Attachment 02.04.03-08AE
TVA letter dated February 2, 2010
RAI Response

ASSOCIATED ATTACHMENTS/ENCLOSURES:

Attachment 02.04.03-8AE: Chickamauga Dam Local Watershed (subbbasins 44B and 45), Unit Hydrograph Validation

(42 Pages including Cover Sheet)

NPG CALCULATION COVERSHEET/CCRIS UPDATE

REV 0 EDMS/RIMS NO.	EDMS TYPE:	EDMS ACCESSION NO (N/A for REV. 0)
L58090424004	calculations(nuclear)	N/A L58 091230 040

Calc Title: Chickamauga Dam Local Watershed (Subbasins 44B and 45) Unit Hydrograph Validation

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT	CN	NUC	GEN	CEB	CDQ000020080064	1	2	Entire calc ☒ Selected pages ☐
NEW								

ACTION	NEW ☐ REVISION ☒	DELETE ☐ RENAME ☒	SUPERSEDE ☐ DUPLICATE ☐	CCRIS UPDATE ONLY ☐ (Verifier Approval Signatures Not Required)	No CCRIS Changes ☐ (For calc revision, CCRIS been reviewed and no CCRIS changes required)

UNITS	SYSTEMS	UNIDS
N/A	N/A	N/A

DCN,EDC,N/A	APPLICABLE DESIGN DOCUMENT(S)	CLASSIFICATION
See** Below	N/A	"E"

QUALITY RELATED?	SAFETY RELATED? (If yes, QR = yes)	UNVERIFIED ASSUMPTION	SPECIAL REQUIREMENTS AND/OR LIMITING CONDITIONS?	DESIGN OUTPUT ATTACHMENT?	SAR/TS and/or ISFSI SAR/CoC AFFECTED
Yes ☒ No ☐	Yes ☒ No ☐	Yes ☐ No ☒	Yes ☐ No ☒	Yes ☐ No ☒	Yes ☐ No ☒

PREPARER ID	PREPARER PHONE NO	PREPARING ORG (BRANCH)	VERIFICATION METHOD	NEW METHOD OF ANALYSIS
HSSAWYER	615.252.4362	CEB	See Page 7	☐ Yes ☒ No

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
Heather Smith Sawyer	12/16/09	Bill Hamilton	12/16/09
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
Bill Hamilton	12/16/09	K. R. Gates K. R. Spates	12/23/09

STATEMENT OF PROBLEM/ABSTRACT

Validate existing unit hydrographs for the subbasins of the Chickamauga Dam watershed (Subbasins 44B and 45) using the 1973 and 2003 floods of record.

**EDCN-22404A (SQN), EDCN-54018 A(WBN), EDCN-LATER (BFN)

This calculation contains electronic attachments and must be stored in EDMS as an Adobe .pdf file to maintain the ability to retrieve the electronic attachments.

MICROFICHE/EFICHE Yes ☐ No ☒ FICHE NUMBER(S)

☐ LOAD INTO EDMS AND DESTROY
☒ LOAD INTO EDMS AND RETURN CALCULATION TO CALCULATION LIBRARY. ADDRESS: LP4D-C
☐ LOAD INTO EDMS AND RETURN CALCULATION TO:

NPG CALCULATION COVERSHEET/CCRIS UPDATE

REV 0 EDMS/RIMS NO.	EDMS TYPE:	EDMS ACCESSION NO (N/A for REV. 0)
L58 090424 004	calculations(nuclear)	N/A

Calc Title: Calculation of Initial Flood Flows from Subbasins 44B and 45, Local Inflows to Chickamauga Dam, for Use in the SOCH Model Calibration and Unit Hydrograph Validation

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT	CN	NUC						Entire calc ☐ Selected pages ☐
NEW	CN	NUC	GEN	CEB	CDQ000020080064	N/A	0	

ACTION	NEW ☒ REVISION ☐	DELETE ☐ RENAME ☐	SUPERSEDE ☐ DUPLICATE ☐	CCRIS UPDATE ONLY ☐ (Verifier Approval Signatures Not Required)	No CCRIS Changes ☐ (For calc revision, CCRIS been reviewed and no CCRIS changes required)

UNITS	SYSTEMS	UNIDS
N/A	N/A	N/A

DCN,EDC,N/A	APPLICABLE DESIGN DOCUMENT(S)	CLASSIFICATION
N/A	N/A	"E"

QUALITY RELATED?	SAFETY RELATED? (If yes, QR = yes)	UNVERIFIED ASSUMPTION	SPECIAL REQUIREMENTS AND/OR LIMITING CONDITIONS?	DESIGN OUTPUT ATTACHMENT?	SAR/TS and/or ISFSI SAR/CoC AFFECTED
Yes ☒ No ☐	Yes ☒ No ☐	Yes ☐ No ☒	Yes ☐ No ☒	Yes ☐ No ☒	Yes ☐ No ☒

PREPARER ID	PREPARER PHONE NO	PREPARING ORG (BRANCH)	VERIFICATION METHOD	NEW METHOD OF ANALYSIS
MCCARNEY	(415) 768-3588	Bechtel (CEB)	Design Review	☐ Yes ☒ No

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
Matthew C. Carney [signature]	4/16/09	Nicholas D. Martin [signature]	4/16/2009
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
Robert E. Swain [signature]	4/16/2009	[signature] K.R. Spates	4/24/2009

STATEMENT OF PROBLEM/ABSTRACT

Prepare initial flood flow hydrographs for Subbasins 44B and 45, Hiwassee River local, Mouth to Charleston (gage at River Mile 18.9), and Chickamauga Dam local, for two floods that occurred in March 1973 and in May 2003 to be used in the SOCH model calibration and unit hydrograph validation.

This calculation contains electronic attachments and must be stored in EDMS as an Adobe .pdf file to maintain the ability to retrieve the electronic attachments.

