

HEC-RTS (REAL-TIME SIMULATION) VERSION 2 FOR REAL TIME FLOOD FORECASTING AND WATER CONTROL

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Abstract

The U.S. Army Corps of Engineers Corps Water Management System (CWMS) is a comprehensive data acquisition and hydrologic modeling system for short-term decision support of water control operations in real time. It encompasses data collection, validation and transformation, data storage, visualization, real time model simulation for decision-making support, and data dissemination. In its Corps implementation, CWMS uses an Oracle database and Sun Solaris workstations for data processes, storage and the execution of models, with a client application (the Control and Visualization Interface, or CAVI) that runs on a Windows PC. HEC-RTS, the Hydrologic Engineering Center's Real-Time Simulation program, is a publicly available version of CWMS's data visualization and modeling capabilities that runs on a single computer without using an Oracle database or a UNIX server

HEC-RTS provides support for operational decision making by forecast simulation modeling using any combination of the following models. Rainfall-runoff modeling with HEC-HMS based on gaged or radar-based precipitation, Quantitative Precipitation Forecasts (QPF) and other future precipitation scenarios provides forecasts of uncontrolled flows into and downstream of reservoirs. Simulation of reservoir operations with either HEC-ResSim or CADSWES's RiverWare provides operational decision information for the engineer. The river hydraulics program HEC-RAS computes river stages and water surface profiles for these scenarios. An inundation boundary and depth map of water in the flood plain can be calculated from the HEC-RAS results using ArcInfo. The economic impacts of different flow alternatives are computed by HEC-FIA. The user-configurable sequence of modeling software allows engineers to evaluate operational decisions for reservoirs and other control structures, and view and compare hydraulic and economic impacts for various "what if?" scenarios.

HEC-RTS version 1 "loosely couples" the modeling programs. Version 2 provides a "tight integration" of the models, where the modeling programs can be accessed directly. For example, in version 1, a water surface profile plot computed from HEC-RAS is displayed in a custom plot generated by RTS, whereas in version 2, such a plot will come directly from the RAS program itself.

HEC-RTS Version 1 is available from HEC on a request basis. HEC-RTS Version 2 is currently under development and is expected to be released next year.

INTRODUCTION

The ability to effectively operate reservoirs to minimize flooding during events and maximize conservation during droughts supports primary missions of the Corps and is critical to the nation. The Corps Water Management System, CWMS, is the Corps comprehensive data acquisition and hydrologic modeling system AIS for short-term real time decision support of water control operations nationwide (USACE, 1995). The regulation of the reservoirs supports the authorized purposes of the reservoir and specifically addresses flood risk management and loss-of-life concerns. CWMS is the primary tool used by Corps water managers, working cooperatively with other federal agencies and Corps operational partners, to help them minimize flooding during an event, optimize storage during droughts, as well as monitor and perform day-to-day operations.

CWMS is a comprehensive system that retrieves precipitation, river stage, gate settings and other data from field sensors, and validates, transforms and stores those measurements in a database. The measurements are used for calibration and adjustment of hydrologic and hydraulic models to reflect current conditions. Once the models have been adjusted to reflect current hydro-meteorological conditions within a watershed, they can be executed to produce forecasts of hydrologic conditions that will assist water managers to evaluate the effects of their operating decisions in the near future.

A public version of the CWMS Control and Visualization Interface, or CAVI, has been implemented in the program HEC-RTS, the Hydrologic Engineering Center's Real-Time Simulation program. HEC-RTS is a Windows based program that does not have the data processing, storage or dissemination capabilities of CWMS. While CWMS has a client-server architecture that utilizes a Sun Solaris server along with an Oracle database, HEC-RTS runs on a single PC that does not use Oracle, but uses the HEC Data Storage System (HEC-DSS) for the management of time series data (Charley, 1998).

In CWMS, the CAVI oversees and controls the operation of the functional modules. The CAVI provides the linkage between incoming data feeds, observed data, models, computed data, operating constraints and the user. It includes mechanisms to: evaluate the quality of incoming data; visualize information in time and space; facilitate primary modeling parameter adjustments; control and execute models; and compare the results of different modeling scenarios. The CAVI is the primary framework of HEC-RTS.

