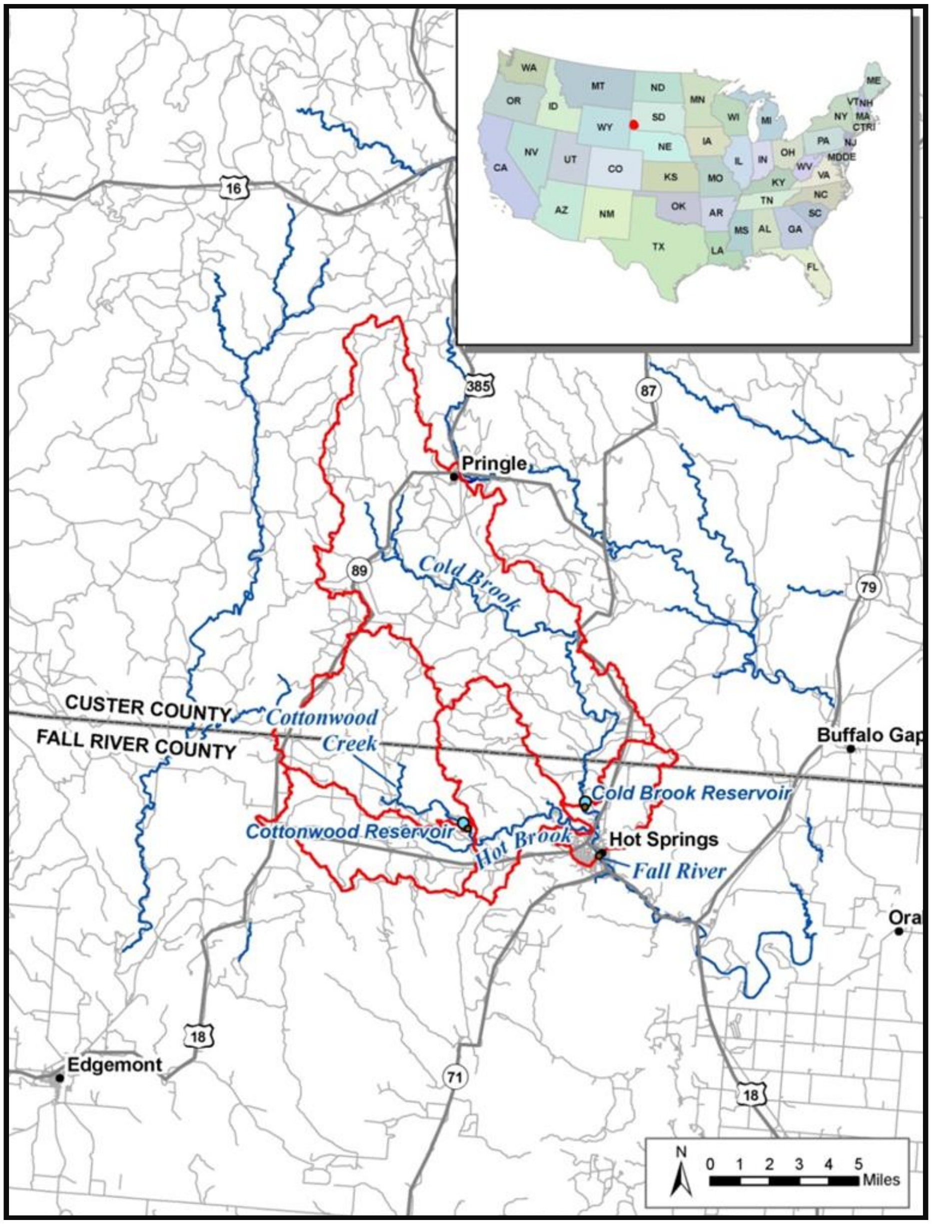


Figure 14. Fall River Basin (WEST)

James River Basin (North Dakota)

Importance

The CWMS deployment will help the Omaha District manage Jamestown and Pipestem dams, which provide flood control, irrigation, municipal water supply, pollution control, recreation, power, and fish and wildlife conservation benefits. Operation objectives include reducing flood risk to Jamestown, as well as Arrowwood National Wildlife Refuge and agricultural areas.

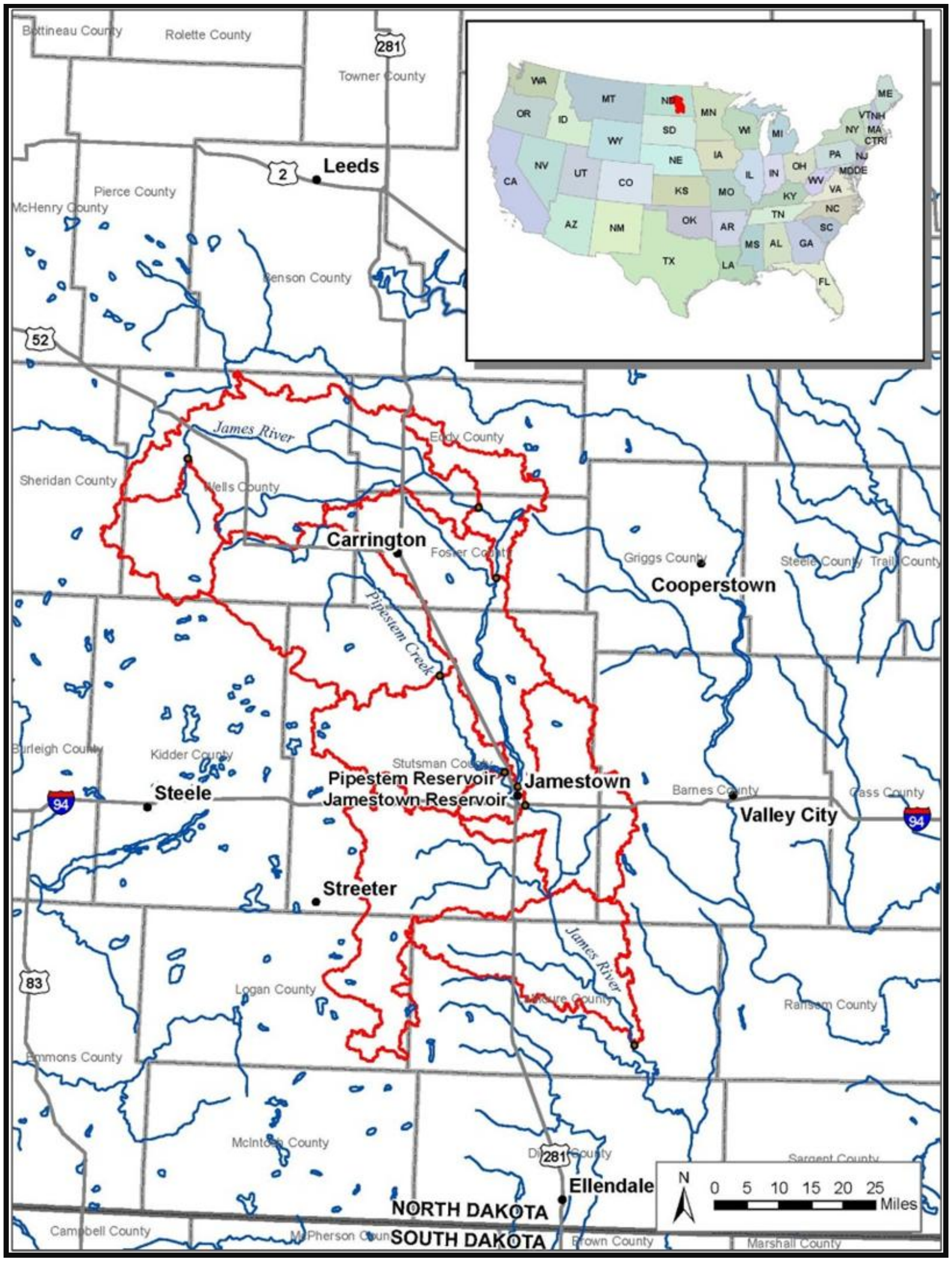


Figure 15. James River Basin - North Dakota (WEST)

The James River basin is prone to frequent and intense flooding, especially due to rapid snowmelt. Flood forecasting is essential in reducing the amount of damages and to aid in estimating reservoir releases. (*Sources: Appendix V - Part C*.)

