Modeling System for Near Real-Time Flood Simulation for Salt Creek in Du Page County, Illinois

A.L. Ishii, Hydrologist, U.S. Geological Survey, Urbana, Ill.; T.J. Charlton, Principal Engineer, Du Page County Department of Environmental Concerns, Wheaton, Ill.; T.W. Ortel, Hydrologist, U.S. Geological Survey, Urbana, Ill.; C.C. Vonnahme, Senior Civil Engineer, Du Page County Department of Environmental Concerns, Wheaton, Ill.

Abstract

A near real-time flood-simulation system is being developed by the U.S. Geological Survey (USGS) in cooperation with Du Page County Department of Environmental Concerns for a 15-mile reach of Salt Creek in Du Page County, Ill. The Hydrologic Simulation Program-FORTRAN (HSPF) is being utilized to simulate rainfall-runoff for input to the Full EQuations (FEQ) model for dynamic-wave routing. The meteorological inputs for the rainfall-runoff simulation are obtained by Internet access and radio-telemetered precipitation gages. Boundary conditions for the dynamic-wave routing model are obtained from telemetered stream-elevation gages and rating curves. The interface for data-base management, developing and processing simulation files, and analysis of simulation results is the program GENeration and analysis of model simulation SCeNarios (GENSCN).

The flood-simulation system is being developed to estimate the downstream effects of diverting streamflow into or out of the Elmhurst Quarry Flood Control Facility, located about 10 miles from the downstream boundary, under various real-time or forecasted rainfall distribution scenarios. The flood-wave characteristics of the stream system are highly dependent upon the distribution of rainfall in time and space and, thus, the most effective management of diversions is dependent on the ability of facility managers to quickly simulate rainfall and snowmelt effects on the stream system.

The full benefit of understanding the complex model output from dynamic-wave routing can be realized only when the results can be quickly visualized and analyzed. Time series and model input files must be efficiently managed and the database made user friendly. Current operational procedures for the flood control facility are partly based upon operator intuition, which does not provide a systematic means to evaluate alternative operational schemes. The interfaced system makes it possible to test and compare various potential rainfall/diversion scenarios. This demonstration includes the GENSCN interface with operational HSPF and FEQ models for Salt Creek. The system includes clickable maps, animated water-surface profiles, and a variety of graphical and analytical tools for evaluating the output scenarios.

BACKGROUND

Du Page County is a rapidly urbanizing area about 17 miles west of the city of Chicago in Cook County, Illinois. Following heavy flooding in August 1987 that resulted in millions of dollars of damage in the metropolitan Chicago area, the State of Illinois gave the counties surrounding Cook County the responsibility to fund and implement storm-water management plans. Subsequent flooding has emphasized the value of both flood-mitigation facilities and data collection networks for planning and flood warning. Du Page County has designed and built one of the largest non-Federal off-line flood-control reservoirs in the Nation, the Elmhurst Quarry Flood Control Facility along Salt Creek (fig. 1). Storage provided in the quarry is about 8,300 acre-feet. The diversion works includes an 140-foot broad-crested fixed side weir, an 80-foot variable-elevation side weir, and a 7-foot by 7-foot sluice gate located at an elevation below the fixed weir. Water flows into a diversion conduit and then through two emergency shutoff gates to a vortex drop shaft. The shaft leads to a tunnel under a highway and into the quarry. After possibility of flooding has passed, the water stored in the quarry is pumped out through an aeration process and back into the creek.