HEC-RTS contains active icons representing gauges, computation points, and other locations of interest, as depicted in Figure 1. The icons can display time series data in a "thumbnail plot", a "color bar", or a graphic form. By selecting one or more icons, a user can display two dimensional plots or tables of data represented by those icons. The display can also contain vector or raster maps or images to provide a geospatial context. The raster layers can include animated sequences of precipitation data from NEXRAD or other sources.

Functions are grouped into modules, corresponding to different water management tasks. These are the Data Acquisition Module, the Data Visualization Module, the Model Interface Module and the Watershed Setup Module. Each has a specific set of commands that are accessed through menus, toolbars, scripts, and from the context menus associated with the schematic elements displayed in the interface.

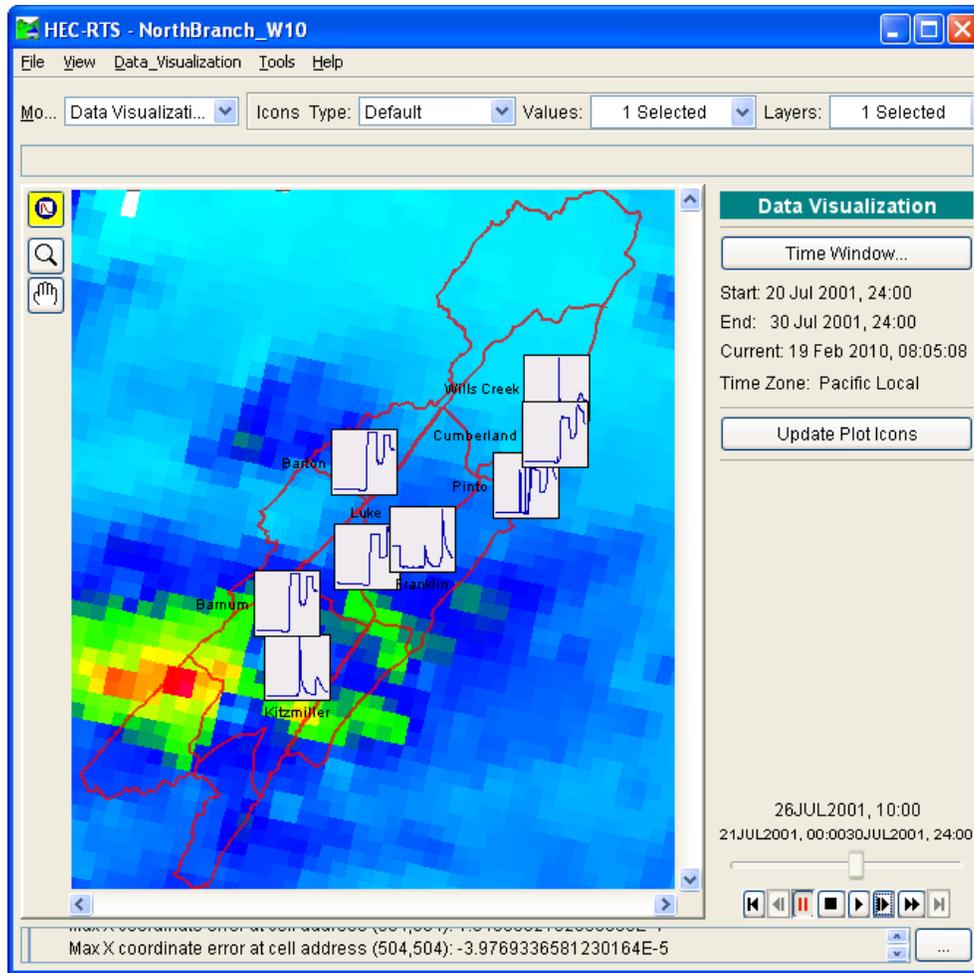


Figure 1 - HEC-RTS Data Visualization Module

HEC-RTS MODELING INTERFACE

HEC-RTS allows the water control manager to make short-term (typically a few days or weeks) forecasts of hydrologic conditions in the watershed. HEC-RTS provides an integrated suite of generalized modeling programs that represent different hydrologic aspects of the watershed. HEC-RTS currently includes the following models (listed in sequence of execution for a typical watershed):

