Automated Hydrologic and Hydraulic Modeling
of a Hydroelectric System
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ABSTRACT

Balancing the needs of regulatory requirements, maximizing energy market returns, mitigating flood hazard, and optimizing snowmelt allotment over a water year is a multifaceted process. Southern California Edison's (SCE) Northern Hydro Division commissioned the BCH_2O Modeling Application to provide a detailed, real-time operating picture of the hydroelectric system based in Big Creek, California. BCH_20 is a fully automated application utilizing the U.S. Army Corps of Engineers' Real Time Simulation software (RTS) which includes HEC-RAS, HEC-HMS, and HEC-ResSim hydrologic and hydraulic models. These models simulate the water cycle on live data feeds, including current and forecast gridded meteorological data, and real-time field data from reservoirs and conduits. This paper will emphasize the usage of ArcGIS software with the ArcHydro extension in preparing the underlying GIS data for the models. It will also cover the integration of the data processing necessary for the automation and execution of the RTS software.

With a service territory that covers over 50,000 square miles and 4.9 million customer accounts, Southern California Edison (SCE) relies on the Big Creek Hydroelectric System to supply about 20% of its total electric capacity or approximately 1,000 megawatts. The Big Creek project covers a watershed of over 1,600 square miles and consists of six major reservoirs that hold over 560,000 acre-feet of water. To achieve an accurate assessment of the water supply for the extensive and topographically complex Big Creek watershed, a combination of remote sensing and human monitoring is used to obtain the most accurate data feasible. Having a detailed and accurate assessment of current and forecasted conditions provides the managers and supervisors of the hydroelectric system with the information to confidently respond to changing conditions in the weather, energy markets or unexpected incidents.

BCH$_2$O Modeling Application was developed with the objective of providing regular reports from the major reservoirs with details of impending changes predicted based on current operating protocols, forecast, and observed weather conditions. The primary use of the application is for the operations managers to adjust water volume among the different reservoirs and control flows based on forecasted scenarios generated by the hydrologic and hydraulic (H&H) models. The core hydrologic and hydraulic modeling software is developed and maintained by the U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC). The Real-Time Simulation (RTS) software used in the BCH$_2$O Modeling Application automates a series of HEC models including Hydrologic Modeling System (HEC-HMS), River Analysis (HEC-RAS), and Reservoir System Simulation (HEC-ResSIM).

In coordination with SCE Northern Hydro management, Integrated Spatial Solutions, Inc. (ISSI) spearheaded the configuration and deployment of the central workstation that aggregates all data sources and performs model simulations. A Perl script was used as the main control mechanism to automate the execution of key components in the process. The Task Scheduler was the logical choice for setting proper timing on the execution of events since Windows XP was used as the operating system for the workstation. Timing of the script initialization was based on the availability of the forecast weather data provided by Custom Weather.

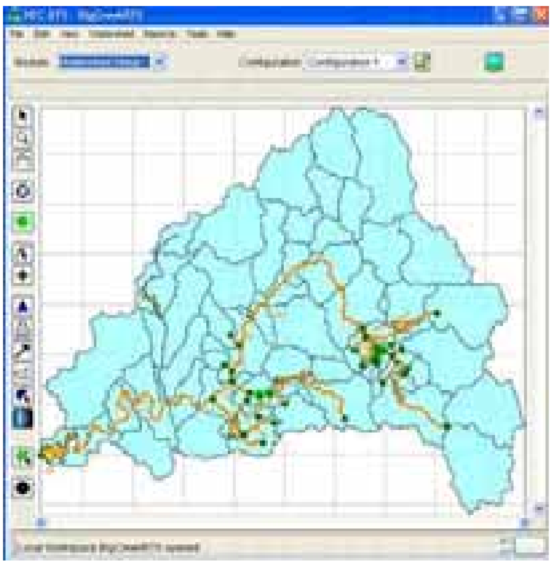

Figure 1 - HEC-RTS Software

When the primary control script is first initialized, it determines the current system time and executes a DOS shell script to retrieve weather data from Custom Weather's FTP server. The use of a DOS shell script is necessary to comply with SCE security restrictions regarding FTP protocol use. Data generated by Custom Weather is provided on a six-hour interval, starting at 0000 GMT time. The entire automated system is set to use GMT time for input regardless of daylight savings. This compromise was set in place to avoid software logistical issues that cannot account for the extra or missing hours that are introduced with using daylight savings.