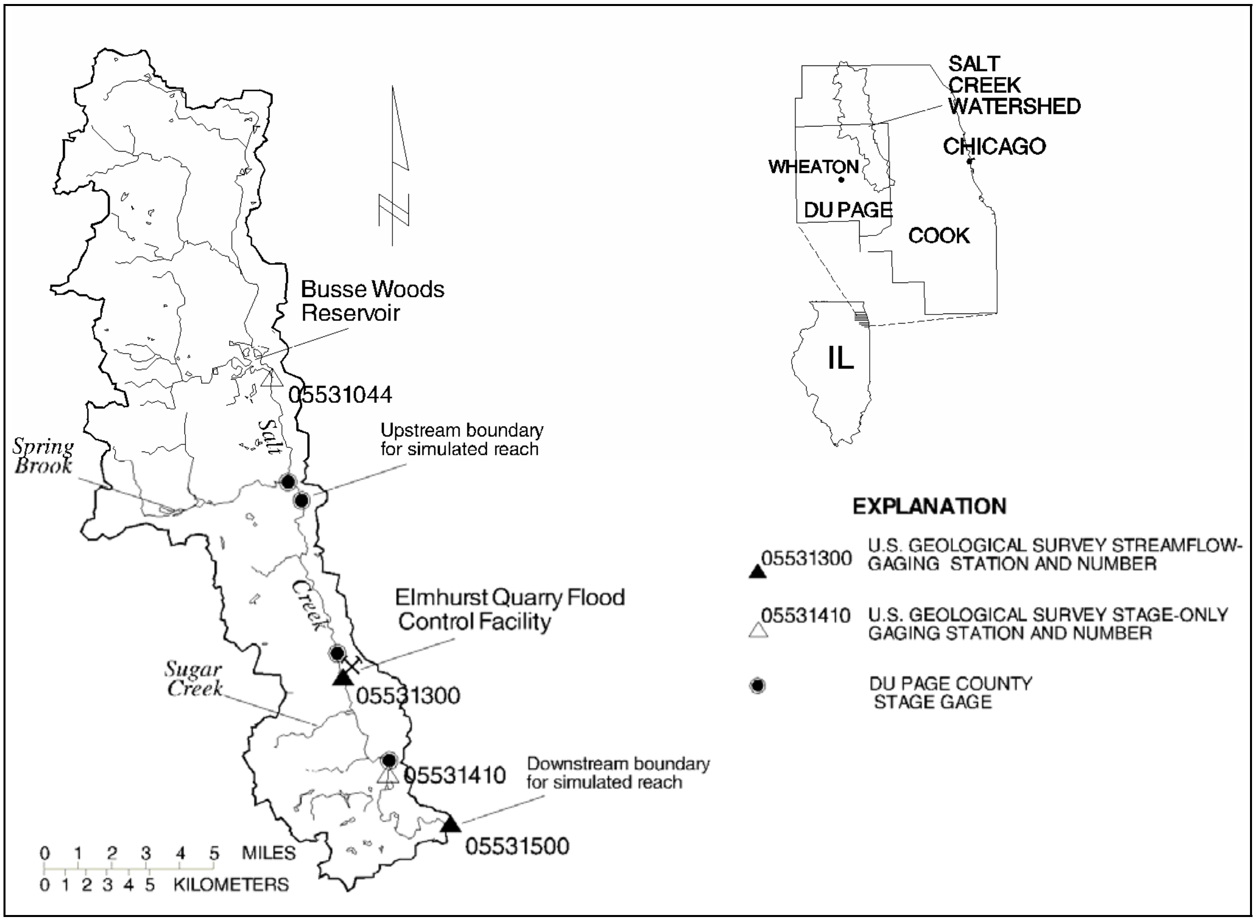


Figure 1. Salt Creek watershed and location of gaging stations on Salt Creek.

The Salt Creek watershed (fig. 1) area is 115 mi^2 to the U.S. Geological Survey streamflow-gaging station (05531500) located 8.8 miles upstream from the mouth. Based on the hydraulic characteristics of flooding, the watershed may be divided into three sections. The upper watershed (52 mi^2) is the section upstream from Busse Woods reservoir. The middle section extends downstream to the junction of Sugar Creek and includes the narrow section from the junction of Spring Brook to the USGS streamflow-gaging station 05531300 (91 mi^2 area at the gage including the upper watershed). The Elmhurst Quarry Flood Control Facility is located in the narrow part of the middle section. The lower section may be considered to start at the junction of the Sugar Creek tributary with Salt Creek.

Continuous simulation rainfall-runoff simulation linked to dynamic-wave routing models were utilized to determine the flood-reduction potential of the Elmhurst Quarry project over its economic life span. Subsequent modeling has demonstrated that the unique hydraulic characteristics of the watershed require near real-time modeling to make effective decisions about planned diversions. The timing of the flood wave in the lower watershed is highly sensitive to the temporal and spatial distribution of rainfall; and consequently, the ability to generate scenarios in near real-time is needed. Hypothetical scenario generation based on predicted rainfall is valuable both to increase lead time in flood warnings and to allow for a safe return of flood waters to the creek. The purpose of this paper is to describe the application of the hydrologic, hydraulic, and scenario-generation programs to the near real-time flood-simulation system.