Deployment Objectives and Results

With the HEC-HMS model, provided improved forecasted inflows (focused on spring snowmelt) for Jamestown Reservoir and improved forecasts for the James River from Jamestown to LaMoure assist the district in making reservoir release decision.

- Developed an HEC-HMS model compatible with CWMS[1].
- Integrated the models into CWMS.
- Completed stress tests.
- Deployed the James River (North Dakota) watershed configuration to the Omaha District.
- Trained the Omaha District's staff on CWMS use.
- Enhanced and expanded the Omaha District's real-time water control management capabilities.

[1] The HEC-HMS model in CWMS requires the snowmelt function. The snowmelt function was not available in CWMS during the deployment. Corps offices can update the CWMS interface once HEC implements the function. Beyond this, the contractor met the objective.

Puyallup River Deployment

Importance

The CWMS deployment will help the Seattle District manage Mud Mountain Dam, which provides flood control benefits. Operation objectives include reducing flood risk to the major population centers of Tacoma and Puyallup, as well as the cities of Enumclaw, Sumner, and Buckley. The 2009 population estimate for Tacoma was about 200,000 and about 38,000 for Puyallup.

State: Washington (Figure 16)
USACE Division: Northwestern
USACE District: Seattle
Major Water Control Projects: Mud Mountain Dam on the White River
Contractor: Riverside

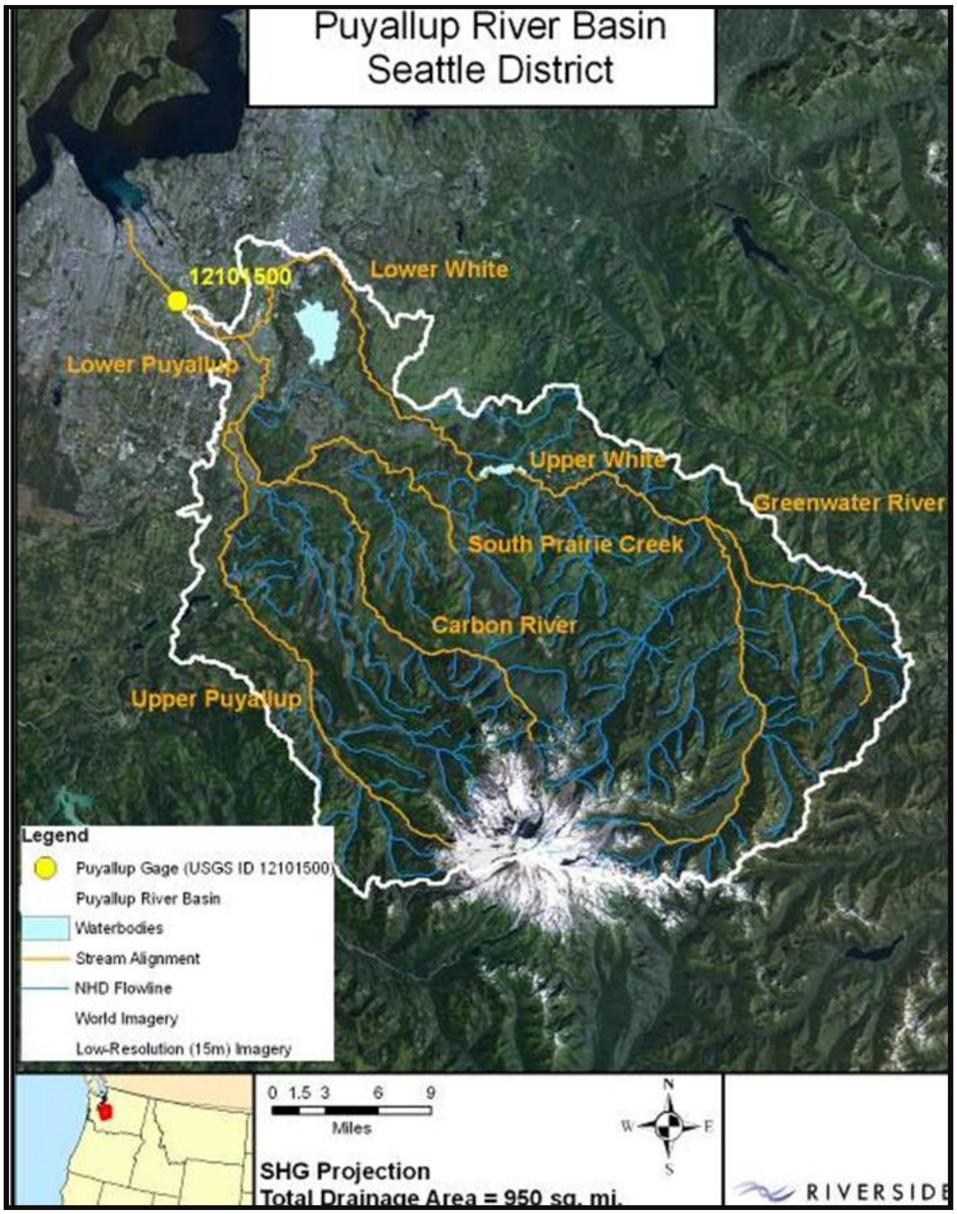
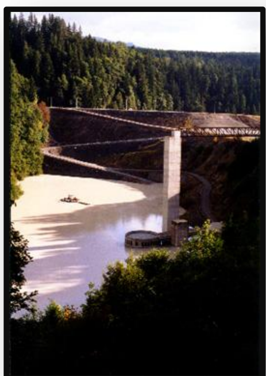


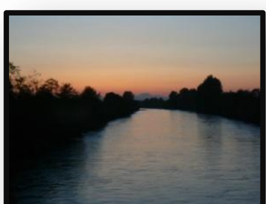
Figure 16. Puyallup River Basin (*Riverside*)

Furthermore, CWMS can contribute to an examination of Mud Mountain Dam operation. During a recent flood event, normal post-flood releases from the dam caused flooding in downstream residences and businesses in the city of Pacific totaling an estimated $5 million in residential damages and $10 million in commercial damages. The apparent cause of the unexpected flooding was a substantial change in channel capacity. U.S. Geological Survey channel measurements indicate an approximate 30% loss of channel capacity between November 2008 and January 2009. The district is committed to determining how to operate the project better to reduce risk in Pacific without increasing risk to the major damage centers further downstream. *(Source: Appendix III; HEC, 2009; US Census Bureau 2009 estimate)*

Deployment Objectives and Results



- Developed CWMS to run faster to facilitate making rapid decisions during flood events. Riverside provided a system that can be calibrated and used to establish release decisions within a 15-minute timeframe by an experienced user.
- Developed CWMS to meet or exceed the functionality available in the existing regulation spreadsheet.
- For data acquisition and visualization modules, provided the Seattle District with sufficient information to obtain an overview of watershed conditions and to establish an appropriate forecast time.
- Developed an HEC-HMS model suitable for use during the flood season when rainfall is the primary source of runoff. The HEC¬HMS model will serve as an alternative to flow forecasts provided by the National Weather Service Northwest River Forecast Center. In addition, set up forecast alternatives to use the National Weather Service flow forecasts as input to HEC-ResSim.



- For HEC-ResSim, developed a representative model for Mud Mountain Dam that includes gate setting estimation and prescription routines.
- Seattle District was concerned about flooding on the Lower White River and on the Lower Puyallup River near the Puyallup gage. For HEC-RAS, developed a well-calibrated model that could be used to simulate stage at these locations.
- For HEC-FIA, implemented thresholds and impact responses consistent with those currently included in the regulation spreadsheet.