Data files retrieved are in an ASCII grid format that covers a predefined grid of the Big Creek watershed. The output DSS file format was selected due to ease of interoperability with HEC conversion tools. DSS files are a proprietary format used in the HEC suite of modeling software including RTS. ISSI coded a series of Python scripts that converts the ASCII grid data into DSS files using the ASC2DSSGRID and DSSUTL command line tools. RTS software requires that the input DSS file be broken up into monthly blocks of data and according to their type. For example, precip.04.2012.dss would contain observed precipitation data for the month of April 2012 as well as any forecast data in the same time period.

Before Custom Weather was brought onto the BCH_2O project, RHS Consulting provided forecast weather data for the watershed. Requested forecast data covered 17 distinct basins within the Big Creek watershed, each being assigned a forecast precipitation and temperature value at six-hour intervals for one week into the future. Due to the coarse nature of these estimates and the lack of processed observed data, ISSI generated suitable hourly datasets for the HEC-RTS program to run properly. ISSI wrote separate Python scripts to process each of the data types, each individually launched and controlled by the primary Perl script.

For forecast precipitation, the decision was made to assume steady rain over 6 hours and thus straight line interpolation was used to fill in the missing hours. For forecast temperature, a cosine curve was applied to the missing hours. The cosine function factored in the highest and lowest temperatures across the whole watershed dataset in addition to a predetermined lapse rate. For observed temperature, the first six hours of the forecast temperature were archived and used to represent observed temperature since the near term forecast was deemed sufficiently accurate.

For observed precipitation, a Python script leveraged the ESRI Spatial Analyst extension for ArcMap to interpolate gage data using the Kriging method. In order to create the best possible grid, data was aggregated from private weather stations operated by SCE and Vaisala and public data available in the California Data Exchange Center (CDEC). All the precipitation data was first imported into SCE's main hydrologic time series database built on the Hydstra software before being extracted through an ODBC driver. The ODBC driver required the use of a definition query on a pre-determined Hydstra table within an ArcMap mxd. This was accomplished in the Python script through use of objects in the ArcPy library.

With all the precipitation, temperature, and snow data processed, the primary control script proceeds to extract time series data from the Hydstra database. Data extracted consists of instruments readings at the reservoirs and at key monitoring points along conduits. Before any data is extracted, some custom database code is executed to ensure bad data is properly tagged or missing data is substituted with interpolated data providing a contiguous set of data when it is requested. Similar to how the original observed precipitation is processed with ArcPy, ISSI wrote a Python script that uses the Hydstra ODBC driver to extract two weeks of time series data and perform a second round of QA/QC to replace bad or missing data. RTS will not execute properly if the hourly record matching the time of initialization is missing for any of the reservoirs. HEC's DSSUTL is also used in this script to convert the tabular data into DSS file format.

With all the input data in the DSS format, the RTS software is executed using a pre-defined set of conditions. With the contributions of RMA (a primary developer of the RTS software itself), a Jython script was developed to properly execute RTS in the correct sequence. The final output of the RTS process is a single forecast DSS file that contains all the results from each stage of the run. A custom tool written by Dewberry extracts the results from the forecast.dss file into an Excel file using the HEC DSSUTL tool. The tool subsequently exports a file PDF report that contains figures such as predicted water volumes in reservoirs, flow rates, and snow water equivalent accumulation for the two weeks before and one week following the time of initialization. The last step in the primary Perl control script emails a copy of that PDF report to SCE managers and uploads a copy of the PDF to an external FTP server for additional access and archiving.

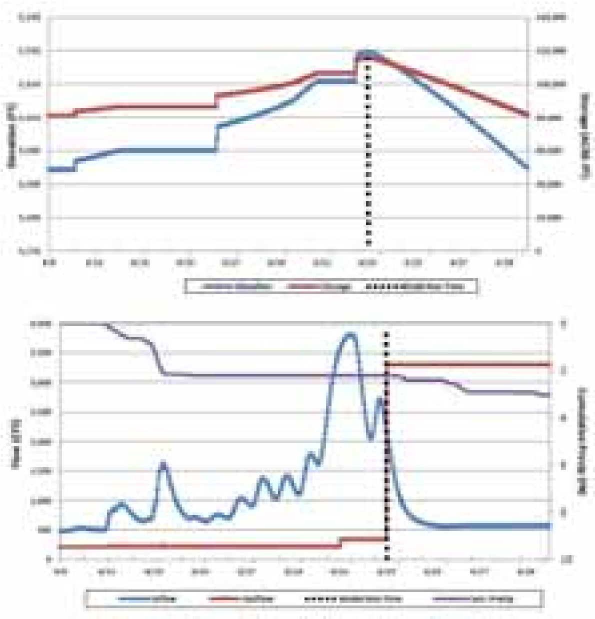

Figure 2 - Predicted elevation levels and water volume at Mammoth Pool Reservoir

Through coordination with water resources engineers at Dewberry and West Consultants, SCE Northern Hydro management developed the model configurations desired of the RTS system. In order for the component HEC-HMS, HEC-RAS, and HEC-ResSIM models to be configured, ISSI utilized the ArcHydro extension for ArcGIS Desktop to preprocess the GIS data needed to develop the base data. Data development for the project included subwatershed delineation, drainage and structure network connectivity, volumetric analysis of reservoirs and digital elevation model (DEM) processing.