MICROFICHE/EFICHE Yes ☐ No ☒ FICHE NUMBER(S)

☐ LOAD INTO EDMS AND DESTROY
☒ LOAD INTO EDMS AND RETURN CALCULATION TO CALCULATION LIBRARY. ADDRESS: LP4D-C
☐ LOAD INTO EDMS AND RETURN CALCULATION TO:

NPG CALCULATION COVERSHEET/CCRIS UPDATE

REV 0 EDMS/RIMS NO.	EDMS TYPE:	EDMS ACCESSION NO (N/A for REV. 0)
L58090424004	calculations(nuclear)	N/A L58 090709 004

Calc Title: Chickamauga Dam Local Watershed (Subbasins 44B and 45) Unit Hydrograph Validation

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT	CN	NUC	GEN	CEB	CDQ000020080064	0	1	Entire calc ☒ Selected pages ☐
NEW	CN	NUC						

ACTION	NEW ☐ REVISION ☒	DELETE ☐ RENAME ☒	SUPERSEDE ☐ DUPLICATE ☐	CCRIS UPDATE ONLY ☐ (Verifier Approval Signatures Not Required)	No CCRIS Changes ☐ (For calc revision, CCRIS been reviewed and no CCRIS changes required)

UNITS	SYSTEMS	UNIDS
N/A	N/A	N/A

DCN,EDC,N/A	APPLICABLE DESIGN DOCUMENT(S)	CLASSIFICATION
See** Below	N/A	"E"

QUALITY RELATED?	SAFETY RELATED? (If yes, QR = yes)	UNVERIFIED ASSUMPTION	SPECIAL REQUIREMENTS AND/OR LIMITING CONDITIONS?	DESIGN OUTPUT ATTACHMENT?	SAR/TS and/or ISFSI SAR/CoC AFFECTED
Yes ☒ No ☐	Yes ☒ No ☐	Yes ☒ No ☐	Yes ☐ No ☒	Yes ☐ No ☒	Yes ☐ No ☒

PREPARER ID	PREPARER PHONE NO	PREPARING ORG (BRANCH)	VERIFICATION METHOD	NEW METHOD OF ANALYSIS
HSSAWYER	615.252.4362	BWSC (CEB)	Design Review	☐ Yes ☒ No

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
Heather Smith Sawyer	7/6/09	Bill Hamilton	7/6/09
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
Bill Hamilton	7/6/09	K. R. Spates	7/9/09

STATEMENT OF PROBLEM/ABSTRACT

Validate existing unit hydrographs for the subbasins of the Chickamauga Dam watershed (Subbasins 44B and 45) using the 1973 and 2003 floods of record.

**EDCN-22404 (SQN), EDCN-54018 (WBN), EDCN-LATER (BFN)

This calculation contains electronic attachments and must be stored in EDMS as an Adobe .pdf file to maintain the ability to retrieve the electronic attachments.

MICROFICHE/EFICHE Yes ☐ No ☒ FICHE NUMBER(S)

☐ LOAD INTO EDMS AND DESTROY
☒ LOAD INTO EDMS AND RETURN CALCULATION TO CALCULATION LIBRARY. ADDRESS: LP4D-C
☐ LOAD INTO EDMS AND RETURN CALCULATION TO:

NPG CALCULATION COVERSHEET/CCRIS UPDATE

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	REV
	CN	NUC	GEN	CEB	CDQ000020080064	2

ALTERNATE CALCULATION IDENTIFICATION

BLDG	ROOM	ELEV	COORD/AZIM	FIRM	Print Report	Yes ☐
				BWSC		

CATEGORIES NA

KEY NOUNS (A-add, D-delete)

ACTION (A/D)	KEY NOUN	A/D	KEY NOUN

CROSS-REFERENCES (A-add, C-change, D-delete)

ACTION (A/C/D)	XREF CODE	XREF TYPE	XREF PLANT	XREF BRANCH	XREF NUMBER	XREF REV
A	P	CO	GEN	CEB	FLDHYDRO Version 1.0	
A	P	CO	GEN	CEB	UNITGRPH Version 1.0	

CCRIS ONLY UPDATES:
Following are required only when making keyword/cross reference CCRIS updates and page 1 of form NEDP-2-1 is not included:

Heather Smith Sawyer PREPARER SIGNATURE	DATE	Bill Hamilton CHECKER SIGNATURE	DATE
PREPARER PHONE NO. 615.252.4362	EDMS ACCESSION NO.		

NPG CALCULATION RECORD OF REVISION		
CALCULATION IDENTIFIER CDQ000020080064		
Title	Chickamauga Dam Local Watershed (Subbasins 44B and 45) Unit Hydrograph Validation Revision 2	
Revision No.	DESCRIPTION OF REVISION	
0	Initial issue 31 pages	
1	This calculation was revised to validate existing unit hydrographs for the subbasins of the Chickamauga Dam watershed (Subbasins 44B and 45) using the 1973 and 2003 floods of record. As a result of this revision, the calculation title has been changed to reflect final validation of the local unit hydrographs. Significant changes to text are marked with a right-hand margin revision bar. Content on pages 1 – 8 of R0 was modified as indicated on pages 1 – 8 of R1 with pages 1a and 7a added. Content on pages 10-12, 31 of R0 was modified and now equivalent to pages 10 – 13, 36 of R1. New Pages 32-37 were added. Calculation header was revised (Chickamauga Dam Watershed (subbasins 44B and 45) Unit Hydrograph Validation, Revision 1) on all revised pages. Added new electronic Attachments 4-1, 4-2 and 4-3. Total hardcopy pages, Revision 1: 39	
2	This calculation was revised to address the following: • PER 203951-The verification of the original calculation was completed by personnel who had not completed the required NEDP-7 Job Performance Record (JPR). A verification JPR is now in place for all personnel engaged in verification tasks. Checking included only changes made in this revision as the checking of the calculation was not impacted by PER 203951. The verification is inclusive of work completed prior to this revision. • PER 203872- replace NEDP-2 forms on Pages 2 through 6 with the forms from the NEDP-2 Revision in effect at the time of calculations issuance. Significant changes in Revision 2 are noted with a right margin revision bar. Administrative changes and typos are excluded. The unverified assumption associated with the approval of the Melton Hill SOCH Calibration calculation, CDQ000020080038, has been removed. Final calibration has been completed and the calculation has been approved. Changes and additions: Content on pages 1-7, 9, 10, and 32 – 35 R1 has been modified as indicated on pages 1-7, 9, 10, and 32-35, R2. Pages 1b and 7b were added. Total hardcopy pages Revision 2: 41	

NPG CALCULATION TABLE OF CONTENTS

Calculation Identifier: CDQ000020080064	Revision: 2	

TABLE OF CONTENTS

NOTE: N/A indicates electronic attachment

NPG CALCULATION TABLE OF CONTENTS

Calculation Identifier: CDQ000020080064	Revision: 2	

TABLE OF CONTENTS (Continued)

SECTION	TITLE	PAGE

List of Tables:

List of Figures:

Attachments: See the list of electronic attachments on the following page.

NPG COMPUTER INPUT FILE STORAGE INFORMATION SHEET

Document CDQ000020080064	Rev. 2	Plant: GEN	

Subject: Chickamauga Dam Watershed Local (Subbasins 44B and 45) Unit Hydrograph Validation

☐ Electronic storage of the input files for this calculation is not required. Comments:

☒ Input files for this calculation have been stored electronically and sufficient identifying information is provided below for each input file. (Any retrieved file requires re-verification of its contents before use.)