- MFP, a simple meteorological model
- HEC-HMS, a hydrologic rainfall-runoff model
- HEC-ResSim, a reservoir flood operations simulation model
- CADSWES RiverWare, a supply-based reservoir operations model
- HEC-RAS, a river hydraulics model
- HEC-FIA, a flood impact economic analysis package

Other simulation programs can be added to the sequence, or used in place of the ones distributed with HEC-RTS. Each of these programs can run independently, but in HEC-RTS they are

combined to provide a comprehensive watershed forecast that can include flow rates, stages, operation plans, economic impacts, and actions to be taken to mitigate the effects of flooding. HEC-RTS does not require the full sequence of models to be used; the number and sequence of models is configurable during setup. The data flow for the models is diagrammed in Figure 2.

To support decision making in uncertain conditions, the user can simulate several scenarios and compare results through a single interface. Typical scenarios may include several different gate-setting plans for dam operations and different precipitation forecasts, which will give rise to several different flow rates through the watershed. The user can, for example, combine any of the dam operating plans with any of the precipitation forecasts to see if those plans will produce acceptable results under a variety of flow conditions. This kind of complex comparison requires the ability to run several alternative versions of individual models and to combine those individual model alternatives to build complete forecast scenarios.

SIMULATION MODELS

HEC-RTS allows users to adjust the parameters of each model individually and save those adjustments. A saved set of parameter adjustments is called an “alternative” for that model. In order to run the models, the user must select one alternative for each model to be executed. The combination of individual model alternatives into a set for execution is called a “forecast alternative.” The user can run several forecast alternatives and display the results of any or all of the alternatives in combination to make comparisons and plan operations. A description of these models follows.

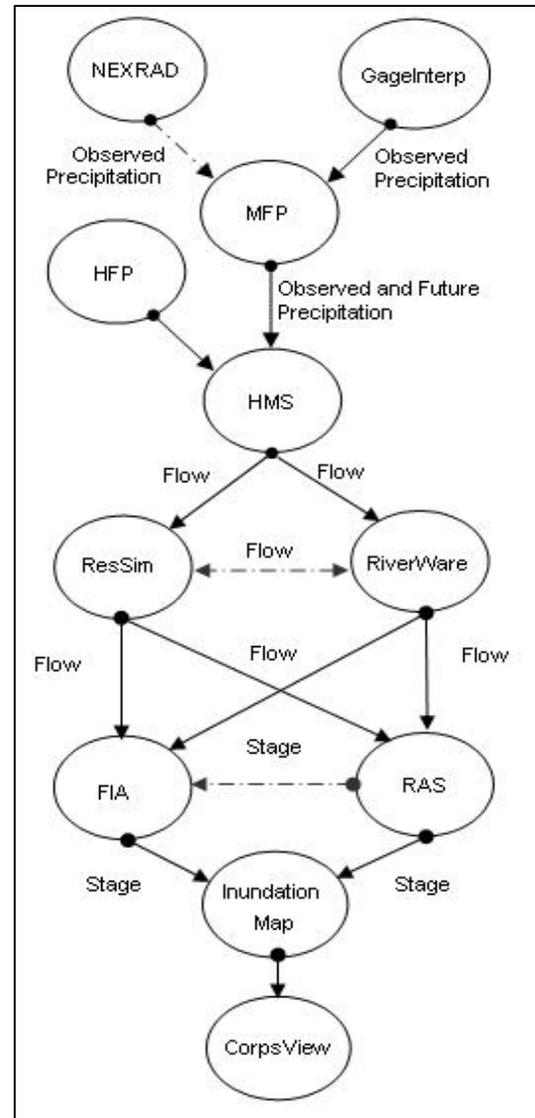


Figure 2 – Simulation Modeling

Meteorology: The Meteorological Forecast Processor, or MFP, combines observed precipitation with future precipitation scenarios. The observed precipitation may be from gridded rain gages or radar-based measurements, such as NEXRAD (Smith, 1999). Future precipitation, which can vary through both time and space, can be derived from National Weather Service QPFs or by manual entry. For manual entry, areas of the watershed are divided into “zones”, and the amounts and timing of future rainfall are entered into MFP for each zone. Based on these inputs, MFP generates precipitation grids to be read by HEC-HMS for hydrologic modeling. The amount and timing of future rainfall is typically varied to produce various “what if?” scenarios.

