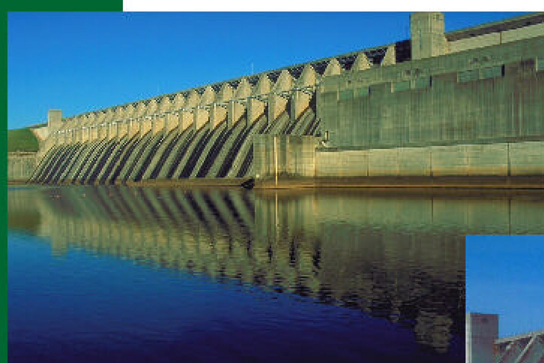
SAVANNAH DISTRICT

OCTOBER 1999

FINAL REPORT

SAVANNAH RIVER BASIN HYDROLOGICAL MODELS EVALUATION



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gsrc / GULF SOUTH RESEARCH CORPORATION

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1.0 INTRODUCTION

1.1 Background

Gulf South Research Corporation (GSRC) was contracted by the U.S. Army Corps of Engineers, Savannah District (Savannah District) to conduct an evaluation of existing hydrological flow models to determine the best model or combination thereof to analyze the potential impacts on the region's significant issues/resources under various water level regimes.

1.2 Project Location

The project study area encompasses the entire Savannah River Basin and includes all or parts of the following counties: Chatham, Effingham, Screven, Burke, Richmond, Jefferson, Glascock, Warren, McDuffie, Columbia, Lincoln, Wilkes, Taliaferro, Greene, Oglethorpe, Clarke, Elbert, Madison, Jackson, Hart, Franklin, Banks, Stephens, Habersham, Raburn, and Towns counties, Georgia; Beaufort, Jasper, Hampton, Allendale, Barnwell, Aiken, Edgefield, McCormick, Saluda, Greenwood, Abbeville, Anderson, Pickens, and Oconee counties, South Carolina; and Clay, Macon, Jackson, and Transylvania counties, North Carolina (Figure 1-1). The maximum length of the basin is approximately 250 miles and the maximum width approximately 70 miles. The total area of the basin is 10,579 square miles, of which 179 square miles are in North Carolina, 4,530 square miles in South Carolina, and 5,870 square miles in Georgia. The Savannah River is formed by the confluence of the Seneca and Tugaloo Rivers, which have their headwaters on the southern slopes of the Blue Ridge Mountains in North Carolina just north of the boundary with South Carolina and Georgia. The river meanders in a southeasterly direction through the Piedmont Plateau and Coastal Plain and with its tributaries forms the boundary between Georgia and South Carolina from the North Carolina state line to the Atlantic Ocean (U.S. Army Corps of Engineers, 1989).

The Savannah River is 312 miles long and it's flow is regulated by three impoundments that are under the jurisdiction of the U.S. Army Corps of Engineers. These include Hartwell Lake, Richard B. Russell Lake, and J. Strom Thurmond Reservoir. Together they form a chain of lakes approximately 120 miles long. These are multi-purpose impoundments that serve fish and wildlife, flood control, hydropower, navigation, water supply, and recreation needs. J. Strom Thurmond Reservoir and Hartwell Lake, for example, are among the top ten most frequently visited U.S. Army Corps of Engineers lakes in the United States. Numerous cities, counties, farms and businesses rely on the river for water, power, navigation, and recreation (U.S. Army Corps of Engineers, 1992).

1.3 Project Objectives

The primary objective of this project is to determine the best flow model or models, or combinations thereof, that can provide accurate predictions under various scenarios and remain cost effective. The selected model, or models must have the ability to address hydropower, drought rules, flood control, and pumped storage.

1.4 Report Organization

This report is subdivided into five sections, including this introduction. A description of data collection efforts is given in Section 2.0. Hydrological models evaluated during the life of the project are presented in Section 3.0. Section 4.0 contains fact sheets for the hydrological models selected for further study. Literature cited in this document is listed in Section 5.0.