- Provided an operational system and trained Seattle district personnel on CWMS use so that the district can begin using CWMS operationally.

- Enhanced and expanded the Seattle District's real-time water control management capabilities.

Cumberland, Tennessee, Lower Ohio Rivers Deployment

Importance

The CWMS deployment will help the Great Lakes and Ohio River Division and Nashville District manage water control projects in the Cumberland, Tennessee, and Lower Ohio Rivers watershed, which provide navigation, flood control, hydropower, water quality, water supply, fish and wildlife management, and recreation benefits.

States: Missouri, Illinois, Tennessee, Indiana, Ohio, West Virginia, Pennsylvania (Figure 17)
USACE Division: Great Lakes and Ohio River
USACE District: Nashville
Major Water Control Projects: Ohio locks and dams on the Ohio River - Martins Fork; Wolf Creek; Cordell Hull; Old Hickory, Cheatham, and Barkley dams on the Cumberland River; Laurel Dam on the Laurel River; Dale Hollow Dam on the Obey River; Great Falls and Center Hill dams on the Caney Fork River; .J. Percy Priest Dam on the Stones River; Normandy Dam on the Duck River; Kentucky Dam on the Tennessee River.
Contractor: Riverside

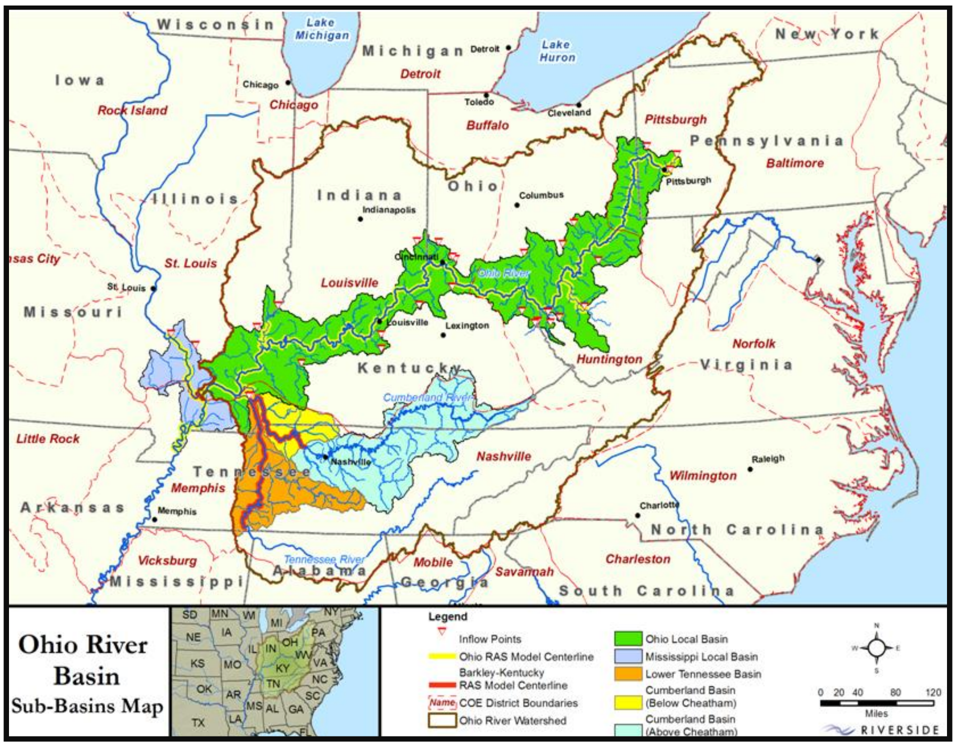


Figure 17. Location of Cumberland, Tennessee, Lower Ohio Rivers (*Riverside*)

The Great Lakes and Ohio River Division oversees lock and dam operations along the Ohio River and major flood control operations of Kentucky and Barkley dams to reduce flood risk below the confluence of the Ohio and Mississippi rivers and to protect the Mississippi River levee system.

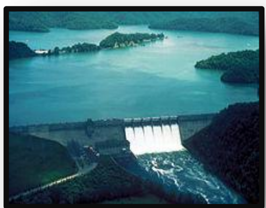
Under normal circumstances, the Tennessee Valley Authority determines releases from Barkley and Kentucky dams in coordination with the Nashville District. During major flooding, the division assumes direction of both dams and determines releases.

The Nashville District is responsible for the operation of the Cumberland River reservoirs to reduce flood risk at Celina, Carthage, Nashville, and Clarksville, TN, in addition to local channel limits below each dam. (*Source: USACE, 2010k; VA, 2010; Appendix I.*)

Deployment Objectives and Results

- Coordinated with the Great Lakes and Ohio River Division and the Nashville District to collect, inventory, and quality control relevant data and models.
- Developed HEC-HMS models for local Ohio River, Cumberland River, and lower Tennessee River subbasins.
- Developed an unsteady-flow HEC-RAS model for the Cumberland and Tennessee rivers for reaches upstream of Barkley and Kentucky dams.

- Enhanced an existing HEC-ResSim implementation for the Cumberland reservoirs to: improve the performance and facilitate data review and release specification, and implement rule-based flood control operations for the Cumberland reservoirs.
- Implemened the action table feature of HEC-FIA for the Ohio and Cumberland CWMS.



- Integrated the developed HEC-HMS, HEC-RAS, HEC-ResSim, and HEC-FIA models and an additional existing HEC-RAS model of the Ohio River into two separate CWMS implementations. Configured the CWMS CAVI and stress tested each CWMS implementation.
- Deployed the fully developed CWMS to the Great Lakes and Ohio River Division and the Nashville District, provided training in the use of the systems, and provided documentation of the system development and implementation tasks.
- Enhanced and expanded both the Great Lakes and Ohio River Division and the Nashville District's real-time water control management capabilities.

Jackson and James Rivers Deployment

State:
Virginia (Figure 18)

USACE Division:
North Atlantic

USACE District:
Norfolk

Major Water Control Projects:
Gathright Dam on the Jackson River

Contractor:
Riverside

Importance

The CWMS deployment will help the Norfolk District manage Gathright Dam, which provides flood control, water quality, and recreation benefits.

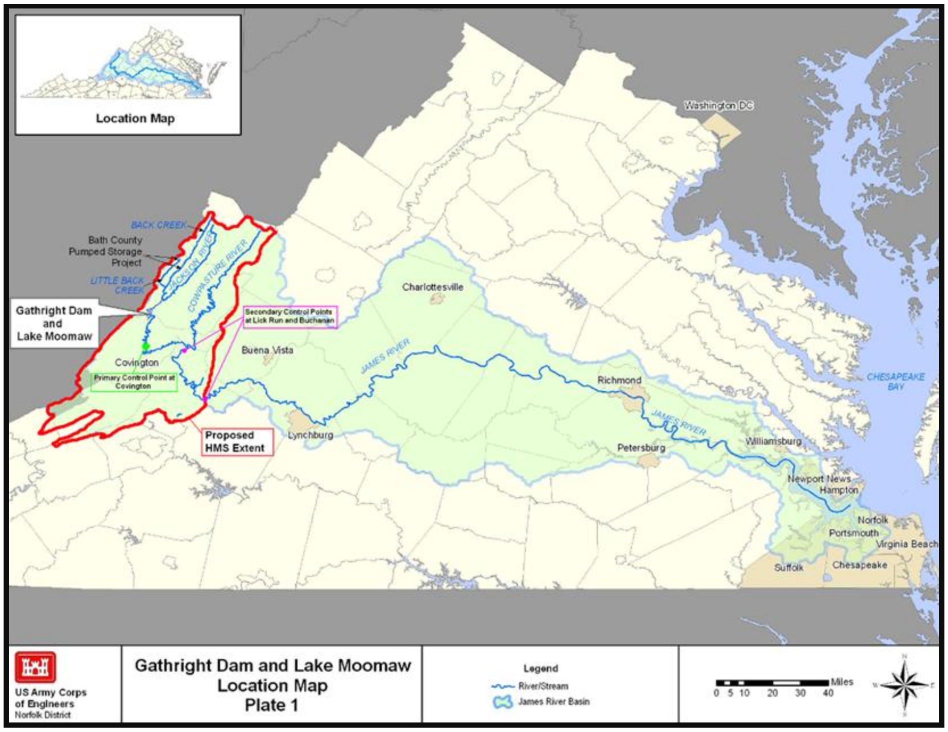


Figure 18. Jackson and James Rivers Basin Study Area (Riverside)

Operation objectives include reducing flood risk to the major population center of Covington. The main industry in the region is a paper mill located along the Jackson River just upstream of the confluence with Dunlap Creek. Protection of the mill from flood damage is vital to the local economy. Agricultural resources within the region are also susceptible to flooding.