Hydrology: The Hydrologic Modeling System (HEC-HMS) computes hydrologic forecasts. HEC-HMS uses the ModClark model for rainfall/runoff transformation from distributed rainfall data, provided in a gridded format. ModClark is an adaptation of the Clark conceptual runoff model for unit hydrographs. Loss and base flow parameters for groups of subbasins are adjusted to match observed conditions through HEC-RTS. This adjustment may be accomplished through parameter optimization routines using observed flow or from manual adjustment. Where they are available, observed flows are substituted in the hydrographs for calculated flows. The results from HEC-HMS are flow hydrographs at points in the watershed where flows are not controlled by dams or other structures.

Reservoir Simulation and Operations: Reservoir operations are modeled for various runoff scenarios with the HEC-ResSim program. HEC-ResSim uses the inflow and local downstream hydrographs generated from HEC-HMS, along with user-defined operating rules and scheduled releases, to simulate reservoir operations for the various flow scenarios. Users can manually set releases to take precedence over the operating rules, although it will not change physical constraints on releases or reservoir capacities. HEC-ResSim computes pool elevation and storage time series, and flow hydrographs at control structures and downstream locations. “Holdout” hydrographs are computed automatically for project benefit analysis.

Reservoir Simulation using RiverWare: The CADSWES program “RiverWare” may be used in place of HEC-ResSim for reservoir operations. RiverWare is a water accounting and water supply based reservoir simulation model. The user has access to variables and parameters through the use of RiverWare “slots”. Custom time-series plots can be viewed to evaluate the RiverWare results (Zagona, 1998).

Hydraulics: River hydraulics are computed with HEC-RAS, which will perform steady or unsteady flow modeling. From the hydrographs produced by HEC-HMS or HEC-ResSim, HEC-RAS computes water surface profiles and stage hydrographs. When used in conjunction with ArcInfo, inundation boundaries and depth maps are computed. Channel friction factors can be adjusted through the interface.

Economics and Impact: Economic analysis and impacts are conducted by the HEC Flow Impact Analysis (HEC-FIA) program. HEC-FIA calculates agricultural and urban damages and project benefits by impact area and then accumulates them for the system. Project benefit accomplishments are computed as the difference between alternative scenarios, typically the with- and without-projects conditions. Benefits are then automatically or manually allocated among the various projects. The results are displayed by event, by damage category and by project for the watershed using any of the specified boundary data. Output reports summarize information on damage, area, number of structures, population flooded, and project accomplishments for various alternatives. “Action Tables” provide a list of actions to take, and when they should occur, based on forecasted stages.

TYPICAL SIMULATION STEPS

Typically, an office will run the HEC-RTS modeling suite once a day. This begins with the engineer reviewing the current hydrometeorological conditions of the watershed are reviewed. This includes viewing animated NEXRAD precipitation radar images, or interpolated grids from gages, for the past few days and examining thumbnail hydrograph plots from gages in the watershed. Full size plots can be displayed by double clicking on the thumbnails. Next, the required data for a forecast, such as reservoir outflows and reservoir elevations, is examined and an appropriate “forecast time” is determined. The forecast time is a chosen time where data prior to that time is observed and is simulated after that time.

The modeling sequence begins by generating a “forecast”. Based upon the conditions of the watershed and the potential future conditions, the user will select the models and conditions that they wish to evaluate. After entering the forecast time, a new directory is created based on that time and the watershed name. Observed time series data, including gridded precipitation, flows, reservoir releases and elevations, from the start of the time window to the forecast time are extracted from the observed HEC-DSS database (Charley, 1995) and copied into a subset HEC-DSS modeling database in that directory. This data includes gridded precipitation, flows, reservoir releases and elevations. The selected model input files are also copied over. The resulting directory will contain all of the information that is needed to execute the models and can be backed up for a potential post-event evaluation.