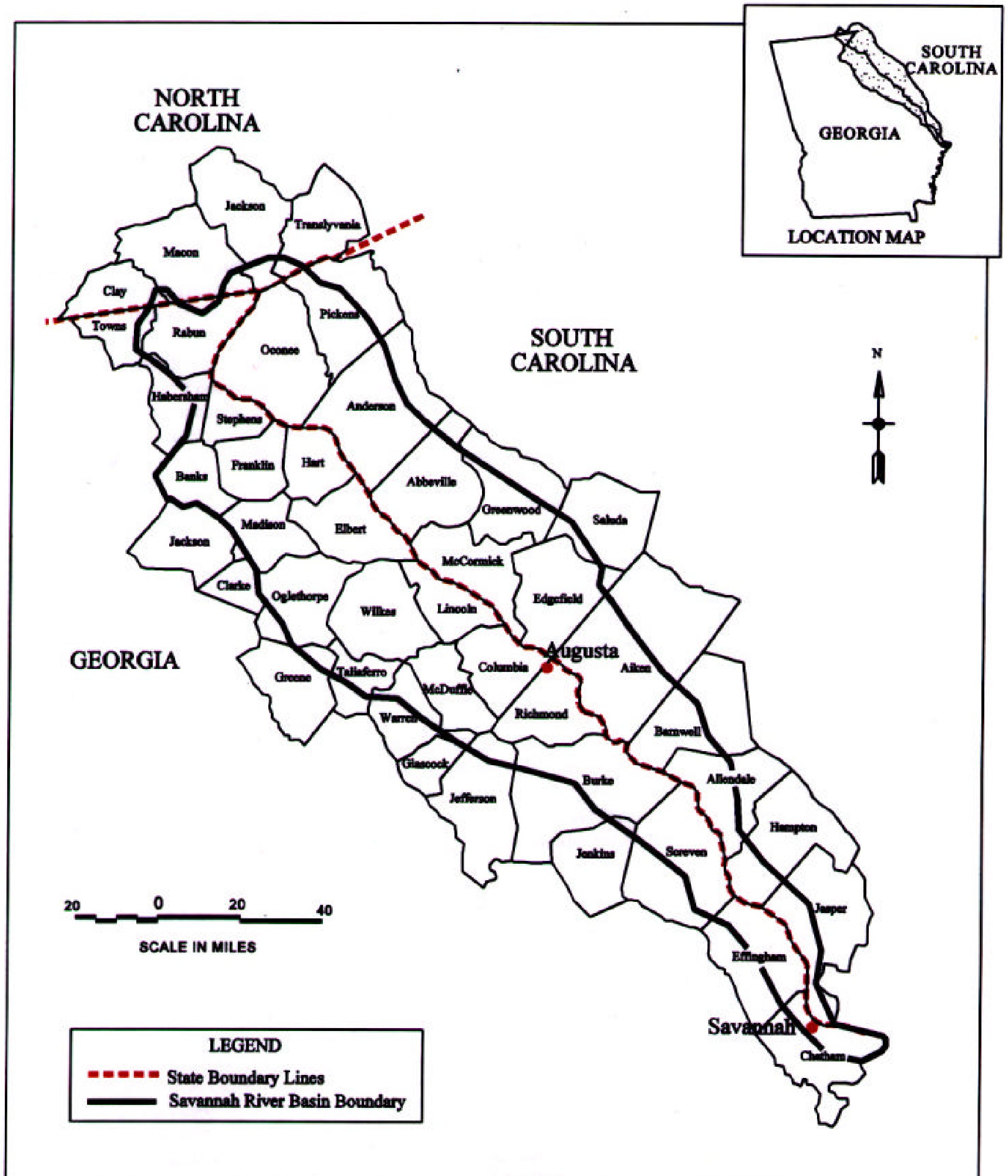

Figure 1-1: Location Map

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SOURCE:

SCALE: On Map

DATE: July 1999

2.0 DATA COLLECTION

2.1 Agency Coordination

A number of Federal and state agencies, state universities and other knowledgeable entities were contacted to provide information on extant hydrological models that address the entire Savannah River Basin. Visits were conducted with modeling experts at the U.S. Army Corps of Engineers, Waterways Experiment Station (WES), and the U.S. Army Corps of Engineers, Savannah District. WES personnel provided information on flow models within their experience, while Savannah District personnel assisted in providing detailed specifics on the HEC series of hydrological models.

Conversations (either via telephone, letter, or both) were conducted with personnel from a number of Federal and state agencies, as well as personnel at various universities. Agencies or universities contacted included the following: Institute for Water Resources (IWR), U.S. Geological Survey (USGS), U.S. Environmental Protection Agency (EPA), Tennessee Valley Authority (TVA), Georgia Department of Natural Resources, South Carolina Department of Natural Resources, South Carolina Department of Health & Environmental Control, Georgia Institute of Technology (Georgia Tech), Louisiana State University, and Colorado State University.