Electronic Attachment	Name of File or Folder	File Location
	Supporting Spreadsheets and Data	
Attachment 1-1	Att 1-1_Subbasins 44B-45 Hydrographs for SOCH.xls	Attached to PDF
Attachment 1-2	Att 1-2_03566000 Hiwassee River at Charleston.txt	Attached to PDF
Attachment 1-3	Att 1-3_wattsbar_rev0.xls (TVA database file)	Attached to PDF
Attachment 1-4	Att 1-4_chickamauga_rev0.xls (TVA database file)	Attached to PDF
Attachment 1-5	Att 1-5_May2003 gridded precip (subbasins 44B-45).xls	Attached to PDF
Attachment 1-6	Att 1-6_Water budget for subbasins 44B-45.xls	Attached to PDF
	UNITGRPH Files	
Attachment 2-1	Att 2-1_Basin45_March1973.dat	Attached to PDF
Attachment 2-2	Att 2-2_Basin45_March1973.prn	Attached to PDF
Attachment 2-3	Att 2-3_Basin45_March1973.plt	Attached to PDF
	FLDHYDRO Files	
Attachment 3-1	Att 3-1_44B-45_March1973_1.dat	Attached to PDF
Attachment 3-2	Att 3-2_44B-45_March1973_1.out	Attached to PDF
Attachment 3-3	Att 3-3_44B-45_May2003_1.dat	Attached to PDF
Attachment 3-4	Att 3-4_44B-45_May2003_1.out	Attached to PDF
Attachment 3-5	Att 3-5_44B-45_March1973_2.dat	Attached to PDF
Attachment 3-6	Att 3-6_44B-45_March1973_2.out	Attached to PDF
Attachment 3-7	Att 3-7_44B-45_May2003_2.dat	Attached to PDF
Attachment 3-8	Att 3-8_44B-45_May2003_2.out	Attached to PDF
Attachment 3-9	Att 3-9_ChickRes_March1973.dat	Attached to PDF
Attachment 3-10	Att 3-10_ChickRes_March1973.out	Attached to PDF
Attachment 4-1	Att 4-1_Chick_Observed vs SOCH Mar1973 Hydrographs 060409.xls	Attached to PDF
Attachment 4-2	Att 4-2_Chick_Observed vs SOCH May2003 Hydrographs 060409.xls	Attached to PDF
Attachment 4-3	Att 4-3 Chick_validated_UH.xls	Attached to PDF

☐ Microfiche/eFiche

NPG CALCULATION VERIFICATION FORM

Calculation Identifier CDQ000020080064 Revision 2

Method of verification used:		Verifier Bill Hamilton Date 12/16/09
1. Design Review	☒	
2. Alternate Calculation	☐	
3. Qualification Test	☐	

Comments:

This calculation entitled, "Chickamauga Dam Local Watershed (Subbasins 44B and 45) Unit Hydrograph Validation" was verified by independent design review. The process involved a critical review of the calculation to ensure that it is correct and complete, uses appropriate methodologies, and achieves its intended purpose. The inputs were reviewed and determined to be appropriate inputs for this calculation. The results of the calculation were reviewed and were found to be reasonable and consistent with the inputs provided. Backup files and documents were consulted as necessary to verify data and analysis details found in the calculation.

Detailed comments and editorial suggestions for the changes made in this revision were transmitted to the author and reviewer by email along with a marked up copy of the calculation. Several issues were discussed and resolved during the verification process. The most important issue revolved around the use of a single storm event (March 1973) for the preparation of the Subbasin 45 unit hydrograph and as one of the two storms used to validate the Subbasin 45 unit hydrograph. Ultimately this approach was approved, as the hydrograph in question was a synthetic hydrograph developed with stream flows estimated from the SOCH model. In addition, a second storm (May 2003) was used, per ANSI/ANS-2.8-1992, to validate the unit hydrograph.

(Note: The design verification of this calculation revision is for the total calculation, not just the changes made in the revision. This complete re-verification is performed to disposition PER 203951 as described in the Calculation Revision Log on Page 3)

NPG CALCULATION VERIFICATION FORM

Calculation Identifier CDQ000020080064 Revision 0

Method of verification used:		
1. Design Review	☒	Verifier Bob Swain Date 4/13/2009
2. Alternate Calculation	☐	
3. Qualification Test	☐	

Comments:

The calculation entitled, "Calculation of Flood Flows from Subbasins 44B and 45, Local Inflows to Chickamauga Dam, for Use in SOCH Model Calibration and Unit Hydrograph Validation" was verified by an independent design review. The process involved a critical review of the calculation to ensure that it is correct and complete, uses appropriate methodologies, and achieves its intended purpose. Backup files and documents were consulted as necessary to verify data and analysis details found in the calculation. Detailed comments and editorial suggestions were transmitted to the author and reviewer by email along with a marked up copy of the calculation.

Several issues were discussed and resolved during the verification process. Almost all of the editorial suggestions were adopted in the final document. The following discussion briefly describes the most important issues and the resolution process.

1. Baseflows were estimated by linearly interpolating between the daily local flows preceding and following the March 1973 and May 2003 floods. The revised approach resulted in baseflows smaller than the value of 2000 cfs found in information provided by the TVA, which was from an earlier study based on the baseflow contribution from Subbasin 45.

2. The reservoir runoff hydrographs in the calculation were designated as "additional reservoir runoff." These hydrographs represent the additional runoff from the Chickamauga Reservoir water surface (where runoff equals rainfall) over and above the runoff captured in the unit hydrograph convolution (the reservoir area was included in the unit hydrograph). The "additional" reservoir runoff was computed separately.

The calculation presents the development of initial simulated flows from Subbasin 44B and 45 for floods that occurred in March 1973 and May 2003. The initial simulated flows are for use in the calibration of the SOCH model and to validate the unit hydrographs for Subbasins 44B and 45.

NPG CALCULATION VERIFICATION FORM

Calculation Identifier CDQ000020080064 Revision 1

Method of verification used:		
1. Design Review	☒	Verifier Bill Hamilton Date 7/2/09
2. Alternate Calculation	☐	
3. Qualification Test	☐	

Comments:

The calculation entitled, “Calculation of Flood Flows from Subbasins 44B and 45, Local Inflows to Chickamauga Dam, for Use in SOCH Model Calibration and Unit Hydrograph ValidationChickamauga Dam Watershed (Subbasins 44B and 45) Unit Hydrograph Validation” was verified by an independent design review. The process involved a critical review of the calculation to ensure that it is correct and complete, uses appropriate methodologies, and achieves its intended purpose. Backup files and documents were consulted as necessary to verify data and analysis details found in the calculation. Detailed comments and editorial suggestions were transmitted to the author and reviewer by email along with a marked up copy of the calculation.