Furthermore, based on both the probability of failure and potential failure consequences, the Corps assigned Gathright Dam a rating of "urgent (unsafe or potentially unsafe)" for dam safety action, which makes it high priority for repairs and studies, including this CWMS study.

CWMS can contribute to both a study to review project operation and a non-Federal hydropower license application. (*Sources: Appendix II; USACE, 2010e.*)

Deployment Objectives and Results

- Provided data visualization that is equal to or exceeds the current capabilities of WCDS and other web-based sources.
- Provided models that are easy to maintain. Norfolk District staff now only spends a half hour to an hour per day updating and using the models.
- Provided a tool that can be used for scenario analysis and for training of staff on the system operations.
- Provided the ability to expand the models (for example, to include other basins such as the Maury River).
- Deployed CWMS to the Norfolk District.
- Trained Norfolk District staff on CWMS use.
- Enhanced and expanded the Norfolk District's real-time water control management capabilities.

American River Deployment

Importance

The CWMS deployment will help the Sacramento District manage Folsom Dam, which provides flood control, water supply, hydropower, fishery, water quality, and recreation benefits.

State: California (Figure 19)
USACE Division: South Pacific
USACE District: Sacramento
Major Water Control Projects: Folsom Dam on the American River
Contractor: Ford Engineers

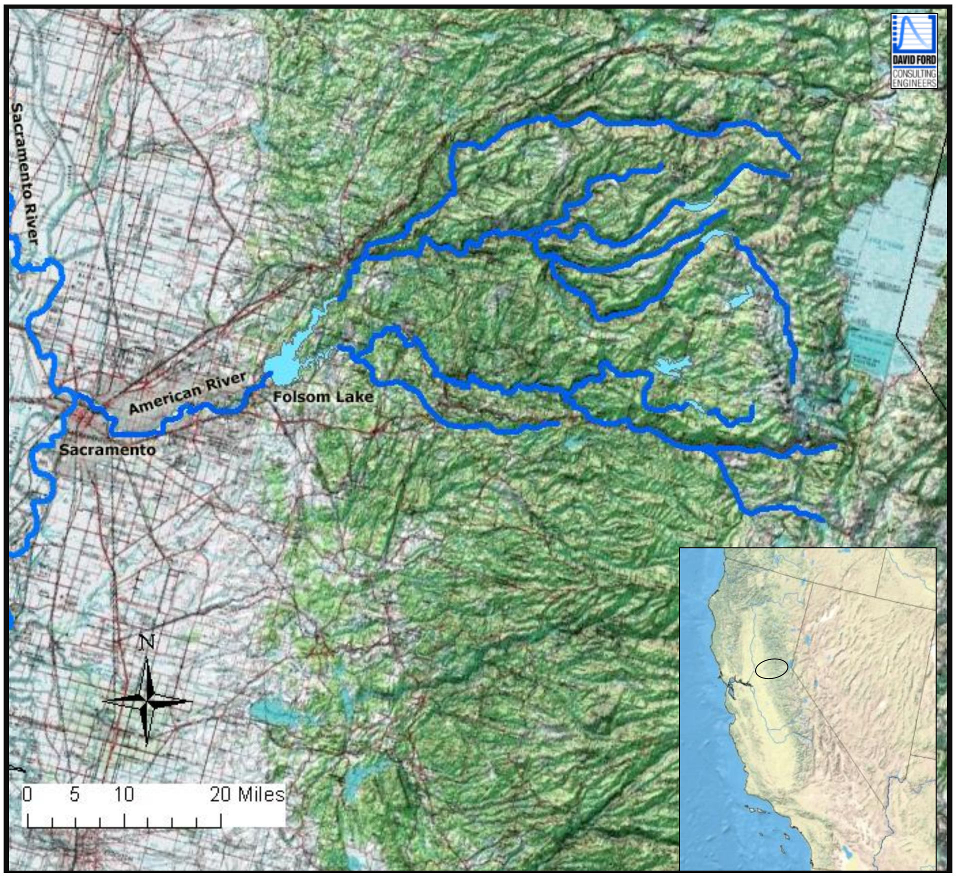


Figure 19. Location of the American River; the river has three main forks, the South, Middle, and North, which flow through the Sierra foothills and converge east of Sacramento, CA (*Coloma Communications, 2011*)

Operation objectives include reducing flood risk in the greater Sacramento area. Sacramento faces an unacceptably high risk of flooding - perhaps the greatest of any major American city. The flood risk stems primarily from these issues:

- The magnitude of flood flows has increased since Folsom Dam was first constructed. When Folsom Dam was designed and constructed in the 1950s, a statistical analysis was done using the historical flow record at that time. The reservoir was sized to manage flow from a flood with exceedence probability of 0.002. Using probability estimates from the current period of record, the reservoir is now found to manage a probability of 0.02 flood.

- Many of the levees protecting Sacramento are old and were not constructed to current engineering standards.

A number of studies and projects are either proposed or already underway at Folsom Dam to help reduce Sacramento's flood risk. CWMS can provide information for these studies. (*Sources: State of California, 2011; Appendix XI.*)

Deployment Objectives and Results

- Used information from three existing HEC-HMS models to create a new HEC-HMS model of the American River watershed. The HEC-HMS model will provide an alternative source of inflow forecasts. The level of funding for this project did not include calibration of the HEC-HMS model; however, the objective of the study was to have the HEC-HMS model ready for calibration and integrated into CWMS.

- Linked the inflow forecasts from either the HEC-HMS model or the National Weather Service to inflow locations in the HEC¬ResSim model.
- Verifyed the unsteady HEC-RAS model.

- Developed a CWMS watershed from the HEC-ResSim model.
- Integrated all models and run a forecast for Sacramento District.
- Installed CWMS and the American River watershed for the Sacramento District.
- Trained Sacramento District staff on CWMS use.
- Enhanced and expanded the Sacramento District's real-time water control management capabilities.

Willamette River Deployment

Importance

The CWMS deployment will help the Portland District manage water control projects in the Willamette watershed, which provide flood control, power, navigation, irrigation, fishery, water quality, and recreation benefits.