For intense, single storms of uniform rainfall, major flooding in the lower section of the watershed may be caused by local runoff from the downstream watershed tributaries, rather than by the flood wave traveling from upstream. For multiple or long-duration storms, the timing of the arrival of the flood wave from the upper watershed is also important because the effect of local inflows may be added to the flood wave arriving from upstream. The simulated average travel time for the flood crest from the upstream boundary gage to the Quarry was about 11 hours for a uniform rainfall assumption for about 100 storms. The time-to-peak of the flood wave from the lower tributary areas to the mainstem was about 4-8 hours for selected events. Thus, the Elmhurst Quarry Flood Control Facility is of greatest benefit for the relatively rare multiple or long-duration rainfall event, which compounds the two flood waves. Snowmelt also has been a contributing factor to flooding in this area. Snowmelt routines are included in the continuous simulation rainfall-runoff model used, the Hydrologic Simulation Program—FORTRAN (HSPF) (Bicknell and others, 1997).

The ability to rapidly simulate flooding will improve the information base available for reservoir operation. Alternative strategies for operating the sluice gate on the flood control structure can be evaluated and compared prior to taking action. In order to achieve rapid hydrologic and hydraulic simulation, automated methods are needed for data retrieval, reformatting, error-checking and data estimation, and storage. Additionally, the links between the hydrologic and hydraulic models need to be streamlined, and graphical and other analyses of the modeled results must be available for quick review to aid in operational decision-making. These improvements form the basis of the flood-simulation system described in this paper.

HYDROLOGIC AND HYDRAULIC MODELS

Continuous rainfall-runoff simulation coupled with one-dimensional, unsteady-flow modeling has been mandated by Du Page County for flood-plain delineation and planning purposes. Design and operational planning have been accomplished using an approach based on the same hydrologic and hydraulic models that are used for flood-plain mapping. There are many advantages to this approach. Use of continuous simulation hydrologic models removes the need for estimating antecedent or initial moisture conditions because moisture balances are maintained continuously in the model for the extended period of the model run (usually many years). The development and use of a standard runoff time series incorporating the selected rainfall gage/land-use combinations and regionalized parameters throughout the county provides for consistency and reliability in projecting the effects of structures, diversions, and land-use changes on stream flows. The continuous runoff series can be coupled to a one-dimensional, unsteady-flow model that enables the simulation of backwater and flood-plain storage (Bradley and others, 1996). This is important where there are many control structures, and watersheds of low-gradient relief.

The continuous simulation rainfall-runoff model used in Du Page County, HSPF, is being modified by John Kittle, Jr., and others to meet the unique needs of the real-time flood-simulation mode (Alan Lumb, U.S. Geological Survey, written commun., 1996). A binary output file of unit runoff time series suitable for direct input as lateral inflows to the one-dimensional, unsteady-flow hydraulic model Full EQuations (FEQ) (Franz and Melching, 1997) has been added to HSPF version 12.0. HSPF is being modified to maintain the state variables in memory, so that the model can be stopped and updated without manually listing the starting state in the new simulation run.

The Full EQuations (FEQ) model, developed by Dr. Delbert Franz of Linsley, Kraeger Associates, Ltd., solves the full, dynamic equations of motion for one-dimensional, unsteady flow in open channels and through control structures. The FEQ model code and field test results have been documented by the USGS (Franz and Melching, 1997; Turner and others, 1996; Ishii and Turner, 1997). Equations for flow and elevation throughout the stream system resulting from the application of principles of conservation of mass and conservation of momentum are approximated by an implicit finite-difference approximation and solved in an iterative solution scheme that includes interpolation for function-table values at computational nodes. Thus, FEQ can output flow and water-surface elevation at any specified node in the modeled stream system. FEQ is uniquely adapted to model a wide variety of fixed and variable-geometry hydraulic controls including weirs, bridges, culverts, dams, and pumps using function tables computed with its companion program, Full Equation UTiLities (FEQUTL) or other hydraulic models (Franz and Melching, in press). FEQ can be applied to simulate a wide variety of stream configurations including looped networks, lateral inflow, and wind-affected flow. FEQ has been utilized by the Illinois Department of Natural Resources Office of Water Resources for the operational management of an upstream reservoir on the Fox River in northeastern Illinois (William Rice, Illinois Department of Natural Resources Office of Water Resources, oral commun., 1996) and for planning and analysis purposes (Knapp and Ortel, 1992) in addition to the flood-plain mapping and project analysis work done in Du Page County (Lan and others, 1996).