HEC-HMS is adjusted for the current conditions by running it with no future rainfall and computing simulated hydrographs at gaged locations. Summary tables and plots are used to compare simulated hydrographs with observed, as shown in Figure 3. The model soil loss rates and base flow parameters upstream of the gage locations are adjusted to attempt to compute simulated hydrographs that correspond more closely to observed hydrographs. This is repeated until the soil moisture parameters are deemed to be within acceptable tolerances. The parameters are then generalized to adjacent areas that do not have downstream gages and cannot be directly calibrated.

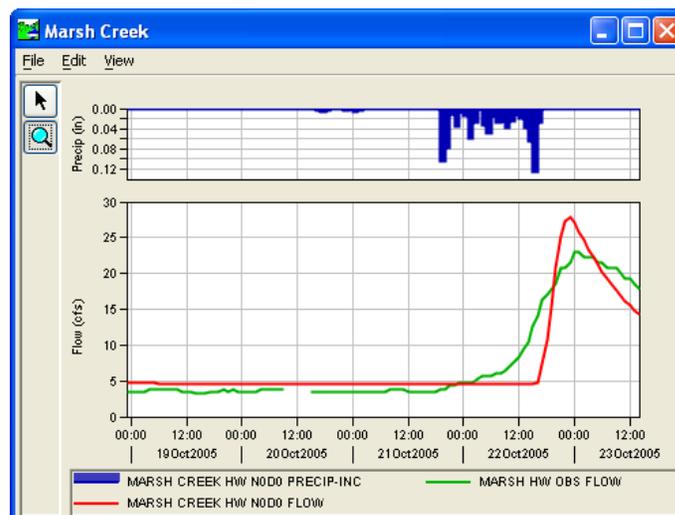


Figure 3 – Typical Comparison of Observed versus Computed Hydrograph

After calibration, HEC-HMS is executed in a forecast mode using a likely future precipitation scenario. In this mode, observed flows are used wherever they are available in order to improve routing results and forecasted hydrographs. Forecasted reservoir inflow hydrographs and downstream local hydrographs are used by HEC-ResSim with the standard operating rule set to simulate reservoir operations. The reservoir operation and computed downstream hydrographs are evaluated and their impacts determined. If the operations are not satisfactory, the user may choose to manually override the reservoir releases or modify the rule set in order to attempt to achieve the desired operations.

HEC-RAS is run with the forecasted hydrographs to compute river stages along the main channel. If flooding is expected, inundated areas can be visualized using Arc. HEC-FIA is subsequently executed with the forecasted stage or flow hydrographs to compute damages and a list of needed actions and when they occur, such as closing flood gates or evacuating areas. This simulation sequence may be re-run to evaluate different precipitation scenarios or different reservoir operations or other conditions, such as levee failures.

VERSION 2 ENHANCEMENTS

In HEC-RTS Version 1, the modeling components are “loosely-integrated”, as described above. Except for HEC-ResSim, all parameters are set through HEC-RTS dialogs and the results viewed from HEC-RTS plots and tables; the user does not have direct access to the native model interface. This architecture streamlined the daily modeling process by providing tables and dialogs for only those parameters that are typically set in real-time modeling. For example, the user could set soil moisture conditions for subbasins, a typical step in the modeling process, but they could not change the area of a subbasin. Although this kept the modeling process more straightforward, users could not access model’s native dialogs and output. In CWMS, models are run on Sun Solaris servers, so the native model interfaces are not available to the CAVI client on the PC anyway.

In HEC-RTS Version 2, the modeling components are “tightly integrated”. The same HEC-RTS parameter dialogs, plots and tables are available to the user, but the native model interfaces are available also. This allows users to change parameters and view output from the native model and access parameters that are not available from HEC-RTS. Model interfaces may be accessed by either selecting the model icon in the tool bar, or by right clicking on a computation node and selecting the model from the popup menu, as shown in Figure 4.

An additional advantage of tight integration of the models is that only a portion of the model may be run, if desired. For example, suppose one wants to compute HMS flows at an upstream location, but does not want to run the entire HMS model. By selecting a computation node, one can run the model to that point and view the output, as depicted in Figure 5.