During data collection, information on a number of extant hydrological models was obtained from the sources indicated previously. Flow models for which data were obtained included the following: HEC-2, HEC-5, IWR, SAVRES, SCDNR, TVARMS, FORFLOW, RIVERSIM, and MIKE11. Information on a planning process, STELLA, was obtained from IWR.

2.2 Workshops

Two workshops were held to identify significant issues that needed to be addressed by the hydrological model or models, and to gain consensus among the appropriate Federal, state, and local agencies and other pertinent entities concerning the project's goals. The workshops were sponsored by the U.S. Army Corps of Engineers, Savannah District with assistance from Gulf South Research Corporation. The workshops were conducted on January 13, 1999 and April 27, 1999, at the J. Strom Thurmond Lake conference facility.

2.2.1 Workshop #1

The first workshop functioned as an orientation workshop to identify the significant issues affecting the Savannah River Basin, as well as, the various extant hydrological models which could be utilized within the basin. Twenty individuals from various Federal and state agencies, as well as, private companies and public interest groups attended the day long session. Each participant received a packet which included a project information sheet, a workshop agenda, hydrological model comparison matrix, and a handout identifying key issues within the basin. The workshop included a morning and afternoon session. The morning session consisted of an overview of the Savannah River Basin Comprehensive Study and how the hydrological model evaluation fits into that study. The format of the morning session involved an open forum, whereas each participant was provided an opportunity to express what he or she believed to be the key issues within the Savannah River Basin. The afternoon session consisted of a discussion of extant and proposed hydrological models.

The morning session resulted in all participants providing valuable input into identifying the key issues affecting the basin. Issues identified as the most important included (and in no particular order of importance) water quality, recreation, fish and wildlife habitat, aquatic plant control, water capacity, pump storage and water release, hydropower, water quantity, wetlands, saltwater intrusion, and flood control. Each participant was also asked to prioritize key issues on a survey sheet, which was returned to the U.S. Army Corps of Engineers at the end of the workshop. The information received from the survey aided in identifying and understanding which issues were critically important in hydrological model selection. Based on discussions and information received from the survey, it appeared that water quality, water quantity, hydropower, and fish and wildlife habitat were the most significant issues within the basin.

The afternoon session involved an open discussion of known or proposed hydrological models that could be considered for the evaluation. It was apparent from the discussions that it would be extremely difficult, if not impossible to separate water quality from water quantity. It was also suggested that only multi-dimensional models be evaluated and that the main constraints of the Savannah River Basin system be identified prior to model selection. It was agreed that it would be virtually impossible to find a single model capable of handling all issues within the basin.

2.2.2 Workshop #2

The second workshop was held to present the preliminary findings of the evaluation and to reach a consensus on the hydrological model or models which, would receive further study. Eighteen individuals from various Federal and state agencies, as well as, private companies and public interest groups attended the half-day session. The workshop consisted of an overview of the Savannah River Basin Hydrological Model Study, discussion of models proposed for further study, and a discussion of model capabilities and limitations. The format involved an open forum, whereas each participant was provided an opportunity to express his or her opinions involving the proposed models.

The second workshop resulted in all participants providing valuable input regarding the list of flow models proposed for further study. These models consisted of HEC-5, SAVRES, SCDNR, and TVARMS. A hydrological model comparison matrix handout was provided to each participant. The matrix provided a quick comparison between proposed models based on a number of criteria. These criteria consisted of water body type, model dimensions, flow regimes, hydropower, water quality links, flood control capabilities, pump storage capabilities, drought rules, model acceptance and support, model familiarity, model maintenance, and availability of the model. Attendees agreed that a number of flow models exist, many with better capabilities than the above proposed models. However, for the purpose of this study (i.e. identification of water quantity models) three of the four models (HEC-5, SCDNR, and TVARMS) were approved for further study. The group unanimously agreed to remove SAVRES from further discussion because of model limitations. The group also recommended and subsequently approved the planning process STELLA, be added to the list for further study.

3.0 HYDROLOGICAL MODELS EVALUATION

3.1 Background

GSRC was scoped by the Savannah District to evaluate four (4) hydrological models which were developed for the Savannah River Basin. These models included, HEC-5 (developed by the Savannah District), SAVRES (a model developed at Georgia Tech under contract to the Savannah District, but later improved by Dr. Aris Georgakakos), IWR Hydrological Model (developed by the Institute for Water Resources), and SCDNR (developed by the South Carolina Department of Natural Resources).