In order to make the Salt Creek model operational for quick simulation for flood-warning purposes, several watershed tributary models that had been routed in detail for mapping and planning purposes required simplification. The effect of routing model detail reductions on the characteristics of the mainstem flood wave is under review, and continued testing is planned. A feature to provide hydrologic routing of watershed tributary flows has been implemented in FEQ, which may be used to improve the routing characteristics of the simplified tributary outflows (Delbert Franz, Linsley, Kraeger Assoc. Ltd., written commun., 1997).

NEAR REAL-TIME DATA ACQUISITION AND INPUT

The calibrated modules utilized in HSPF require precipitation, air temperature, dewpoint temperature, wind velocity, potential evaportranspiration, and solar radiation data to compute rainfall runoff and snowmelt. Precipitation is acquired from a precipitation network consisting of 26 gages installed throughout the county by the USGS. The network is operated in real time by spread-spectrum radio telemetry reporting to a base station located in the County offices in Wheaton. Stream elevation data at the four stage gages operated by the county on the mainstem of Salt Creek also are transmitted to the base station. The gages provide information on the flood-wave movement for warning and simulation. The status of pumps and reservoirs throughout the Salt Creek watershed is monitored by the supervisory control and data acquisition (SCADA) system. Next generation Doppler radar (NEXRAD) data provide storm tracking information for manual interpretation and warning.

Meteorologic data (air and dewpoint temperature, wind velocity, and solar radiation) are acquired from the Argonne National Laboratory Atmospheric Sciences World Wide Web page or from the emergency management office instruments at the County offices. The Meteorologic and hydrologic GENSCN Input Convertor (MAGIC) program is used to convert the data as received to an HSPF format required for input to the Watershed Data Management (WDM) data base. Automated and manual methods for estimating missing or erroneous data are provided in the input interface. Potential evapotranspiration time series are computed by the methods utilized in calibrating the HSPF model for the county (Price, 1994). A sample window for the data input converter is shown in figure 2. Testing and implementation of the system are needed to verify the adequacy of the various data sources and estimation routines for short-term event simulations. The current plan is for the system to be operated with provisional data and to be updated as quality-assured data is received.

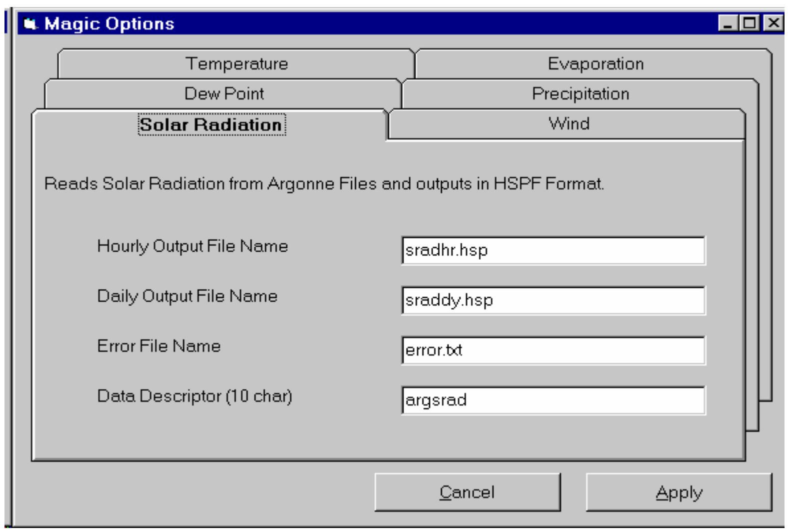


Figure 2. Meteorologic and hydrologic GENSCN Input Converter (MAGIC).