The calculation presents the development of initial simulated flows from sSubbasin 44B and 45 for floods that occurred in March 1973 and May 2003, which were used in the calibration of the SOCH model. The initial simulated flows are used in the calibration of the SOCH model and to validate the unit hydrographs for Subbasins 44B and 45.The comparison between the observed and simulated flows and water surface elevation at several locations supports the conclusion that the unit hydrographs developed for subbasins 44B and 45 have been indirectly validated against floods that occurred in March 1973 and May 2003.

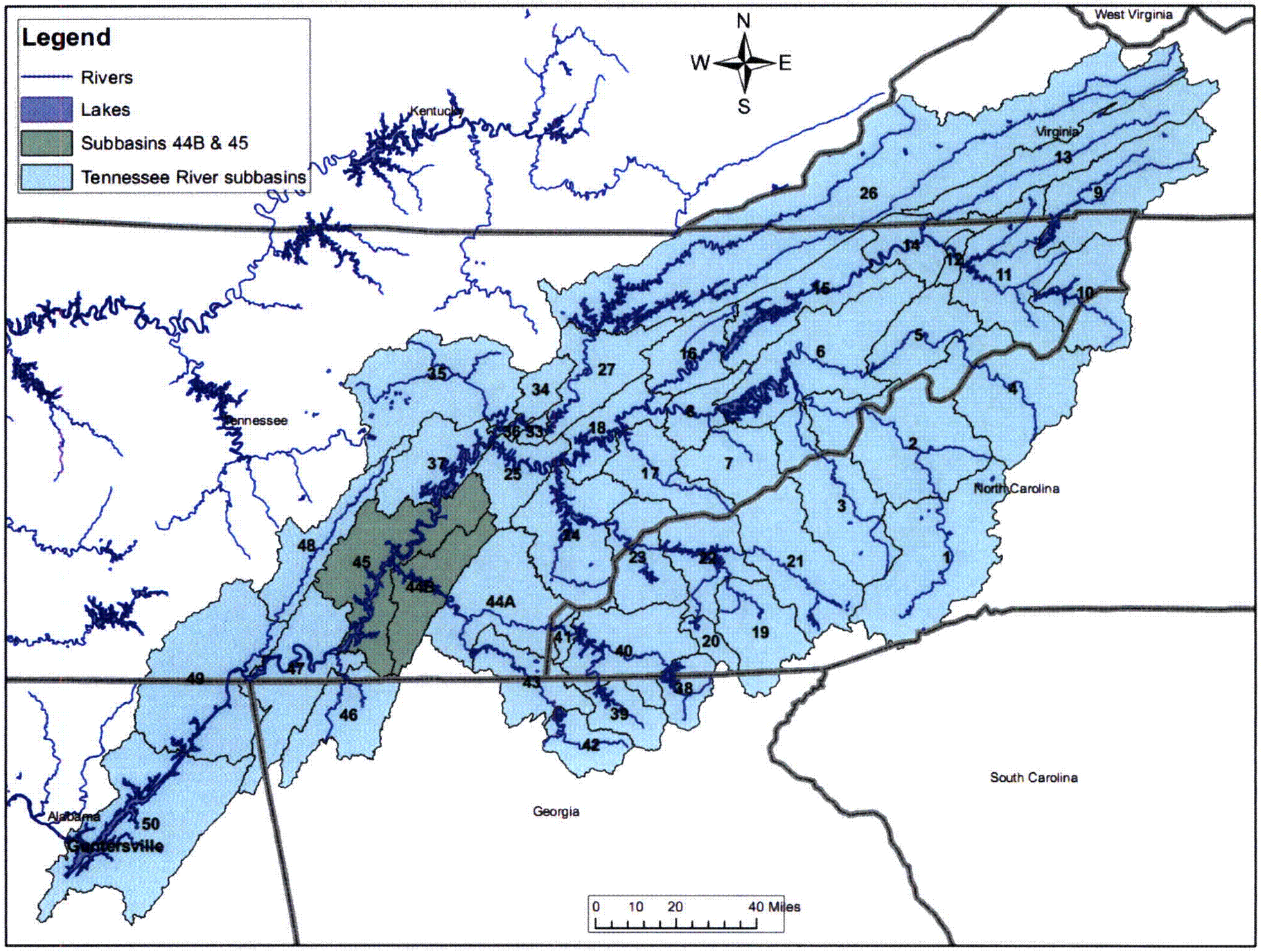
1 Purpose

The TVA's Water Management Group has adapted computer codes and data sets developed from flood studies carried out over the past 40 years to develop a dynamic hydrologic model (Reference 1) of the Tennessee River upstream of the Guntersville Dam for use in the Probable Maximum Flood (PMF) and dam break analysis for the Sequoyah, Watts Bar, and planned Bellefonte Nuclear Plant sites (Note that this calculation will also be used in similar future PMF and dam break analyses for the Browns Ferry Nuclear Plant).

Inputs to the dynamic model include hydrographs for 47 subbasins developed from design rainfall inputs convoluted with unit hydrographs (UH) developed specifically for each subbasin. These unit hydrographs were developed by the TVA in previous studies, mostly in the 1970s and early 1980s, using observed rainfall and streamflow and reservoir headwater and discharge data, and are being validated by checking their performance in reproducing recent floods.

As part of the dynamic hydrologic model of the Tennessee River system, the subbasin hydrographs are used as inputs to the Simulated Open Channel Hydraulic (SOCH) code. The SOCH code is used to determine elevation and discharge hydrographs at the planned Bellefonte Nuclear Plant (BLN) site. This calculation presents the development of initial simulated flows from Subbasin 44B, Subbasin 45, and from the Chickamauga Reservoir surface as well as the validation of the unit hydrographs for the two subbasins, for floods that occurred in March 1973 and in May 2003. The March 1973 and May 2003 floods were selected by the TVA to be analyzed using the SOCH model. The simulated flows will be used by the TVA in the calibration of the SOCH model and to validate the unit hydrographs for Subbasins 44B and 45. Subbasins 44B and 45 are located in the Tennessee River watershed as shown in Figure 1.

Figure 1: Locations of Subbasins 44B and 45 in the Tennessee River Watershed.



2 References

1. Tennessee Valley Authority, Bellefonte Nuclear Plant - White Paper, Hydrologic Analysis, Revision 1, July 25, 2008, (EDMS No. L58 081219 800).FOR INFORMATION ONLY

2. Tennessee Valley Authority, response to Bechtel Request for Information (RFI) 25447-000-GRI-GEX-00052, No. 44B, Hiwassee River local, Mouth to Charleston, gage at mile 18.9, Rev. 0, (EDMS No. L58 081119 801).

3. Tennessee Valley Authority, File Book Reference for Unit Area 45, Chickamauga Local (EDMS No. L58 081223 831).

4. Tennessee Valley Authority, *UNITGRPH-FLDHYDRO-TRBROUTE-CHANROUT User's Manual*, Version 1.0, March 2009 (EDMS No. L58 090325 001).