Additionally, GSRC was tasked to evaluate at least six additional hydrological models that were developed and utilized for other watersheds (generally or specifically) to determine their applicability to the needs and objectives of the Savannah River Basin Study. These models included FORFLOW, IFIM, RIVERSIM, STELLA, MIKE11, and HEC-2. In addition to the ten (10) models mentioned previously, GSRC also conducted evaluations on six (6) other hydrological models. These included, TVARMS, TVA BETTER, TVA RIVER, GADOSAG, QUAL-2E, and CE-QUAL-W2.

3.2 Procedures

The scope of the project, when examined closely, specifically addressed flow models. During the workshops, much was said regarding water quality models; such discussion was appropriate since many of the participants were engaged in water quality activities. This discussion was valuable because it provided a base for a paralleling effort involving water quality models. Therefore, water quality models such as GADOSAG, QUAL-2E, CE-QUAL-W2, RQUAL (TVA), and BETTER (TVA), while important to name, recognize, and discuss, were outside the scope of the project. The IFIM model is a fisheries model that uses as input the output of a flow model. Therefore, IFIM was not comparable to flow models.

For those flow models considered, criteria used in sorting out candidates for recommendation included the following: (1) Availability of the model; (2) Applicability of the model to meet needs; (3) Experience in use by Savannah River Basin agencies; (4) Probability of support of the model by “caretakers”; and (5) Willingness of Savannah River Basin agencies to accept an unfamiliar model.

The southeastern United States has perhaps the most highly developed and complex operational plans for reservoirs of any area in the country. This area of the country contains a number of reservoirs operated by the U.S. Army Corps of Engineers, Tennessee Valley Authority, and private power companies. These operators have a vast amount of experience in using flow models in the streams and reservoirs of the area. Early in the review process, it became evident that models developed outside the southeast were not likely to receive a great deal of consideration from users in the southeast. For this reason, the FORFLOW, RIVERSIM, and MIKE 11 models were removed from further consideration.

The selection criteria mentioned previously were used to narrow the field of possible models to a small group. Effort was placed on selecting the best group of models fitting the criteria, rather than conducting time consuming modeling runs. The list of possible models was narrowed down to four, two well proven models used extensively in the southeast (HEC series and TVARMS) and two models developed in the southeast for use there, but not used extensively. This latter group consisting of the South Carolina Department of Natural Resources (SCDNR) model and

SAVRES, which was developed by Georgia Tech for use in the Savannah River Basin. The SAVRES model; however, has not been used in the study area, and therefore was removed from further consideration.

In the second workshop, participants suggested that the IWR planning process known as STELLA be considered for further study. STELLA is not a flow model, but rather a thinking and learning process that can be used to better analyze situations. According to the developers of STELLA, “the STELLA software is designed specifically to support the building of understanding, the development of the capacity for building understanding, and the development of the capacity for sharing understanding”. The workshop participants spoke of the use of STELLA in the ACT and ACF studies of recent years.

3.3 Results

Based on the criteria described in Section 3.2, it is recommended that any further considerations of flow models focus on the HEC series, the ADYN module of the TVARMS series, and the SCDNR model. These models have the essential capability, experience base, and support base to produce acceptable results in use. Model users, with their hopefully intimate knowledge of the system being modeled, will instinctively find the model or models that best suit their needs. There is, therefore, no such thing as a “best model” for all uses.

Additionally, no comparisons (model runs, etc.) were made between the three proposed models; inclusion was based solely on the satisfaction of the criteria detailed previously. It is also recommended that the STELLA process be studied and applied whenever appropriate, especially in situations involving multiple and perhaps conflicting interests.

4.0 HYDROLOGICAL MODELS FACT SHEETS

4.1 HEC Series

MODEL NAME: HEC Series

ORGANIZATION/PERSON HOLDING AND DISTRIBUTING THE MODEL: Hydrologic Engineering Center, U.S. Army Corps of Engineers, 609 Second Street, Davis, California, 95616-4687

Phone: 530-756-1104
Fax: 530-756-8250
Email: www.hec.usace.army.mil

ORGANIZATION/PERSON RESPONSIBLE FOR MODEL MAINTENANCE: Marilyn Hurst, Hydrologic Engineering Center

TYPE OF MODELING OR APPLICATION:

River and reservoir hydraulics

NUMBER OF MODEL DIMENSIONS: One

LINKAGES WITH OTHER MODELS:

Can be run as HEC5Q (quality) to obtain estimates for concentrations for water quality parameters. The model has the capability to satisfy control point objectives for temperature, three conservative constituents, three non-conservative constituents, and dissolved oxygen for combinations of either tandem or parallel impoundments.