The upstream boundary condition for the FEQ model will be the stage hydrograph obtained from a stream-elevation gage operated by the county (fig. 1). These data are transmitted by radio telemetry. The location of the upstream boundary may be moved upstream in the future to increase the lead time for flood warning. Other data that can be obtained from the USGS real-time data page on the World Wide Web (WWW) includes the stream elevation at the three downstream streamflow-gaging stations along Salt Creek. Du Page County operates three additional stream-elevation gages with data transmitted by radio telemetry. These data are useful for determining the accuracy of the streamflow simulations. Discharge computed from a rating at the downstream boundary streamflow-gaging station (05531500) can be compared with the simulated discharge to determine overall accuracy of the simulation.

GENSCN GRAPHICAL USER INTERFACE

The application of hydraulic and hydrologic models to near real-time flood simulation requires an interface to streamline and unify pre- and post-processing of data input and output, linkage between the models, and analysis. The interactive computer program GENeration and analysis of model simulation SCeNarios (GENSCN) has been developed by John Kittle, Jr. and others (Alan Lumb, U.S. Geological Survey, written commun., 1996) in support of several USGS projects. A graphical user interface (GUI) currently is being developed for use on the personal computer platform. The GUI makes it possible to use the simulation and analysis features of GENSCN in a Microsoft Windows-based environment[1]. GENSCN is being applied to the Truckee and Carson River Basins in Nevada and California to assess the effects of reservoir and diversion operations (Bohman and others, 1995), and to the Guadalupe River Basin in Texas as part of the National Water-Quality Assessment (NAWQA) program of the USGS (Marshall Jennings, U.S. Geological Survey, oral commun., 1997).