State: Oregon (Figure 20)
USACE Division: Northwestern
USACE District: Portland
Major Water Control Projects: Big Cliff and Detroit dams on the North Santiam River; Blue River Dam on the Blue River; Cottage Grove Dam on the Coast Fork Willamette River; Cougar Dam on the South Fork McKenzie River; Dexter, Hills Creek, and Lookout Point dams on the Middle Fork Willamette River; Dorena Dam on the Row River; Fall Creek Dam on the Fall Creek River; Fern Ridge Dam on the Long Tom River; Foster Dam on the South Santiam River; Green Peter Dam on the Middle Santiam River
Contractor: WEST

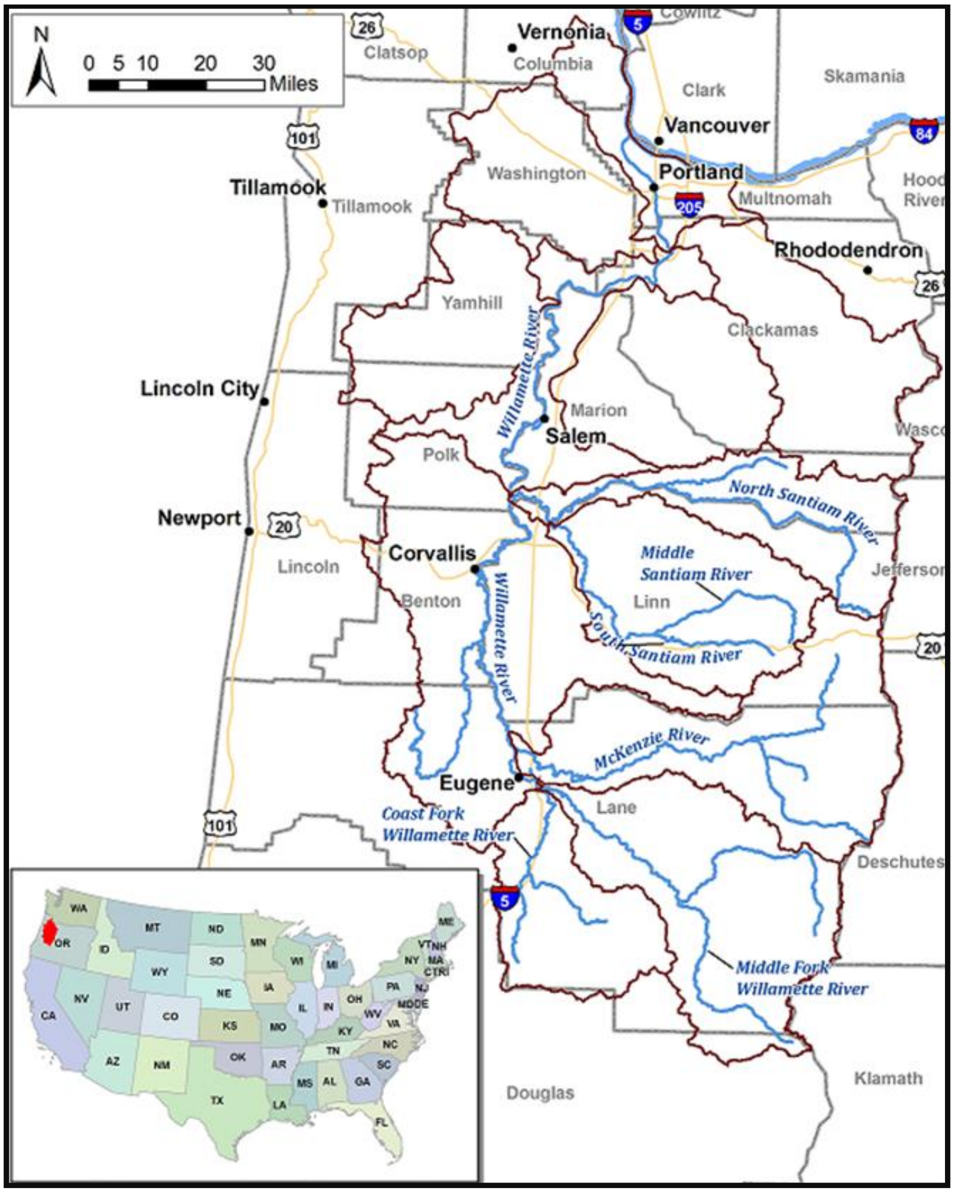


Figure 20. Willamette Watershed (*WEST*)

The Willamette River basin contains thirteen multi-purpose dams, which were constructed by the Corps. The primary purpose of these projects is to prevent flood damages to the downstream metropolitan areas of the

Willamette Valley. The regulation of flood storage in each reservoir is coordinated with the regulation of flood storage in all of the other reservoirs.

The Willamette River Basin covers eleven counties in Oregon comprising two-thirds of Oregon's population, including the state's largest city, Portland, and capital city, Salem. Communities along the main stem at risk of flooding include Springfield and Eugene in Lane County; Harrisburg in Linn County; Corvallis in Benton County; Albany in Linn and Benton counties; Salem in Marion County; Newberg in Yamhill County; Oregon City, West Linn, Milwaukie, and Lake Oswego in Clackamas County; and Portland in Multnomah and Washington counties.

The Willamette River is known for flooding because of the high amounts and variations of precipitation in the valley. The largest flood on the Willamette River in recorded history occurred in 1861 when rainstorms and warm temperatures combined with a well-above-average snowpack in the Cascades. From Eugene to Portland, thousands of acres of riverside farmland were washed away and many towns in the valley were damaged or destroyed. Peaking at 635,000 cubic feet per second, the 1861 flood inundated approximately 353,000 acres of land.

Although the Willamette River is regulated and controlled by a complex system of dams, severe flooding is still a concern. In 1996, a high snowpack combined with massive rainfall and warm temperatures caused some of the costliest floods to ever affect the Willamette Valley. *(Source: Appendix X; USACE, 2011c.)*

Deployment Objectives and Results

- Developed an HEC-ResSim model compatible with CWMS. The primary intent of the model is to assist the district in making real-time reservoir release decisions during major flood events.
- Integrated the HEC-ResSim model into CWMS.
- Completed stress tests.

- Deployed CWMS to the Portland District.
- Trained Portland District staff on CWMS use.
- Enhanced and expanded the Portland District's real-time water control management capabilities.

Juniata River Deployment

State:	Pennsylvania (Figure 21)
USACE Division:	North Atlantic
USACE District:	Baltimore
Major Water Control Projects:	Raystown Dam on the Juniata River
Contractor:	Riverside

Importance

The CWMS deployment will help the Baltimore District manage Raystown Dam, which provides flood control, water quality, fisheries, recreation, and hydropower benefits.

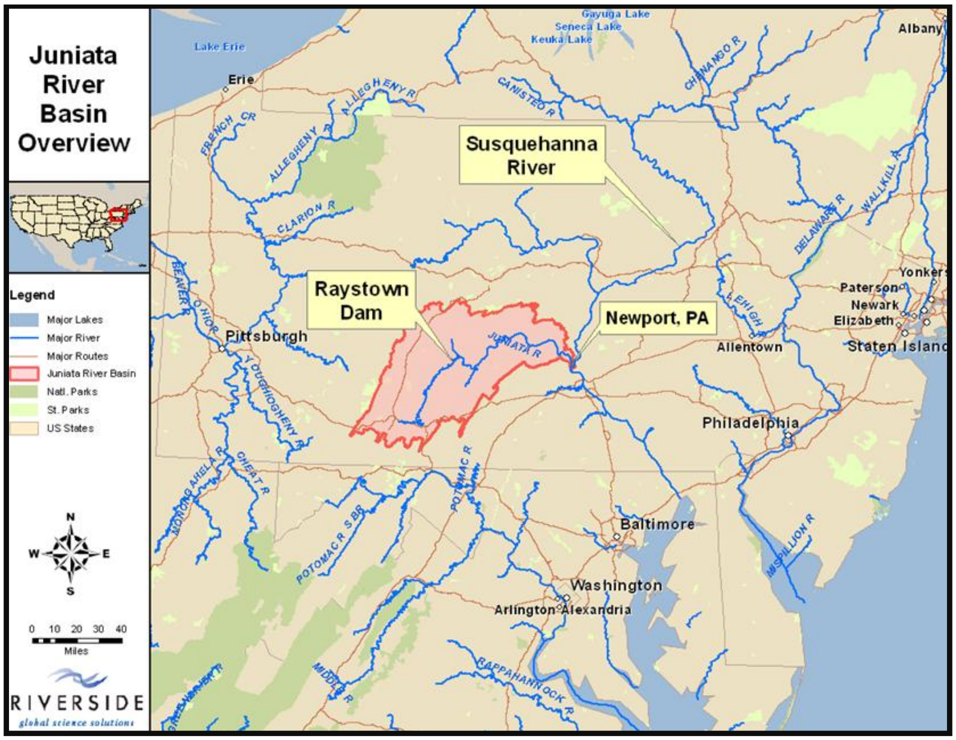


Figure 21. Juniata River Watershed *(Riverside)*

Operation objectives include reducing flood risk for downstream locations including Mount Union, Lewistown, Mifflintown, and Newport, and to a lesser extent, along the Susquehanna River below the confluence with the Juniata River.