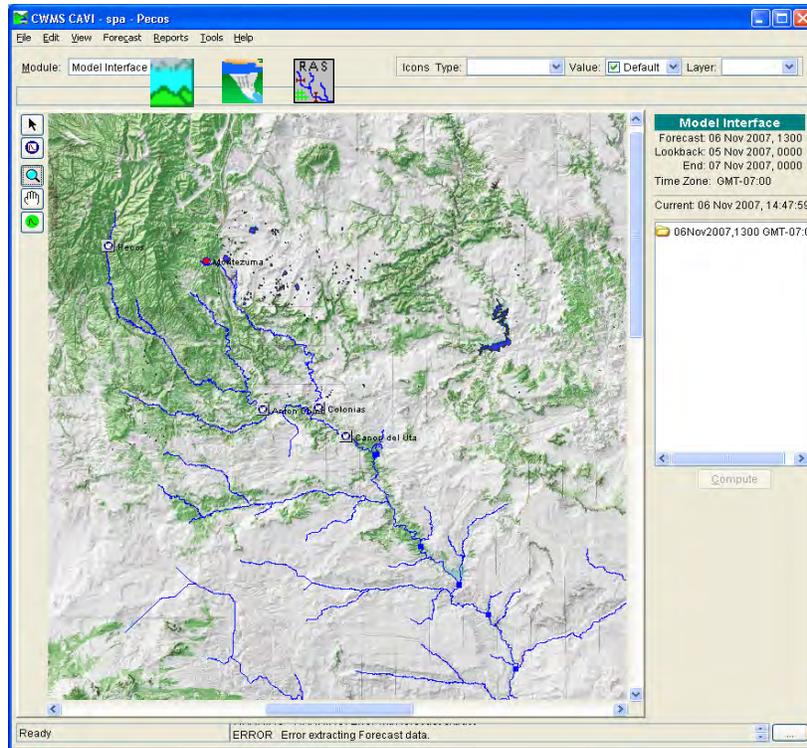


Figure 4 – HEC-RTS Model Interface Screen

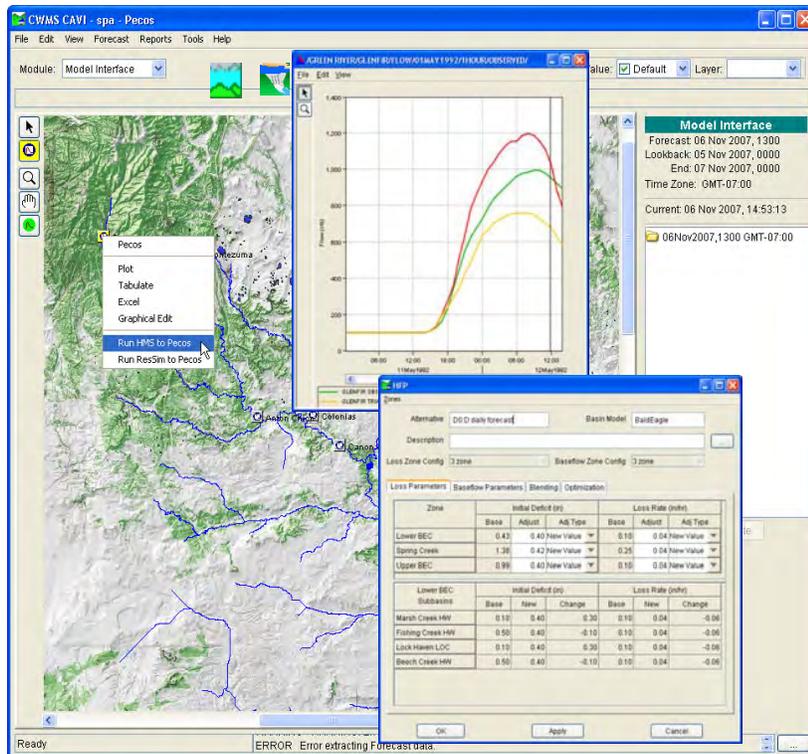


Figure 5 – Adjusting HMS Parameters

GRAPHICAL PARAMETER CALIBRATION TOOL

Running the models locally on the PC provides additional potential enhancements. One such enhancement that will be available in HEC-RTS Version 2.0 is the graphical parameter calibration tool for HEC-HMS soil moisture parameters. Currently, a user sets soil moisture parameters in HEC-RTS dialog labeled HFP (Hydrologic Forecast Processor), then runs HMS for the entire basin model, reviews the HMS results, and then returns to HFP to make adjustments in the parameter values. This process is time consuming and is difficult to finely adjust parameters. The graphical parameter calibration tool allows a user to select an HMS computation point and move parameter “slider bars” to