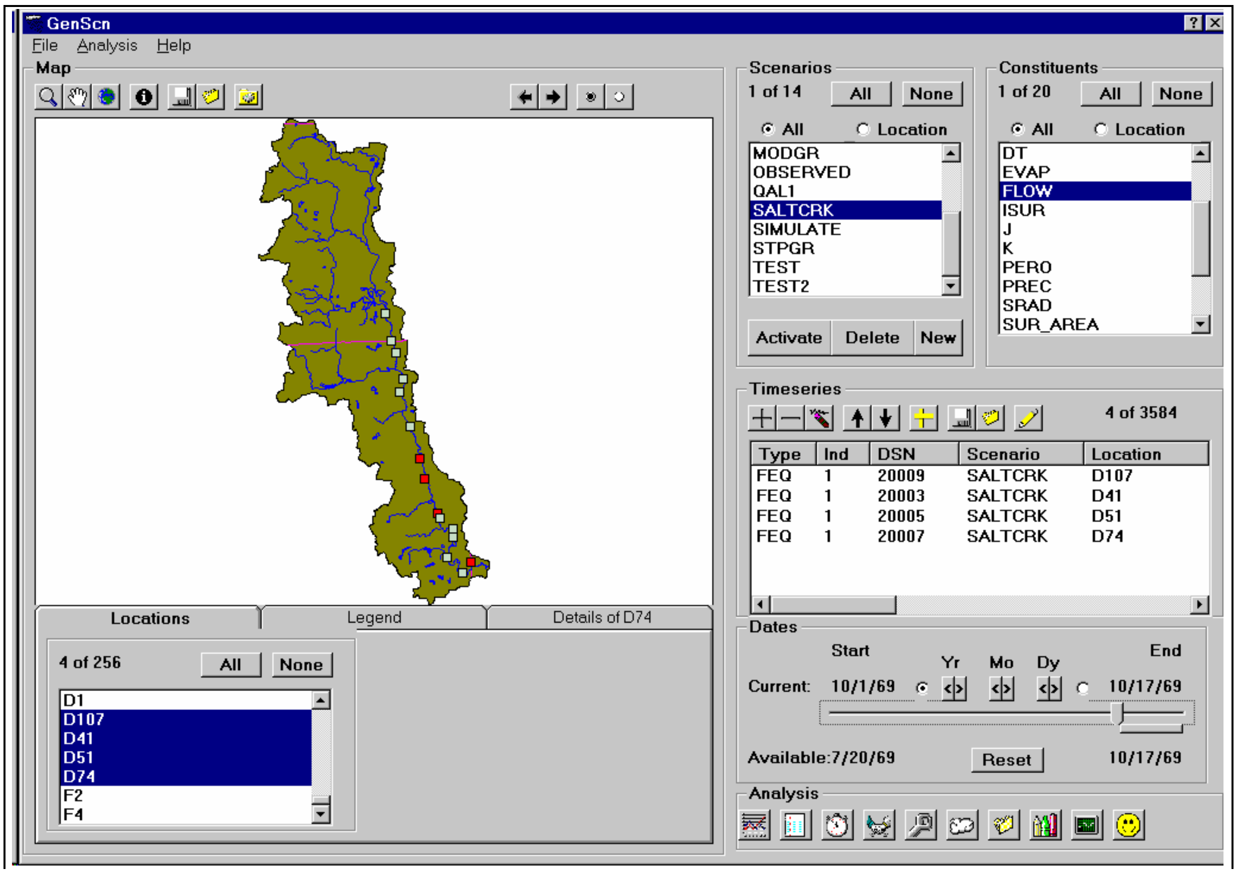


Figure 3. GENeration and analysis of model simulation SCeNarios (GENSCN) window showing selection of data set for processing and analytical option buttons (lower right).

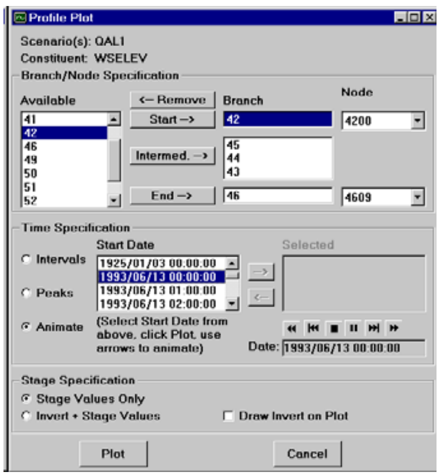
The scenario generation and analysis options available in HSPF are fully implemented in GENSCN. The user can simulate previously developed scenarios, modify scenarios, or create new scenarios from within GENSCN. The HSPF program can be run from within the GENSCN interface. The analysis and plotting of output also is accomplished without exiting from the interface.

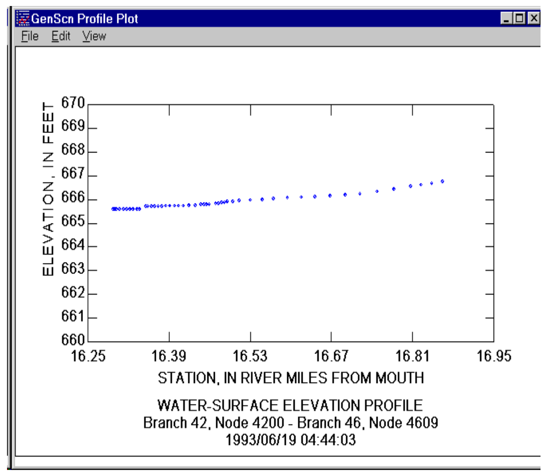
---

[1] The use of firm, trade, and brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Time series data sets, such as, flow, elevation, precipitation, storage, volume, and other data are referred to as constituents in the GENSCN interface. The user selects the scenarios (for example, simulated and observed data), the constituent (for example, flow or water-surface elevations), and the location for the desired data. The data sets, meeting all criteria are added to the buffer by choosing the add (+) button. The analytical options available for listing, plotting, comparing, and statistical analysis of the selected data are accessed through a drop-down menu or the button bar in the lower right panel (fig. 3). The GENSCN window displays shown in figures 3-5 are intended to illustrate features available in GENSCN and do not indicate citable or quantitative model results.

In order to analyze and display the results of unsteady-flow hydraulic modeling in GENSCN, an additional output format has been added to FEQ. The special FEQ output file, which includes water-surface elevation and discharge at each node specified in the FEQ input for each time step, is read in GENSCN. Additional values that can be plotted and listed with time include hydraulic channel and node properties such as cross sectional top width, area, conveyance, and volume available in level-pool reservoir nodes. GENSCN includes an animation option for viewing the time series at points along the river as an animated profile. The thalweg can be included and displayed. An example of the FEQ model output is shown as a profile plot in figure 4(b). The controls for running the animation are shown on the right in figure 4(a). The animation may be run forward and backward, or paused for a snapshot of the simulated profile at any time. The peak water-surface elevation at all locations also may be plotted.