5. Viessman, W., J.W. Knapp, G.L. Lewis, and T.E. Harbaugh, *Introduction to Hydrology*, *Second Edition,* Harper & Row, Publishers, 1977.

6. Chow , V.T., D.R. Maidment, and L.W. Mays, *Applied Hydrology*, McGraw-Hill Book Company, 1988.

7: Tennessee Valley Authority, [Map] *Drainage Areas above Guntersville Dam*, June 18, 2008.

8. USGS Water-Data Report 2007 for gage 03566000 Hiwassee River at Charleston, TN, available online at: http://wdr.water.usgs.gov/, accessed on Nov. 11, 2008.
9. Tennessee Valley Authority, *TVA Water Control Projects and Other Major Hydro Developments in the Tennessee and Cumberland Valleys*, Technical Monograph No. 55, Volume 1, Knoxville, TN, March 1980.
10. USGS, Daily discharge data for years 1898 to 2007 at gage 03566000 Hiwasseee River at Charleston, TN, obtained from the National Water Information System (NWIS), online at: http://waterdata.usgs.gov/nwis, accessed 10/30/2008.
11. Tennessee Valley Authority, Data request for developing inflows to the SOCH model for the 1973 flood, for stage-storage tables, and for all reservoir and stream flow data for years 1997 to 2007, Response to Bechtel Request for Information RFI 25447-000-GRI-GEX-00053, Rev. 0, 11/12/2008. (EDMS No. L58 081126 800)
12. Tennessee Valley Authority, Rainfall data for the March 1973 storm – subbasins 44B & 45, Response to Bechtel Request for Information RFI 25447-000-GRI-GEX-00036, Rev. 0, 10/31/2008. (EDMS No. L58 081030 006)
13. Tennessee Valley Authority, Calculation No. CDQ000020080055, Processing and Validation of National Weather Service's NEXRAD Stage III Hourly Precipitation Data for Hydrologic and Hydraulic Analysis of Watersheds, Revision 3
14. Kohler, M.A., and R.K. Linsley, Predicting the Runoff from Storm Rainfall, *Research Paper No. 34*, U.S. Department of Commerce, September 1951. (EDMS No. L58 080910 001)
15. Tennessee Valley Authority, Calculation CDQ00020080039, SOCH Model Calibration, Chickamauga, Rev 0 (not approved).
16. *American Nuclear Society, American National Standard for Determining Design Basis Flooding at Power Reactor Sites*, ANSI/ANS-2.8-1992, 1992.
17. US Nuclear Regulatory Commission, Standard *Review Plan 2.4.3, Probably Maximum Flood (PMF) on Streams and Rivers*, NUREG-0800, Revision 4, March 2007.

3 Assumptions

3.1 General Assumptions

None.

3.2 Unverified Assumptions

None.

4 Background

4.1 Unit Hydrograph Theory

The unit hydrograph is used to predict the runoff response at the outlet of a watershed, or subbasin, to the input of one inch of excess rainfall applied over a given duration of time. Runoff from other depths of excess rainfall can be obtained by scaling (References 5 and 6).

The unit hydrograph is used to obtain the direct runoff hydrograph resulting from a series of excess rainfall inputs of any depth using the process of "convolution." The discrete convolution equation, states that the direct runoff, Q, is obtained by summing the products of the excess rainfall depths (direct runoff depths), P, and the unit hydrograph ordinates, U (References 5 and 6). The reverse process, called deconvolution, is used to derive the ordinates of the unit hydrograph by reconstituting floods from rainfall and streamflow data. The unit hydrograph is derived from the unit duration of uniform excess rainfall applied evenly across the watershed.

Unit hydrograph theory is applicable under the following conditions (Reference 6):

1. Excess rainfall has a constant intensity within the effective duration.
2. Excess rainfall is uniformly distributed over the entire subbasin.
3. The duration of direct runoff resulting from a unit of excess rainfall is constant.
4. The ordinates of the unit hydrograph are directly proportional to the total amount of direct runoff (linear response).
5. The surface runoff hydrograph reflects all the unique physical characteristics and runoff processes in the drainage basin in a given "epoch."

5 Methodology

Direct runoff originating within several subbasins of the Tennessee Valley watershed, which empty directly into the Tennessee River, cannot be accurately calculated because the observed flood hydrograph at the subbasin outlet is not available. For these subbasins, the dynamic streamflow model, SOCH, is used to validate the unit hydrographs. The SOCH model requires estimated flood hydrographs for these subbasins as inputs during the model calibration process.

Input flood hydrographs for individual subbasins requiring SOCH model validation are estimated by using a water budget to calculate total flow volume during a flood. The water budget area is chosen so that the observed flood hydrograph at the outlet of the water budget area can be reliably estimated. Total inflow to the water budget area is then partitioned among the component subbasins to obtain input flood hydrographs for individual subbasins using the methods described below and in Section 7.4.

The methodology used for unit hydrograph validation follows that described in ANSI/ANS-2.8-1992 (Reference 16). This document is included as a reference in the NRC's Standard Review Plan 2.4.3, Probable Maximum Flood on Streams and Rivers (Reference 17). ANSI/ANS-2.8-1992 states that "deterministic simulation models including unit hydrographs should be verified or calibrated by comparing results of the simulation with the highest two or more floods for which suitable precipitation data are available."

The methodology used for this calculation includes the following steps:

1. Delineate the area for water budgeting, which in this calculation is the combined area of Subbasins 44B and 45. Perform water budget calculations for the March 1973 and May 2003 floods to estimate the volume of each flood that originates within this area.
2. Separate baseflow from the total local flow to obtain the direct runoff for the budget area.
3. Obtain observed rainfall data for the March 1973 and May 2003 floods and calculate the basin-average rainfall for each subbasin within the water budget area and also for the reservoir area.
4. Convert the observed rainfall series to excess rainfall series using the TVA's API-RI method as implemented in FLDHYDRO (Reference 4). The observed direct runoff volumes are used by FLDHYDRO to ensure that the calculated excess rainfall volumes agree with the observed. FLDHYDRO allocates excess rainfall among the subbasins according to their calculated API values.
5. Compute the additional direct runoff generated by rainfall on the surface of the reservoir. All rain falling on the reservoir surface becomes runoff. Therefore, the additional direct runoff is equal to the observed rainfall (Step 3) less the direct runoff calculated in Step 4. Check that the volume of direct runoff from Step 2 equals the sum of the direct runoff from Steps 4 and 5. If necessary, adjust the CHKVOL value in FLDHYDRO and redo Steps 4 and 5.
6. Convolute the TVA unit hydrograph and the excess rainfall series to generate the initial simulated local direct runoff hydrograph for each subbasin.
7. Compare the SOCH model simulated and the observed discharge and stage hydrographs for appropriate stations along the Tennessee River to indirectly validate the performance of the TVA unit hydrographs in simulating local runoff along the study reach of the Tennessee River.