immediately view graphs showing the affect of the parameter change. This is done by sending the new parameter value to HMS, running HMS to that computation point and then refreshing plots and tables. Because HMS is running locally, this process occurs very fast and the plots appear to refresh almost instantly. The main screen for graphical parameter calibration tool is depicted in Figure 6.

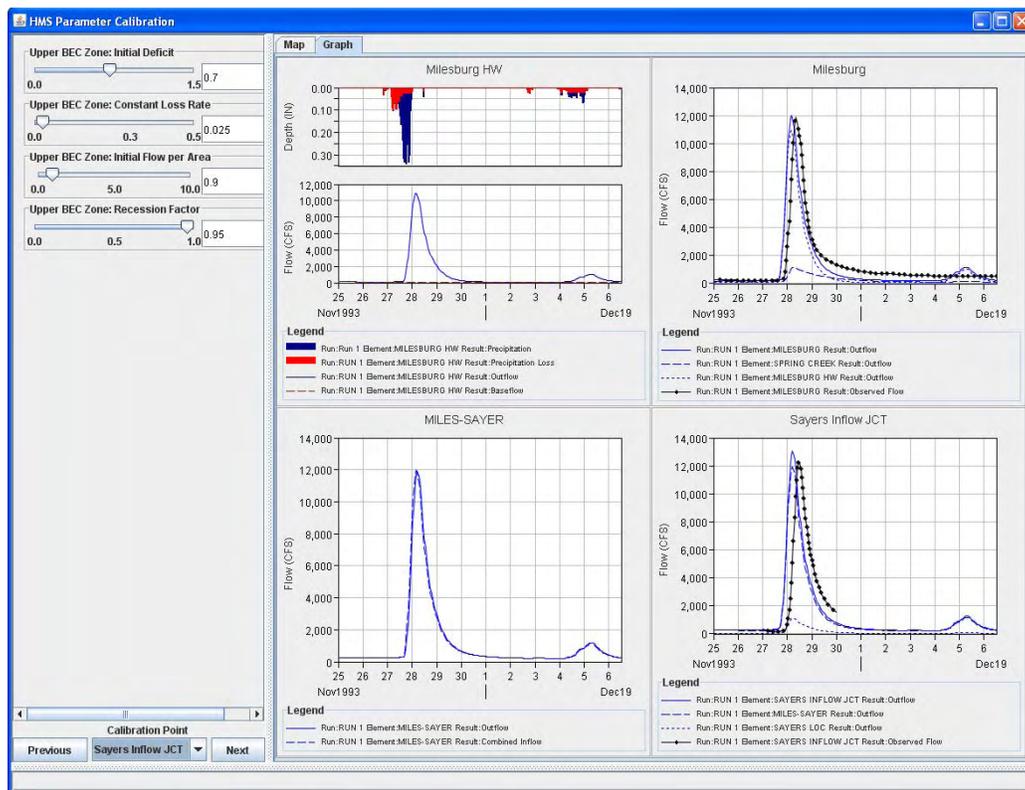


Figure 6 – Graphical Calibration Tool

In the above screen, four HMS soil moisture parameters for a portion of the basin may be adjusted. The user simply selects the slider bar pointer for the parameter the under consideration and moves it left or right to decrease or increase the value. When the slider is released, the graphs are updated with new results from that change. Parameters are adjusted until computed values are close to observed values.