(a) **(b)**

Figure 4. Selecting and plotting an animated water-surface profile plot option for analysis of the Full Equations (FEQ) model output.

The distributed routing output hydrographs also can be analyzed utilizing the time series output options available in GENSCN. The selection of the standard (time series) plot option is shown in figure 5. For this example, the discharge hydrographs at the model output nodes selected in figure 3 are shown for a particular simulation.

This example demonstrates the use of distributed routing for observing the hydraulic characteristics of the watershed. The most downstream hydrographs (at nodes D74 and D107) peak before the flood peak from upstream (D1 and D51) has arrived at the downstream locations. Local inflows from the subwatersheds in the lower watershed are the main source of inflow for the initial peak. This particular rainfall event was short and intense. Long duration or multiple storms result in local inflow peaks being added to the flood wave traveling from upstream, and, consequently, a larger downstream peak resulting later. This simulation is for the uniform rainfall case, and does not represent actual streamflow for the simulated period.

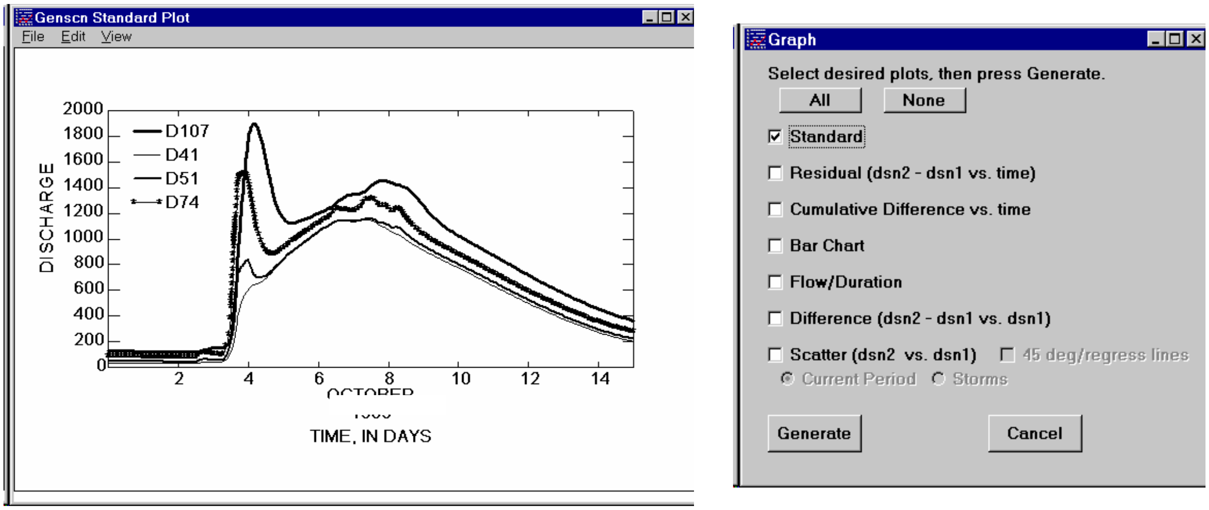


Figure 5. Standard plot option for analysis of time series data.

In addition to the time-series analysis options, GENSCN has the capability of displaying and animating spatial data through the map window. The selection of plotted nodes is illustrated in figure 3. Information regarding the constituents, scenarios, and time-series data available at the individual nodes may be selected. Additional geographic information system (GIS) coverages may be incorporated, and areas of interest may be enlarged through the zoom feature of the map window. The USGS Truckee-Carson program in Nevada and California utilizes animation to display time-series data on the map window. Different colors or line thickness are utilized to specify up to three different ranges of data on the river segments (Bohman and others, 1995). Future enhancements for the flood-warning system may include the ability to display and animate precipitation amounts throughout the County.

After the documentation and testing of the GENSCN system for near real-time flood warning are completed, the programs will be released and distributed for other applications to other watersheds. GENSCN is based on a modular design concept that allows for the efficient linking of other models and addition of new features and enhancements.