Between 1972 and 2006, Raystown Dam prevented damages in excess of $252 million (without any adjustment for price level changes). *(Source: Appendix IX.)*

Deployment Objectives and Results

- Developed an operational system that can be used on a daily basis.
- Calibrated the models under a wide range of hydrologic conditions.

- Provided guidance about reasonable parameter ranges and general procedures for the forecasting process.
- Deployed CWMS to the Baltimore District.
- Trained Baltimore District staff on CWMS use.
- Enhanced and expanded the Baltimore District's real-time water control management capabilities.

Lessons Learned

Lessons about CWMS Deployment

Dedicated funding, expertise, and close coordination between the contractors, Corps offices, HEC, and the lead contractor enabled the success of this project. The effort spent was an investment that yielded for the Corps offices a modern and efficient decision support system for real-time water control management that can be used Corps-wide. This project can serve as a pilot for nationwide deployment in the future.

The following are lessons learned about CWMS deployment for real-time water control management:

- Deploying CWMS is a time-consuming, complex process. Funding contractors to deploy CWMS enabled Corps offices to have functioning CWMS configurations within about one year. Without dedicated funding, the districts and divisions would have pieced together resources from various studies to develop CWMS components - a slow-moving approach that yields components that are not optimized to work in parallel within CWMS for real-time water control management.

- Configuration and calibration of models for CWMS deployment requires expertise beyond that required for common hydrology and hydraulics studies. Team members should be skilled in developing CWMS components specifically for the purpose of real-time forecasting.

- The models developed in this deployment stood up to stress testing and were approved by technical reviewers. Choosing contractors with CWMS expertise ensured the development of high-quality products.

- The contractors' skilled developers exercised their judgment in translating data and Corps guidelines into model specifications. For example, water control manuals, which dictate the rules for reservoir operation, do not come with directions on how to interpret the rules into HEC-ResSim input. An engineer with skills and experience in CWMS development can work with Corps water managers to establish the best approach to match HEC-ResSim operation to operation prescribed in water control manuals.

- Planning and coordination between the contractors, Corps offices, HEC, and the lead contractor resulted in CWMS products that the

Corps offices could readily use. Each district and division has specific needs for the watersheds that are beginning managed. Contractors communicated with the Corps offices, HEC, and the lead contractor before and throughout the deployment to plan, strategize, establish objectives, make key decisions, and troubleshoot.

- HEC designed the deployments so that contractors submitted their modeling work in 30%-, 60%-, and 100%-complete phases. HEC and the lead contractor reviewed the work to ensure that it was of high quality, followed Corps guidelines, and met standards of practice. Incremental review allowed HEC, the lead contractor, and the Corps offices to raise concerns early enough to allow the contractors time to revise their work.

- HEC provided contractors with the latest software release versions and oversaw resolution of technical issues to ensure that the Corps offices received up-to-date, functional CWMS configurations and models.

- HEC's active participation is critical to successful CWMS deployment to any district or division.

- At the end of deployment, the contractors debriefed and trained Corps water managers - who had varying experience with CWMS - on CWMS development and use. Thus, the water managers received not only a usable product, but also gained the knowledge to use it and adjust it as necessary.

- The ARRA funding enabled deployment to eleven Corps offices. These deployments can be a catalyst for other deployments, with the districts and divisions sharing their experiences with other offices and the benefits of full CWMS implementation being realized.

- Knowledge of CWMS components and capabilities within Corps offices is fleeting. As staff turns over, expertise with usage is difficult to maintain without constant focus and funding.

Observations about CWMS Components

The following are observations about CWMS components:

- CWMS 2.0, the version implemented during this project, had no interface to HEC-HMS for modeling snowmelt, a significant factor in some watersheds. CWMS Version 2.1, scheduled to be released in Summer 2011, has this interface implemented.

- Contractors discovered a number of technical issues in the new versions of CWMS programs during this deployment. HEC began addressing these technical issues as they arose. Developers and users of CWMS should realize that CWMS is continually evolving and may require modifications and updates.

- For this deployment, some contractors wrote scripts to add custom functions to their models. HEC should evaluate the use of scripts. Custom scripts can make models more complex, opening the possibility for more technical issues, which Corps water managers may not be able to resolve readily. In addition, the project's reviewers found that some scripts were not compatible with some program versions. For future deployments, HEC may consider budgeting time for reviewing scripts and establishing guidelines for script development. HEC may also consider adding functions to CWMS to eliminate the need for scripts.

HEC Staff Acknowledgments

The following HEC staff members contributed to the project:

- Mr. Christopher N. Dunn is the Director of HEC and was the contracting officer's technical representative for the project. Mr. Dunn developed the proposal that secured the ARRA funding for the project.

- Ms. Diane Cuming was the contracting officer's representative for the project.

- Mr. George "Chan" Modini is the chief of the HEC Water Management Systems Division.

- Mr. William Charley was HEC's project manager for deployment to the eleven districts.

- Mr. Tom Evans worked on gridded data and HEC-HMS issues, as well as financial management components of the project.

- Mr. Fauwaz Hanbali worked with the contractors to resolve program and data issues and evaluate models. He worked on HEC¬HMS, HEC-ResSim, and HEC-RAS.

- Ms. Joan Klipsch, Mr. Bill Scharffenberg, Ms. Penni Baker, Ms. Marilyn Hurst, and Mr. Mike Perryman also provided support.

References

Publications

Fritz, J.A., Charley, W.J., Davis, D.W., and Haines, J.W., 2002. "New Water Management System Begins Operation at US Projects", *The International Journal on Hydropower & Dams*, Issue No. 3, pages 49-53.

Hydrologic Engineering Center, 1990. *HEC-2: Water Surface Profiles*, User's Manual, CPD-2A. Revised September 1991.

Hydrologic Engineering Center, 1995a. *HEC-DSS: User's Guide and Utility Program Manuals*, User's Manual, CPD-45.

Hydrologic Engineering Center, 1995b. *Water Control Data System (WCDS) Past, Present and Future*, RD-39.

Hydrologic Engineering Center, 1998a. *HEC-1: Flood Hydrograph Package*, User's Manual, Version 4.1, CPD-1A.

Hydrologic Engineering Center,1998b. *HEC-5: Simulation of Flood Control and Conservation Systems,* User's Manual, Version 8.0, CPD-5.

Hydrologic Engineering Center, 2007. *HEC-ResSim: Reservoir System Simulation*, User's Manual, Version 3.0, CPD-82.

Hydrologic Engineering Center, 2010. *HEC-RAS: River Analysis System*, User's Manual, Version 4.1, CPD-68.

Hydrologic Engineering Center, 2010a. *HEC-HMS: Hydrologic Modeling System*, User's Manual, Version 3.5, CPD-74A.

USACE, 1982. ER 1110-2-240, *Water Control Management*, HQUSACE, Washington, D.C.

USACE, 1994a. EM 1110-2-1417, *Flood-Runoff Analysis*, HQUSACE, Washington, D.C

USACE, 1994b. EP 1110-2-10, *Hydrologic Engineering Analysis Concepts for Cost-Shared Flood Damage Reduction Studies*, HQUSACE, Washington, D.C.

USACE, 1994c. EP 1110-2-9, *Hydrologic Engineering Studies Design*, HQUSACE, Washington, D.C.

Additional Publications for Reference

USACE, 1992. "*Drought Contingency Plan*", Appendix DCP to the Orwell Dam and Reservoir Regulation Manual, Ottertail River, Minnesota. St. Paul District, St. Paul, MN.