6 Design Input Data

The input data necessary for developing SOCH inflow hydrographs for Subbasins 44B (Hiwassee at Mouth) and 45 (Chickamauga Dam Local) are summarized below.

- Subbasin drainage areas and the surface area of Chickamauga Reservoir
- Unit hydrograph ordinates and durations
- Observed daily flows of the Hiwassee River at Charleston, River Mile (RM) 18.9
- Observed daily discharges at Watts Bar Dam
- Observed daily storage and discharges at Chickamauga Dam
- Observed rainfall data associated with the March 1973 and May 2003 floods

Each of these inputs is described in more detail in the following sub-sections.

6.1 Subbasin Locations and Areas

A hydrologic map of Subbasins 44B and 45 is shown in Figure 2. A schematic diagram of the Chickamauga Dam Local system, including Subbasins 44B and 45, is shown in Figure 3.

Figure 2: Hydrologic Map of Subbasins 44B and 45.

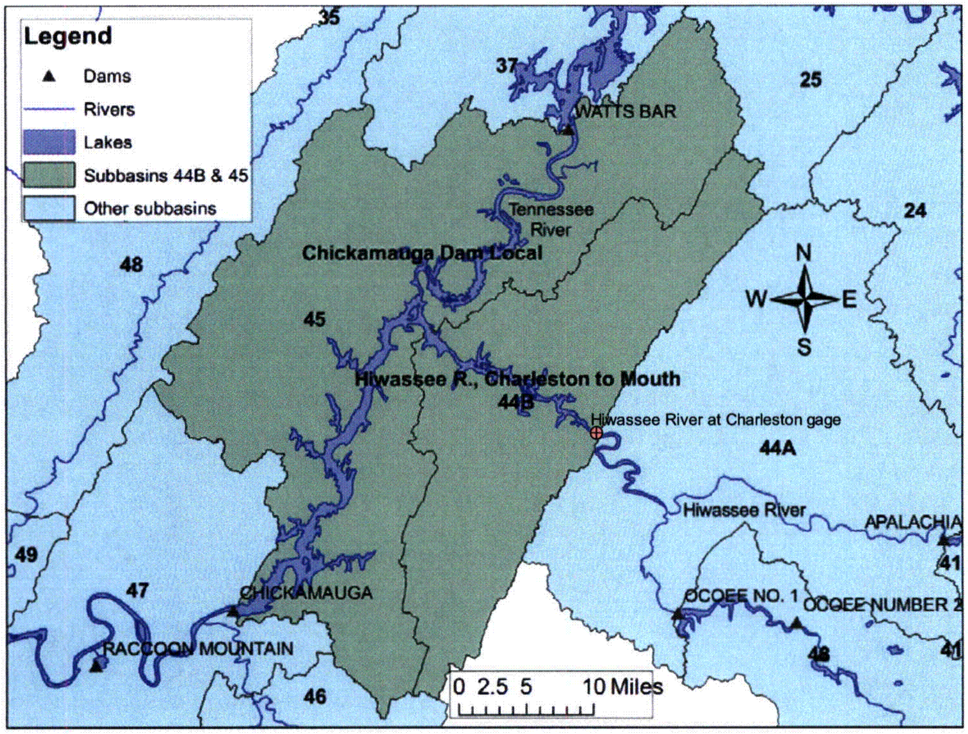
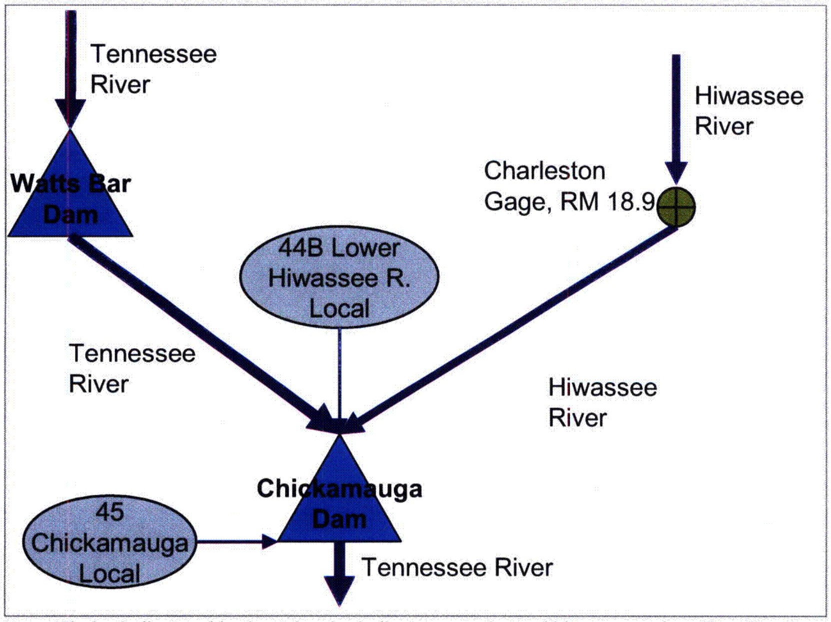


Figure 3: Schematic of Subbasins 44B and 45.



Note: Circles indicate subbasins, triangles indicate reservoirs, and blue arrows show flow directions of rivers.

The flows of the Hiwassee and Tennessee Rivers in Subbasins 44B and 45 are affected by multiple upstream dams. In addition, due to backwater effects, reverse flows at Charleston have occurred for short periods in each year since closure of Chickamauga Dam downstream on the Tennessee River in 1939 (Reference 8).

The drainage areas of Subbasins 44B and 45 are shown in Table 1 (Reference 2, 3, and 7).

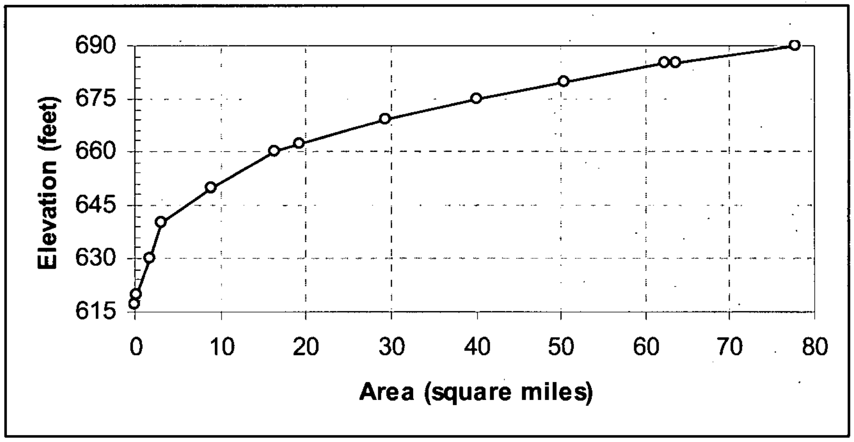
Table 1: Subbasin Drainage Areas.