Links with other modules to produce estimates of damages resulting from a flood event.

MODEL LIMITATIONS: One dimensional nature limits the definitive description of water quality conditions, particularly in reservoir applications.

EXPERIENCE:

The HEC Series is extensively used throughout the United States for determination of flow and water level resulting from rainfall runoff or from operations in regulated systems.

CURRENT VERSION:

HEC1-Ver. 4.1, June 1998
HEC HMS-Ver. 1.1, March 1999
HEC2-Ver. 4.6, February 1991
HEC RAS-Ver. 2.2, September 1998
HEC5-Ver. 8.0, October 1998

INPUT REQUIREMENTS:

Beginning water levels

Cross-section characteristics (providing area and wetted perimeter)
Slope(s)
Roughness estimates

OUTPUT:

Resulting water levels
New cross-section characteristics
Weighted roughnesses
Flow estimates

AVAILABLE REFERENCES AND REPORTS ON APPLICATIONS:

HEC1 User Manual-“Flood Hydrograph Package, Version 4.0”, September 1990, Hydrologic Engineering Center.

PROHEC1-“The Dodson Professional HEC1 System”, Dodson and Associates, Inc., 5629 FM 1960 West, Suite 314, Houston, Texas, 77069 (Included as a representative of proprietary training material).

HEC2 User Manual-“Flood Plain Analyst”, February 1991, Hydrologic Engineering Center.

PROHEC2-“The Dodson Professional HEC2 System”, Dodson and Associates, Inc., 5629 FM 1960 West, Suite 314, Houston, Texas, 77069 (Included as a representative of proprietary training material).

HEC RAS User Manual-“River Analysis System’, Ver. 2.2, September 1998, Hydrologic Engineering Center.

HEC5 User Manual-“Simulation of Flood Control and Conservation Systems”, Ver. 7.2, March 1991, Hydrologic Engineering Center.

Water Quality Modeling of Reservoir System Operations Using HEC5, September 1987, Hydrologic Engineering Center.

Duke, J. H., D. J. Smith, and R. G. Willey (1985); “Reservoir System Analysis for Water Quality”; Technical Paper No. 99, Hydrologic Engineering Center.

Eubanks, M. J. and J. Greenfield (1999); “Water Quality Modeling for the Alabama-Coosa-Tallapoosa and Apalachicola-Chattahoochee-Flint River Basins Using BASINS and HEC5Q; presented at the 1999 Georgia Water Resources Conference; Athens, Georgia.

Hathorn, J. E. (1999); Using Reservoir System Modeling (HEC5) as Basis for a Programmatic Evaluation Framework (Apalachicola-Chattahoochee-Flint River Basin Allocation EIS); presented at the 1999 Georgia Water Resources Conference; Athens, Georgia.

Martin, J., C. Hesterlee, and T. Cole (1999); “Two-Dimensional Water Quality Modeling Using CEQUAL-W2 on Selected Reservoirs; presented at the 1999 Georgia Water Resources Conference; Athens, Georgia.

PC COMPATIBLE: yes

COMMENTS:

Bill Eichert, Richard Hayes, and Donald Smith worked extensively at developing and/or applying the HEC Series. Information on these individuals are provided below.

Bill Eichert was associated with the Hydrologic Engineering Center and worked extensively with the HEC Series. Now retired and in private practice, he continues to work in the updating and utilization of the series. His web address is www.mother.com/~beichert/caph5.htm.

Richard Hayes is currently a HEC staff member. He assisted with the development of the HEC2 and HEC5 programs, as well as, the HEC5 model of the Georgia-Alabama-South Carolina system, which includes the Savannah River Basin.

Donald J. Smith of RMA Associates, Suisan, CA worked extensively with the HEC Series in applications in the Alabama-Coosa-Tallapoosa and Apalachicola-Chattahoochee-Flint studies in the Southeastern U.S. His phone number is 707-864-2950, and is Email address is rma@community.net.