USACE, 1994d. Water Control Manual, "*Lake Traverse Project*", December 1994 revision, St. Paul

USACE (2009a). "Accelerated CWMS deployment lead contractor". Contract: BPA W91238-08-A-0017 #0010 ARRA LC, Sacramento District, Sacramento, CA.

USACE (2009b). "Accelerated CWMS deployment through ARRA for American River Basin". Contract: BPA W91238-08-A-0017 #0020 ARRA American, Sacramento District, Sacramento, CA.

USACE (2009c). "Accelerated CWMS deployment through ARRA for Apalachicola-Chattahoochee-Flint basin". Contract: BPA W91238-08-A-0016 #0008 ARRA ACF, Sacramento District, Sacramento, CA.

USACE (2009d). "Accelerated CWMS deployment through ARRA for Buffalo Bayou". Contract: BPA W91238-08-A-0017 #0018 ARRA Buffalo, Sacramento District, Sacramento, CA.

USACE (2009e). "Accelerated CWMS deployment through ARRA for Cumberland, Tennessee, and lower Ohio River basins". Contract: BPA W91238-08-A-0018 #0003 ARRA Cumberland, Sacramento District, Sacramento, CA.

USACE (2009f). "Accelerated CWMS deployment through ARRA for Jackson and James River basin". Contract: BPA W91238-08-A-0018 #0002 ARRA JackJames, Sacramento District, Sacramento, CA.

USACE (2009g). "Accelerated CWMS Deployment through ARRA for Juanita River Basin". Contract: BPA W91238-08-A-0018 #0005 ARRA Juanita, Sacramento District, Sacramento, CA.

USACE (2009h). "Accelerated CWMS deployment through ARRA for Puyallup River basin". Contract: BPA W91238-08-A-0018 #0004 ARRA Puyallup, Sacramento District, Sacramento, CA.

USACE (2009i). "Accelerated CWMS deployment through ARRA for Red River basin". Contract: BPA W91238-08-A-0017 #0019 ARRA Red River, Sacramento District, Sacramento, CA.

USACE (2009j). "Accelerated CWMS deployment through ARRA for Santa Ana River basin". Contract: BPA W91238-08-A-0016 #0009 ARRA PWS Santa Ana, Sacramento District, Sacramento, CA.

USACE (2009k). "Accelerated CWMS deployment through ARRA for Upper Missouri River Tributaries". Contract: BPA W91238-08-A-0016 #0010 AARA PWS MisTrib.doc, Sacramento District, Sacramento, CA.

USACE (2009l). "Accelerated CWMS Deployment through ARRA for Willamette River Basin". Contract: BPA W91238-08-A-0016 #0011 ARRA Willamette, Sacramento District, Sacramento, CA.

USACE (2009m). "Initial Deployment Site Assessment for Accelerated CWMS Deployment through ARRA". Contract: BPA W91238-08-A-0016 #0006 (WEST), Sacramento District, Sacramento, CA.

USACE (2009n). "Initial Deployment Site Assessment for Accelerated CWMS Deployment through ARRA". Contract: BPA W91238-08-A-0017 #0011 (Ford Engineers), Sacramento District, Sacramento, CA.

USACE (2009o). "Initial Deployment Site Assessment for Accelerated CWMS Deployment through ARRA". Contract: BPA W91238-08-A-0018 #0001 (Riverside), Sacramento District, Sacramento, CA.

USACE (2009p). Project Management Plan: Accelerated CWMS Deployment Campaign. Revised September 11, 2009, HEC, Davis, CA.

Information from the Internet

City of Houston, 2011. "*Houston Facts and Figures*", Houston, TX, web site, http://www.houstontx.gov/abouthouston/houstonfacts.html

Coloma Communications, 2011. "*The American River*", Corvallis, OR, web site, http://www.theamericanriver.com/

Environment Canada, 1999. "*Red River Basin Map*", Red River Basin, North Dakota University, web page, http://www.rrbdin.org/data/redriverbasin.pdf

Georgia Power, 2010. "*Bartletts Ferry Project*", Atlanta, GA, web site, http://www.georgiapower.com/lakes/hydro/bartletts.asp

Hydrologic Engineering Center, 2010a. Corps Water Management System (CWMS), web page, http://www.hec.usace.army.mil/cwms/cwms.html

Hydrologic Engineering Center, 2010b. Hydrologic Engineering Center, web site http://www.hec.usace.army.mil/

Orange County, 2011. "*Dam Failure*", Santa Ana, CA, web page, http://ocgov.com/vgnfiles/ocgov/EOC/Doc/DAM%20FAILURE.pdf

ProjNet, 2011. "*About DrChecks*", Washington, D.C., Corps only https://www.projnet.org/projnet/binKornHome/index.cfm?strKornCob=DrCkSubscription

Recovery Accountability and Transparency Board, 2010. "*Recovery.gov: Track the Money*", Washington, D.C., web site, http://www.recovery.gov

State of California, 2011. "*California State Parks - Folsom Dam*", Sacramento, CA web page, http://www.parks.ca.gov/?page_id=882

Tennessee Valley Authority (TVA), 2010. "*TVA Reservoirs and Power Plants*", Knoxville, TN, web site, http://www.tva.com/sites/sites_ie.htm

USACE, 2010a. "*Ashtabula Lake/Baldhill Dam*", St. Paul District, St. Paul, MN, web page, http://www.mvp.usace.army.mil/recreation/default.asp?pageid=151

USACE, 2010b. "*Cottonwood Springs and Cold Brook Dams & Lakes Homepage*", Omaha District, Omaha, NE, web page, http://www.nwo.usace.army.mil/html/Lake_Proj/bigbend/cottonwoodcoldbrook.html

USACE, 2010c. "*Frequently Asked Questions*", HQUSACE, Washington, D.C., web page, http://www.usace.army.mil/recovery/Pages/FAQ.aspx

USACE, 2010d. "*Gathright Safety: Frequently Asked Questions*", Norfolk District, Norfolk, VA, web page, http://www.nao.usace.army.mil/gathright_faq.asp

USACE, 2010e. "*Lake Sidney Lanier*", Mobile District, Mobile, AL, web page, http://lanier.sam.usace.army.mil/

USACE, 2010k. "*Recreation in the Nashville District*", Nashville District, Nashville, TN, web page, http://www.lrn.usace.army.mil/pao/lakeinfo/lakeinfo.html

USACE, 2010l. "*Tri-Lakes Homepage*" and "*Brochure*" link, Omaha District, Omaha, NE, web page, http://www.nwo.usace.army.mil/html/Lake_Proj/TriLakes/TLHome2.htm

USACE, 2011c. "*Portland District Operating Locations*", Portland District, Portland, OR, web page, http://www.nwp.usace.army.mil/locations/home.asp

USACE, 2011d. "*Reservoir Regulation*", Los Angeles District, Los Angeles, CA, web page, http://www.spl.usace.army.mil/resreg/

USACE, 2011e. "*The Addicks and Barker Dam Safety Program*", Galveston District, Galveston, TX, web page, http://www.addicksandbarker.info/index.php?option=com_content&view=article&id=24&Itemid=4

White House Office of Management and Budget (OMB), 2010. "*Recovery Act*", Washington, D.C., web page, http://www.whitehouse.gov/omb/recovery_default

Additional Information from the Internet for Reference

USACE, 2010h. "*Mission & Vision*", HQUSACE, Washington, D.C., web page, http://www.usace.army.mil/about/Pages/Mission.aspx

USACE, 2010i. "*Overview of the American Recovery and Reinvestment Act of 2009*", HQUSACE, Washington, D.C., web page, http://www.usace.army.mil/recovery/Pages/OverviewRecoveryAct.aspx

USACE, 2010m. *US Army Corps of Engineers Civil Works SUMMARY Agency Recovery Act Plan*, HQUSACE, Washington, D.C. web page, http://www.usace.army.mil/recovery/Documents/ARRAUSACECWSummaryAugust2010.pdf

USACE, 2011a. "*Implementing the American Recovery and Reinvestment Act of 2009*", HQUSACE, Washington, D.C., web page, http://www.usace.army.mil/recovery/Pages/ImplementingRA.aspx

US Census Bureau, 2010. "*Population Finder*", Suitland, MD, web page, http://www.factfinder.census.gov/servlet/SAFFPopulation?_submenuId=population_0&_sse=on

Terms

ACF Apalachicola, Chattahoochee, Flint Rivers

AE Contractors Architect-engineer contractors

ARRA American Recovery and Reinvestment Act of 2009; funding source.