Generally, parameters in gaged headwater subbasins are adjusted so that the hydrograph computed by HMS closely resembles the observed hydrograph up to the time of forecast, which is typically one to two hours in the past from the current time, and the time at which the observed data ends. The adjusted parameters are generalized to adjacent subbasins that are either ungaged or downstream. This collection of subbasins is called a “zone”. In Figure 6, the first plot shows an ungaged headwater subbasin, followed by a plot of the gaged downstream subbasin. The two plots on the bottom are for an adjacent subbasin and a further downstream gaged subbasin. The user adjusts parameters to try and match the computed hydrographs to the observed hydrographs for the two plots on the right side of the panel.

The parameters to be adjusted, the locations to adjust at, and what data to plot are preconfigured. Typically, one or two gaged subbasins within a group of subbasins, or zone, are selected to represent the parameters for all subbasins in that zone. The user selects the subbasin and the parameter or state to be adjusted from a dialog, such as the one shown in Figure 7. In addition, limits may be set for each parameter to keep them within a reasonable range.

Figure 7– Selecting Subbasins and Parameters

The graphs to display for the selected computation point are generated from another dialog, the graph editor. In this dialog, the user selects which locations to graph and what data at each location should be displayed. An example dialog for configuring the plot in the upper left corner (“Milesburg HW”) is shown in Figure 8.

This new capability for HEC-RTS Version 2 allows the user to quickly and accurately adjust the soil moisture states in HEC-HMS real-time forecasting and reservoir operations. Because the CWMS CAVI and HEC-RTS share the same framework, these capabilities will be available to Corps CWMS users as well.

Graph Editor

Associate graph with computation point Sayers Inflow JCT Graph Name Milesburg HW

Element	Time Series	Graph Content	
Spring Creek LOC	Cumulative Precipitation	Milesburg HW	Incremental Precipitation
Houserville HW	Cumulative Excess	Milesburg HW	Incremental Excess
HOUSE-SPRIN	Cumulative Loss	Milesburg HW	Baseflow
Spring Creek	Incremental Loss	Milesburg HW	Outflow
Milesburg HW	Direct Runoff	Milesburg	Outflow
Milesburg	Potential Evapotranspiration	Milesburg	Observed Flow
MILES-SAYER	Soil Evapotranspiration		
Sayers LOC	Moisture Deficit		
Sayers Inflow JCT	Saturation Fraction		
Blanchard			
Marsh Creek HW			

Show Summary Table for Element Milesburg Show Legend

Apply OK Cancel

Figure 8 – Configuring Graphs

CONCLUSION

CWMS provides a comprehensive integrated system for the Corps of Engineers to collect, analyze, and model real-time data for decision support of water control operations. HEC-RTS is the public version of the CWMS CAVI. A full range of modeling software allow engineers to evaluate operational decisions for reservoirs and other control structures, and to compare the impacts of various “what if?” scenarios in both CWMS and HEC-RTS. Version 2 of HEC-RTS tightly couples models to give users complete access to the models, as well faster computation speeds. This architecture allows for use of the HMS graphical calibration tool, which allows users to modify soil moisture and other parameters and view graphical results immediately. HEC-RTS has been designed to allow the engineer to concentrate on the hydrology and alternatives of an event, instead of the computer aspects of processing data and running programs.

REFERENCES

- Charley, W., Pabst, A., 1998, Hydrologic Engineering Center NEXGEN Data Storage System (HEC-DSS), Proceedings of the First Federal Interagency Hydrologic Modeling Conference, April 19-23, 1998, Las Vegas, NV, 5-33.
- Smith, M, 1999, NEXRAD and Hydrologic Modeling for River Forecasting: Spatial and Temporal Scale Issues Facing the National Weather Service, Proceedings of the AWRA 31st Annual Conference, Nov 5-9, 1999, Houston, TX,

U.S. Army Corps of Engineers, 1995, Water Control Data System (WCDS) – Past, Present and Future, Hydrologic Engineering Center, Davis, California.

Zagona, E., et al, 1998, RiverWare: A general River and Reservoir Modeling Environment, Proceedings of the First Federal Interagency Hydrologic Modeling Conference, April 19-23, 1998, Las Vegas, NV, 5-113.