4.2 SCDNR

MODEL NAME: Savannah River Basin Budget and Reservoir Operation Model

ORGANIZATION/PERSON HOLDING AND DISTRIBUTING THE MODEL: Bud Badr, Water Resources Division, South Carolina Department of Natural Resources, 1201 Main Street, Suite 1100, Columbia, South Carolina, 29201

Phone: 803-737-0800
Fax: 803-765-9080
Email: badr@water.dnr.state.sc.us

ORGANIZATION/PERSON RESPONSIBLE FOR MODEL MAINTENANCE: Bud Badr, SCDNR

TYPE OF MODELING OR APPLICATION:

Reservoir water budget
River routing
Estimated Streamflow Prediction (ESP) to improve operation
Network power optimization
Real time data acquisition and operation

NUMBER OF MODEL DIMENSIONS: Two

LINKAGES WITH OTHER MODELS: Model output files that can be used as input for other models

MODEL LIMITATIONS: Only applicable to Savannah River (five reservoirs and nine points in the system)

EXPERIENCE: Used by the South Carolina and Georgia Departments of Natural Resources

CURRENT VERSION: Original Model

INPUT REQUIREMENTS:

52 weeks of inflows
Evaporation data (52 weeks)
Power prices (52 weeks)
Reservoir elevation targets for all uses
River flow targets for all uses
Pumping storage data

OUTPUT:

Reservoir elevations (52 weeks)
River flow level and magnitude (52 weeks at nine points on the river)
Power generation and price for all reservoirs, including pumped storage
Constraints status (52 weeks)

AVAILABLE REFERENCES AND REPORTS ON APPLICATIONS: SCDNR

PC COMPATIBLE: Yes

COMMENTS: Model output is comparable with HEC 5 output for the same operational criteria

4.3 TVARMS

MODEL NAME: Tennessee Valley Authority River Modeling System (ADYN Module)

ORGANIZATION/PERSON HOLDING AND DISTRIBUTING THE MODEL: Tennessee Valley Authority, Resources Group, Engineering Services, Gary Hauser, TVA Engineering Lab, 129 Pine Road, Norris, Tennessee, 37828

Phone: 423-632-1888
Fax: 423-632-1840
Email: gehauser@tva.gov

ORGANIZATION/PERSON RESPONSIBLE FOR MODEL MAINTENANCE: Gary Hauser, TVA

TYPE OF MODELING OR APPLICATION:

River and resource hydraulics
One-dimensional, longitudinal, unsteady flow
Hydraulics of floods and man-made transients (e.g., hydropower releases)
Effects of dynamic tributary systems, local inflow sources

Assessment of wetted areas for environmental flow assessments

NUMBER OF MODEL DIMENSIONS: One
LINKAGES WITH OTHER MODELS:

Can be linked to “RQUAL” module to provide water quality
Can be linked to “RHAB” module to provide physical habitat effects
Can be linked to “FISH” module to provide effects on fish growth
Can be linked to “CONTRAN” module to provide information on 2D (lateral and longitudinal) contaminant transport

MODEL LIMITATIONS: When linked to “RQUAL”, does not currently model water quality in dynamic tributaries

EXPERIENCE: Used extensively by the Tennessee Valley Authority

CURRENT VERSION: 2.91

INPUT REQUIREMENTS:

River geometry
River and local tributary hydrology (water surface elevation and flow rate at boundaries)

OUTPUT:

Discharge and water surface elevation
Water velocity
Water depth
Wetted area
Travel times
Water volume
Froude number

AVAILABLE REFERENCES AND REPORTS ON APPLICATIONS:

TECHNICAL REPORTS

Hauser, G. E., et.al (1998); “Model Exploration of Hydrodynamics, Water Quality, and Bioenergetics Fish Growth in Bull Shoals and Norfork Tailwaters”; WR98-1-590-174; TVA Engineering Laboratory; Norris, Tennessee; November.

Shiao, M. C., W. D. Proctor, C. R. Montgomery, G. E. Hauser, and J. H. Hoover (1997); “Development of a Wadeability Index for TVA Tailwaters”; TVA Engineering Laboratory Report WR28-1-590-166; September (draft).

Hoover, J. H., and G. E. Hauser (1997); “Feasibility Assessment for A Reregulation Weir Below Cedar Cliff Dam on Tuckasegee River East Fork”; TVA Engineering Laboratory Report WR97-3-760-109; September.