OPERATIONAL USE

The near real-time flood-simulation system for Salt Creek will be operated by the staff of Du Page County. Regular updates of the continuous simulation rainfall-runoff model will be needed in preparation for flood events. The fully routed results are not expected to be needed on a continuous basis but are to be implemented whenever elevations along Salt Creek are expected to approach flood stage. The major functions of the system are: (1) to simulate possible flood-stage creek elevations based on real-time or forecasted rainfall and snowmelt, (2) to simulate alternative operating strategies for the sluice gates at the Elmhurst Quarry and compare resulting creek elevations, (3) to simulate elevations in the creek resulting from pumped flows returned from the quarry with consideration of precipitation and other meteorologic conditions.

The system operator retrieves the hydrologic data from the WWW and the local base-station computer. The data input converter program is opened and the files are converted for input to the WDM data base. Errors and missing data reports are reviewed, automatic data revisions are either accepted or exchanged for data from other sources or estimates, and forecasted precipitation amounts may be entered. The GENSCN interface is used to write the data to the WDM; to run the hydrologic model, using updated initial conditions from the previous simulation; and to create the runoff files for hydraulic routing. The hydraulic model is run under one or more operational scenarios and the routed results are reviewed within the GENSCN interface for discharge, elevation, and storage at critical locations. Additional forecast precipitation scenarios then may be applied and the process repeated. Future enhancements to the system may include the display and animation of precipitation reported by the radio-telemetered precipitation network.

REFERENCES CITED

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Donigian, A.S., Jr., and Johanson, R.C., 1997, Hydrological Simulation Program--FORTRAN, User's Manual for Version 11: U.S. Environmental Protection Agency EPA/600/R-97/080, in press.

Bohman, L.R., Berris, S.N., and Hess, G.W., 1995, Interactive computer program to simulate and analyze streamflow, Truckee and Carson River Basins, Nevada and California: U.S. Geological Survey Fact Sheet FS-165-95, 4 p.

Bradley, A.A., Cooper, P.J., Potter, K.W., and Price, T., 1996, Floodplain mapping using continuous hydrologic and hydraulic simulation models: American Society of Civil Engineers, Journal of Hydrologic Engineering, vol. 1, no. 2, p. 63-68.

Franz, D.D., and Melching, C.S., 1997, Full equations (FEQ) model for the solution of the full, dynamic equations of motion for one-dimensional unsteady flow in open channels and through control structures: U.S. Geological Survey Water-Resources Investigations Report 96-4240, 258 p.

Franz, D.D., and Melching, C.S., in press, Full equations utilities (FEQUTL) model for the approximation of hydraulic characteristics of open channels and control structures during unsteady flow: U.S. Geological Survey Water-Resources Investigations Report 97-4037.

Ishii, A.L., and Turner, M.J., 1997, Verification of a one-dimensional, unsteady flow model for the Fox River in Illinois: U.S. Geological Survey Water-Supply Paper 2477, 65 p.

Knapp, H.V., and Ortel, T.W., 1992, Effect of Stratton Dam operation on flood control along the Fox River and Fox Chain of Lakes: Illinois State Water Survey Contract Report 533, 79 p.

Lan, Y., Rogers, S. Sikora, J., Cooper, P., and Klepp, C., 1996, Unsteady flow hydraulic modeling for flood plain mapping along the West Branch Du Page River, Du Page County, Illinois: International Water Resources Association Rivertech96 Proceedings of the 1st International Conference on New/Emerging Concepts for Rivers, Chicago, p. 204-211.

Price, T.H., 1994, Hydrologic calibration of HSPF model for Du Page County—West Branch Du Page River at West Chicago, West Branch Du Page River at Warrenville, East Branch Du Page River at Maple Avenue, Salt Creek at Western Springs; including hydraulic evaluation—Salt Creek at Western Springs, Salt Creek at Rolling Meadows: Northeastern Illinois Planning Commission, 92 p.

Turner, M.J., Pulokas, A.P., and Ishii, A.L., 1996, Implementation and verification of a one-dimensional, unsteady-flow model for Spring Brook near Warrenville, Illinois: U.S. Geological Survey Water-Supply Paper 2455, 35 p.