Subbasin	44B	45	Sum
Original TVA estimate	402	780	1,182
Calculated using GIS	396.0	792.1	1,188.1
Difference (%)	-1.5%	1.6%	0.5%

Table 1 shows that the GIS calculated areas agree closely with the TVA's original estimates. In this calculation, the GIS drainage areas were used.

The Chickamauga Reservoir elevation-area table was obtained from Reference 9 and is plotted in Figure 4. It may be seen from this figure that the reservoir covers approximately 8% of Subbasin 45 when the water surface approaches an elevation of 685.44 feet (top of gates). The elevation-area data were used to compute the additional reservoir runoff from the March 1973 and May 2003 floods (Section 7.3.3).

Figure 4: Chickamauga Reservoir Elevation-Area Curve.



6.2 *Unit Hydrograph Ordinates*

The unit hydrographs for Subbasins 44B and 45 are plotted in Figure 5 and Figure 6. The time base and ordinates for the unit hydrographs are provided in Table 2 and Table 3, along with volume checks demonstrating that the total volumes of runoff are equivalent to one inch of excess rainfall over the subbasins. The unit hydrograph discharges are specified in units of cubic feet per second (cfs). The unit hydrographs for Subbasins 44B and 45 are also provided on the "UHs" worksheet in Attachment 1-1.

The Subbasin 44B unit hydrograph was developed in 2008 as a synthetic unit hydrograph by the TVA (Reference 2).

Figure 5: Six-Hour Unit Hydrograph for Subbasin 44B, Hiwassee River Local, Mouth to Charleston.

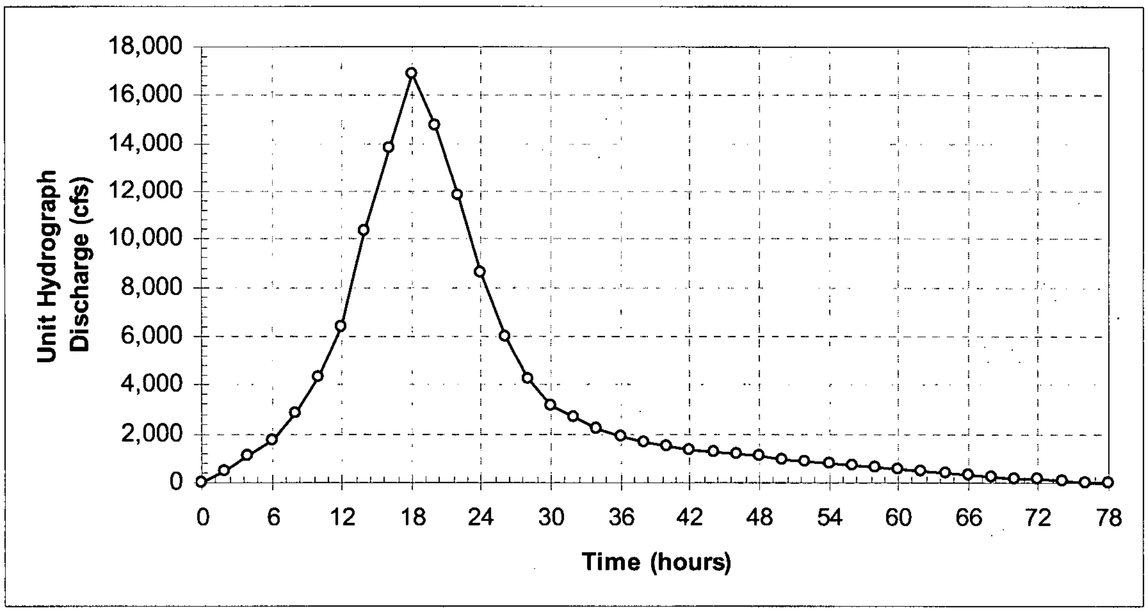


Table 2: Six-Hour Unit Hydrograph for Subbasin 44B, Hiwassee River Local, Mouth to Charleston.

Ordinate no.	*t*, hours	*Q*, cfs
1	0	0
2	2	493
3	4	1,084
4	6	1,773
5	8	2,857
6	10	4,334
7	12	6,403
8	14	10,344
9	16	13,791
10	18	16,870
11	20	14,777
12	22	11,821
13	24	8,570
14	26	6,009
15	28	4,236
16	30	3,152
17	32	2,660
18	34	2,216
19	36	1,872
20	38	1,675
21	40	1,527
22	42	1,379
23	44	1,281
24	46	1,182
25	48	1,084
26	50	985
27	52	896
28	54	808
29	56	719
30	58	640
31	60	562
32	62	483
33	64	404
34	66	335
35	68	266
36	70	197
37	72	128
38	74	59
39	76	20
40	78	0
Volume, acre-feet (1)		21,139
Drainage Area (sq. miles)		396.0
Runoff depth, inches (2)		1.0009

Notes:

1) $$Volume = \sum_{i=1}^{no.ordinates} Q_i \tfrac{ft^3}{sec} \times 3600 \tfrac{sec}{hr} \times \Delta t(hours) \times \frac{1acft}{43560\,ft^3}$$

2) $$Depth = \frac{Volume.acft}{Area.mi^2} \frac{mi^2}{640.acre} \frac{12.inch}{ft}$$

The TVA developed the Subbasin 45 unit hydrograph from the flood of March 16, 1973 and verified its performance on the flood of March 12, 1963 (Reference 3). The flood hydrographs for the local area (Subbasin 45) used in the unit hydrograph development were determined using the SOCH model. Single unit hydrographs were computed by the TVA for each of the two floods and a composite unit hydrograph was computed using both floods. The unit hydrograph developed from the 1973 flood was adopted by the TVA because the composite results were not satisfactory and it gave a little better duplication of the two floods than the unit hydrograph developed from the 1963 flood (Reference 3).

The six-hour unit hydrograph for Subbasin 45 was developed using the UNITGRPH program (Reference 4). The TVA smoothed the unit hydrograph and interpolated to obtain tri-hourly discharge ordinates. The TVA inputs for the UNITGRPH program for Subbasin 45 were obtained from Reference 3 and were rerun using the revised 2008 version UNITGRPH program to verify the existing TVA unit hydrograph, which was developed in 1977. Attachments 2-1 to 2-3 provide the input and output files for this verification. The TVA's original unit hydrograph for Subbasin 45, shown in Figure 6 and Table 3, is used in this calculation.