Proctor, W. D., J. H. Hoover, and G. E. Hauser (1996); “Tenkiller Ferry Aerating Weir”; WR28-1-590-166; TVA Engineering Laboratory; Norris, Tennessee; April.

Shiao, M. C., G. Hauser, B. Yeager, and T. McDonough (1993); "Development and Testing of a Fish Bioenergetics Model for Tailwaters"; WM-94-002; TVA Engineering Services and TVA Water Management Services; Norris, Tennessee; October.

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Hauser, G. E., and W. D. Proctor (1990); "Flow Patterns in the Big Sandy Embayment of Kentucky Reservoir Using a One-Dimensional Dynamic Model"; WR28-1-8-103; TVA Engineering Laboratory; Norris, Tennessee; November.

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Hauser, G. E. (1990); "One-Dimensional Modeling of Summer Minimum Flow and Temperature in Chilhowee Tailwater"; WR28-2-590-145; TVA Engineering Laboratory; Norris, Tennessee; January.

Hauser, G. E. (1990); "Unsteady One-Dimensional Modeling of Dissolved Oxygen in Nickajack Reservoir"; WR28-1-590-150; TVA Engineering Laboratory; Norris, Tennessee; January.

Hauser, G. E. (1989); "Turbine Pulsing for Minimum Flow Maintenance Downstream from Tributary Projects"; WR28-2-590-147; TVA Engineering Laboratory; Norris, Tennessee; September.

Bender, M. D., G. E. Hauser, and B. Johnson (1991); " Town Creek Embayment Investigation"; WR28-1-6-102; TVA Engineering Laboratory; Norris, Tennessee; July.

Hauser, G. E., M. K. McKinnon, and D. Bender (1988); "Model Investigation of the Downstream Effects of Douglas Reservoir Release Improvements"; WR28-1-590-143; TVA Engineering Laboratory; October.

Hauser, G. E. (1991); "User's Manual for One-Dimensional Unsteady Flow and Water Quality Modeling in River Systems with Dynamic Tributaries "; WR28-3-590-135; TVA Engineering Laboratory; Norris, Tennessee; July.

Miller, B. A., G. E. Hauser, and M. D. Bender; "Development of Procedures for Routing Spills in the Holston River Basin - Interim Report.

Hauser, G. E., and M. D. Bender; "Model Investigation of Minimum Flow Request for Industrial Cooling Water on the Upper Holston River - Technical Note; WR28-2-590-141; TVA Engineering Laboratory; Norris, Tennessee; May 1988.

Hauser, G. E., and M. D. Bender; "Model Investigation of Waste Permit Requests on the Upper Holston River - Technical Note; WR28-1-590-140; TVA Engineering Laboratory; Norris, Tennessee; December 1987.

Hauser, G. E., and M. D. Bender; "Temperature Modeling to Investigate the Use of Reservoir Releases to Create Trout Fishery Between Apalachia Dam and Powerhouse"; WR28-1-15-102; Engineering Laboratory; TVA Division of Air and Water Resources; Norris, Tennessee; June 1987.

Shiao, M. C., G. E. Hauser, and L. M. Beard; "Modeling of Clinch River Water Quality in the Norris Dam Tailwater"; WR28-1-590-126; Engineering Laboratory; TVA Division of Air and Water Resources; Norris, Tennessee; February 1986 (draft).

Hauser, G. E., and R. J. Ruane; "Model Exploration of Holston River Water Quality Improvement Strategies"; WR28-1-590-109; Water Systems Development Branch and Water Quality Branch; TVA Division of Air and Water Resources; Norris, Tennessee; July 1985.

Hill, D. M., and G. E. Hauser; "Effects of Proposed Water Supply Withdrawals on Fish Habitat in the Piney River"; TVA Office of Natural Resources and Economic Development; Norris, Tennessee; January 1985.

Hauser, G. E., and M. K. McKinnon; "Mathematical Modeling of a Rock Reregulating Structure for Enhancement of Norris Reservoir Releases"; WR28-1-2-109; Water Systems Development Branch; TVA Division of Air and Water Resources; Norris, Tennessee; December 1983.

Hauser, G. E., L. M. Beard, R. T. Brown, and M. K. McKinnon; "Modeling the Downstream Improvements in Dissolved Oxygen from Aeration of Cherokee and Douglas Releases"; WR28-1-590-103; Water Systems Development Branch; TVA Division of Air and Water Resources; Norris, Tennessee; September 1983.