BPA Blanket purchase agreement. USACE contracting mechanism utilized for this study, which allows contractors to be "on call" for work.

BPA contractors Blanket purchase agreement contractors prequalified and preselected by the Corps Hydrologic Engineering Center to complete the work. The BPA contractors for work described herein include:

- David Ford Consulting Engineers, Inc. (Ford Engineers)
- Riverside Technology, Inc. (Riverside)
- WEST Consultants, Inc. (WEST)

CAVI Corps Water Management System Control And Visualization Interface. The CAVI allows the user to execute application programs and display results.

Contracting Officer For this project, the contracting officer was Ms. Niki Haas, USACE, Sacramento District. The contracting officer was responsible for all contracts on this project and was the only person authorized to make changes to performance work statements, fees, and schedules.

Contracting Officer's Representative For this project, the contracting officer's representative was Ms. Diane Cuming of the Corps Hydrologic Engineering Center. Certain responsibilities of the contracting officer were delegated to the contracting officer's representative.

Contracting Officer's Technical Representative For this project, Mr. Christopher Dunn, Director, USACE, Hydrologic Engineering Center was the contracting officer's technical representative. The contracting officer's technical representative or designee was responsible for all final decisions on technical aspects of this project.

Corps US Army Corps of Engineers.

CWMS Corps Water Management System. The real-time decision support system designed and developed by the Corps Hydrologic Engineering Center to assist Corps water managers by providing information about watershed and channel behavior and reservoir performance.

Deployment Site Manager This was a BPA contractor's employee who was in charge of the deployment at a selected district or division.

DrChecks Document Review and Checking System, the Corps' online review system.

EM USACE guidance documentation, Engineer Manual

EP USACE guidance documentation, Engineer Pamphlet

ER USACE guidance documentation, Engineer Regulation

Flow blending The capability of CWMS to transition from observed flows during the "lookback period" to simulated flows during the forecast period. The lookback period is the period of time occurring prior to the time of forecast.

Ford Engineers David Ford Consulting Engineers, Inc., one of three United States contractors tasked with deploying CWMS under a blanket purchase agreement contract. Ford Engineers also was lead contractor for this project, helping the Corps Hydrologic Engineering Center manage the eleven deployments.

GIS Geographic information system. This is an integrated database and cartographic system, designed to manage and display spatially-oriented data and information.

Google Earth® a virtual globe, map, and geographical information program developed by Google. Maps the Earth with images obtained from aerial photograph and satellite imagery.

HEC Hydrologic Engineering Center

HEC-1 HEC's Flood Hydrograph Package; was designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. Replaced by the HEC-HMS software.

HEC-2 HEC's Water Surface Profiles; was designed for calculating water surface profiles for steady gradually varied flow in natural or nam-made channels. Replaced by the HEC-RAS software.

HEC-5 HEC's Simulation of Flood Control and Conservation Systems; software developed to assist in planning studies for evlauating proposed reservoirs in a system and to assist in sixing the flood control and conservation storage requirements for each reservoir in a system. Replaced by the HEC-ResSim software.

HEC-DSS	HEC's Data Storage System; is a database system desgined to store and retieve scientific data that is typically sequential. Data types available are time sereies, curve data, spatial-oriented gridded data, and others
HEC-FIA	HEC's Flood Impact Analysis software application; computes indices of flood consequences, given hydrologic inputs measured or inputs computed with another of HEC's software applications.
HEC-HMS	HEC's Hydrologic Modeling System; forecasts watershed runoff, given meteorological inputs, a description of the watershed properties, and initial watershed states.
HEC-RAS	HEC's River Analysis System; software application simulates fluvial processes, routing flows through open channels and computing water surface elevations.
HEC-ResSim	HEC's Reservoir Simulation System; software application that simulates performance of a system of interconnected reservoirs, operating for multiple purposes, given system properties, initial states, hydrologic inputs, and operational rules.
HEMP	Hydrologic Engineering Management Plan. The HEMPs for this project identified and scheduled deployment activities and described technical details. For each task, the HEMPs defined what the deliverables and completion criteria were. The HEMPs also described the contractors' internal quality control/quality assurance procedures, the agency review and revision process, and what the contractors needed from the government to complete the tasks.
HQUSACE	Headquarters, US Army Corps of Engineers. This is used to designate the leadership of the Corps.
Lead contractor	Lead blanket purchase agreement contractor for this project. The lead contractor managed the day-to-day activities of this project, coordinating with other members of the project delivery team and facilitating work of other BPA contactors. Ford Engineers was the lead contractor.
LRD	Great Lakes and Ohio River Division
OMB	White House Office of Management and Budget.
Oracle®	an object-relational database management system produced and marketed by Oracle Corporation; the CWMS database.
PC	Personal computer. With permission, CWMS servers can be accessed remotely using a PC.

Performance Work Statement	Document that defines the scope of work to be undertaken by a blanket purchase agreement contractor, including the objectives, deliverables, and work schedule.
Project Delivery Team	The people and institutions involved in execution of the project. For this project, that included the contracting officer, contracting officer's technical representative, project manager, technical representatives from each division/district, lead contractor, and a designee from each blanket purchase agreement contractor.
Project Management Plan	The plan for execution of the project.
Project Manager	This was Mr. William Charley of HEC. The project manager was responsible for the overall success of the project. Mr. Charley developed performance work statements, consulted with District staff regarding expectations and progress, facilitated work by blanket purchase agreement contractors, assisted with CWMS troubleshooting, and worked cooperatively with the lead contractor throughout the duration of the project.
QA/QC	Quality assurance, quality control.
Riverside	Riverside Technology, Inc., one of three United States contractors tasked with deploying CWMS under a blanket purchase agreement contract.
Stress Test	A test to see if CWMS will run properly under high-flow conditions.
Technical Representative	This is the USACE employee at a district or division who is responsible for assisting the BPA contractor with deployment to that district or division.
Technology Transfer	Contractors transferred technology to USACE offices by giving Corps staff presentations about how they developed the CWMS models and configurations and training staff on using and modifying CWMS.
TVA	Tennessee Valley Authority
USACE	US Army Corps of Engineers
WCDS	Water Control Data System. The decision support system that was the predecessor to CWMS.

WEST	WEST Consultants, Inc., one of three United States contractors tasked with deploying CWMS under a blanket purchase agreement contract.

Appendices I thru XI

Riverside, WEST, and Ford Engineers wrote detailed, comprehensive final reports describing deployment to each Corps office. They are listed in Table 12.

Table 12. List of the Separate Appendices Written by the Contractors

Appendix Number	Appendix Name	Contractor
I	Cumberland, Tennessee, Lower Ohio Rivers site report	Riverside
II	Jackson and James rivers site report	Riverside
III	Puyallup River site report	Riverside
IV	Apalachicola, Chattahoochee, Flint rivers site report	WEST
V Part A	Missouri River tributaries sites report: Fall River site	WEST
V Part B	Missouri River tributaries sites report: South Platte River site	WEST
V Part C	Missouri River tributaries sites report: James River site	WEST
VI	Santa Ana River site report	WEST
VII	Buffalo Bayou site report	Ford Engineers
VIII	Red River site report	Ford Engineers
IX	Juniata River site report	Riverside
X	Willamette River site report	WEST
XI	American River site report	Ford Engineers