Initial digital terrain model (DTM) data needed to be reconditioned in order to start the subwatershed delineation. Using interferometric synthetic aperture radar data (IFSAR) DTM data acquired from Intermap via SCE, ISSI modified the data by “burning” in a selection of key waterways from the National Hydrologic Dataset (NHD) to impose known flowpaths that may be inaccurate/unreflected in the gathered IFSAR data. The resulting dataset was further modified by removing sinks from the terrain. Following the prescribed workflow of the GeoHMS toolset in the ArcHydro extension, initial subwatersheds were derived from the catchments once flow direction, flow accumulation, and the drainage line network were defined. Since some initial subwatersheds were too small or too large, manual manipulation of the subwatersheds was necessary to create more meaningful areas for study and observation.

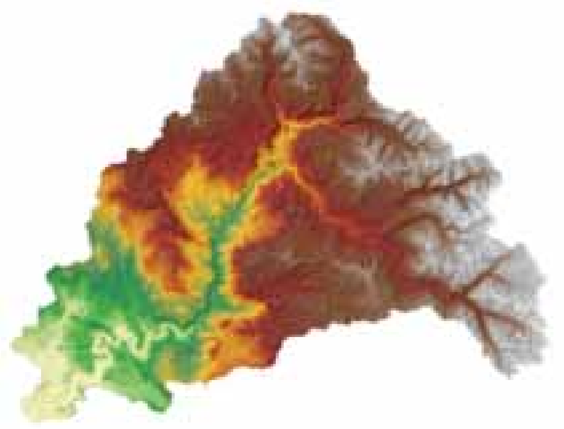

Figure 3 - Big Creek - IFSAR Digital Terrain Model (DTM)

The initial drainage lines created by the ArcHydro tools were missing unique components of the network: man-made structures. Manual editing of the data was necessary in integrating those structures into a unified network. Many coordinates for gages did not line up with the generated drainage lines and had to be snapped to a node on the network in order to participate properly in any analysis. The positioning of conveyances (conduits, penstocks, siphons, tunnels) also needed to be improved based on aerial photography, USGS quads and in-house data. Once all the features were integrated, water flow could properly be traced up and down the network through all the theoretical paths.

Capacity of several reservoirs and forebays in the Big Creek project was analyzed to improve the accuracy and precision of the input data for the H&H models. The study consisted of combining bathymetry data for the known contours below the water surface and LIDAR data above the surface to create a mosaic. The resulting mosaicked raster was used to generate contours with the Spatial Analyst extension in ArcMap. Using a Python script with the 3D Analyst's Surface Volume tool, the volume was calculated based on a selection of the contours below the known crest for each body of water.

In order to set up HEC-RAS, water resources engineers at Dewberry required the best base DEM data available to generate river cross sections for hydraulic analysis. Dewberry provided the initial drainage line features of specific rivers and reservoir areas that needed to be used to create the cross sections. ISSI generated a 100-meter buffer around the drainage lines and used it to clip the IFSAR 5-meter DTM raster data. The clipped 5-meter DTM was then converted to a 2-foot DEM using the raster calculator in ArcMap. The resulting dataset was mosaicked with existing high quality 2-foot reservoir LIDAR, bathymetry and survey data of selected areas and features in the Big Creek watershed to yield a final delivered DEM for Dewberry to create cross sections.

By integrating a variety of disparate components, the BCH_2O Modeling Application provides a seamless and ordered structure for producing complex analyses without the need for manual and daily direct input from water resource engineers. The ArcGIS Desktop and the ArcHydro extension played a crucial role in rapidly and effectively processing the base data for the application and will continue to do so as more accurate source data becomes available. With this initial deployment of the application, SCE's Northern Hydro managers have an additional tool to better manage their primary energy resource. Plans are already in place for enhancements to further leverage the outputs of the model run, to improve the accuracy of the models by adding observation points into the system, and to calibrate the system based on observed historical data.