TECHNICAL ARTICLES

Hauser, G. E., J. Stark, B. Herrold, and G. Robbins (1999); "Thermal and Bioenergetics Modeling For Balancing Energy and Environment"; Water Power 99 Proceedings; January.

Bevelhimer, M., V. Alavian, B. Miller, and G. Hauser (1997); "Modeling Thermal Effects of Operational and Structural Modifications at a Hydropower Facility on a Premier Trout Stream in Southwestern Montana"**;** Water Power 97 Proceedings.

Hauser, G. E., M. C. Shiao, J. A. Parsly, and B. L. Yeager (1997); "Modeling Approaches for Tailwater Enhancement"; presented at International Association of Hydraulic Research Conference; San Francisco; August.

Montgomery, C. R., W. D. Proctor, J. H. Hoover, and G. E. Hauser (1997); "TVA Experience with Minimum Flow Techniques at Hydropower Dams"; Waterpower 1997; Atlanta, Georgia.

Shiao, M., G. Hauser, G. Chapman, B. Yeager, T. McDonough, and R. Ruane (1994);"Tailwater Fishery Management Using a Fish Bioenergetics Model"; ASCE Water Management and Planning Conference; Norris, Tennessee; May.

Shiao, M. C., G. E. Hauser, G. Chapman, B. Yeager, T. McDonough, and R. J. Ruane (1992); "Dynamic Fish Growth Modeling for Tailwater Fishery Management"; prepared for proceedings of ASCE Water Forum 1992; Baltimore, Maryland; August.

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Hauser, G. E., and R. J. Ruane; "Tradeoffs Between Stream Regulation and Point Source Treatments in Cost-Effective Water Quality Management"; proceedings of the Third International Symposium on Regulated Streams - Advances in Stream Ecology; sponsored by Alberta Environment and University of Alberta; Edmonton, Alberta; June 1985.

Podar, M. K., J. C. Crossman, D. E. Burmaster, R. J. Ruane, G. E. Hauser, and S. L. Sessions; "Optimizing Point/Nonpoint Source Tradeoff in the Holston River Near Kingsport, Tennessee"; Proceedings of the National Conference on Nonpoint Sources of Pollution, Kansas City, Missouri; EPA 440/5-85-001; May 1985.

Hauser, G. E., and L. M. Beard; "Oxygen Modeling In Tailwaters of Hydro Projects"; presented at ASCE Hydraulics Division Specialty Conference, Cambridge, Massachusetts; Water Systems Development Branch; TVA Division of Air and Water Resources; Norris, Tennessee; August 1983.

PC COMPATIBLE: Yes

COMMENTS:

4.4 STELLA

SOFTWARE NAME: Systems Thinking Experiental Learning Laboratory

ORGANIZATION/PERSON HOLDING AND DISTRIBUTING THE SOFTWARE: High Performance Systems, Incorporated, Barry Richmond, 45 Lyme Road, Suite 200, Hanover, New Hampshire, 03755

Phone: 603-643-9636
Fax: 603-643-9502
Email: support@hps-inc.com

ORGANIZATION/PERSON RESPONSIBLE FOR SOFTWARE MAINTENANCE: Barry Richmond, High Performance Systems, Incorporated

TYPE OF SOFTWARE OR APPLICATION: Model-building and simulation tool that facilitates the capacity for understanding dynamic interrelationships within biological, social, and physical systems

NUMBER OF MODEL DIMENSIONS: Not applicable

LINKAGES WITH OTHER MODELS: Output from virtually any model can be interconnected into STELLA

MODEL LIMITATIONS: Limitless

EXPERIENCE: Used in over 45 countries in a variety of applications

CURRENT VERSION: 5.1

INPUT REQUIREMENTS: Limitless

OUTPUT: Limited by the information input into the system

AVAILABLE REFERENCES AND REPORTS ON APPLICATIONS: Contact High Performance Systems, Incorporated

PC COMPATIBLE: Yes

COMMENTS:

5.0 LITERATURE CITED

U.S. Army. 1989. Savannah River Basin Drought Contingency Plan. U.S. Army Corps of Engineers, Savannah District, Savannah, Georgia.

U.S. Army. 1992. An Assessment of Issues Affecting the Savannah River Basin. U.S. Army Corps of Engineers, Savannah District, Savannah, Georgia.