Figure 6: Six-Hour Unit Hydrograph for Subbasin 45, Chickamauga Dam Local.

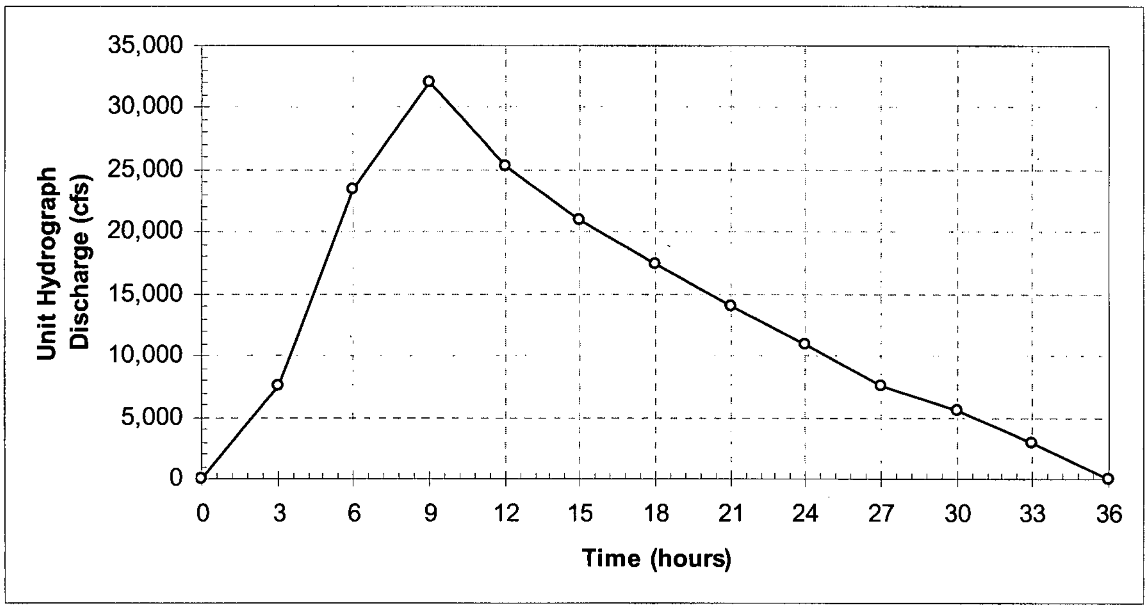


Table 3: Six-Hour Unit Hydrograph for Subbasin 45, the Chickamauga Dam Local.

Ordinate no.	*t*, hours	Q, cfs
1	0	0
2	3	7,500
3	6	23,500
4	9	32,000
5	12	25,250
6	15	21,000
7	18	17,500
8	21	14,000
9	24	11,000
10	27	7,500
11	30	5,500
12	33	2,900
13	36	0
Volume, acre-feet (1)		41,566
Drainage Area (sq. miles)		792.1
Runoff depth, inches (2)		0.9839

See notes 1 and 2 at the bottom of Table 2.

6.3 Observed Discharge and Storage

The daily discharge record at U.S. Geological Survey (USGS) gage 03566000 Hiwassee River at Charleston, Tennessee was obtained from the USGS (Reference 10; Attachment 1-2). The observed daily outflows from Watts Bar Dam and the observed daily storage and discharges at Chickamauga Dam were obtained from the TVA databases (Attachments 1-3 and 1-4; Reference 11). These observed flows were used in the water budget analysis, which is presented in Section 7.3.

6.4 Observed Rainfall

Two sources of observed rainfall data were used in this calculation: TVA rain gage data with Thiessen weights were used to simulate the March 1973 flood, and gridded precipitation data from the U.S. National Weather Service (NWS) were used to simulate the May 2003 flood. The TVA rainfall data are presented in Reference 12. The NWS gridded precipitation data (Reference 13) are discussed in this section.

Radar-based, geospatially referenced precipitation data is extremely useful for hydrologic analysis because of its comprehensive spatial and temporal detail. Gridded daily precipitation data are available at http://water.weather.gov/ from 2005 to present. Hourly precipitation data are not generally available without special arrangements with the National Weather Service (NWS).

NWS NEXRAD Stage III hourly precipitation data were obtained from the Lower Mississippi River Forecast Center (LMRFC) from January 1997 to April 2008. A Microsoft.Net utility was developed to generate radar-based Mean Areal Precipitation (MAPX) time series for each of the subbasins (Reference 13). The utility reads the raw hourly precipitation depth data for each 4-km square grid cell, performs necessary coordinate system and projection calculations, and then calculates the average precipitation depth within each subbasin, grouping output into a matrix of MAPX elements arrayed by subbasin and time (Greenwich Mean Time, GMT). Each column of this matrix is equivalent to an annual hyetograph for each subbasin in the TVA model. The results are stored in an Excel spreadsheet for each year of record. Reference 13 describes the methodology used to process the precipitation data and includes resulting subbasin-averaged hourly values for the January 1997 to April 2008 period of record. The precipitation data needed to simulate the May 2003 flood were obtained from this database.

7 Computations and Analyses

7.1 Floods for Unit Hydrograph Validation

As mentioned above, the March 1973 and May 2003 floods have been selected for analysis by the SOCH model. In Subbasins 44B and 45, the storms generating these floods spanned the following times:

- March 15, 1973, 06:00 hrs to March 17, 1973, 00:00 hrs, the "March 1973" storm
- May 5, 2003, 06:00 hrs to May 7, 2003, 18:00 hrs, the "May 2003" storm

7.2 Observed Rainfall

Observed rainfall for the March 1973 and May 2003 storms were obtained from References 12 and 13. The hourly precipitation series developed from NWS gridded data for the May 2003 storm is provided in Attachment 1-5, along with adjustments for Central time and unit conversion. The March 1973 rainfall data are shown in the "1973 Rainfall" and "1973 Reservoir" worksheets in Attachment 1-1.

7.3 Water Budget Analysis

A daily water budget analysis was performed to determine the daily runoff from Subbasins 44B and 45 for the March 1973 and May 2003 floods. Baseflows were subtracted from the flood flows to obtain direct runoff hydrographs for these floods. Finally, reservoir runoff series were also developed to account for the quick response at Chickamauga Dam due to rain falling on the Chickamauga Reservoir water surface. These operations are discussed in the following subsections.

7.3.1 Flood Volumes

The water budget analysis consists of solving the continuity equation for the water budget area (Subbasins 44B and 45), which can be stated in discrete form as (Reference 6):

$$L = O + \frac{dS}{dt} - I, \tag{1}$$

where L is the local inflow from Subbasins 44B and 45, O is the outflow from Chickamauga Dam, and I is the inflow from Watts Bar Dam and from the Hiwassee River at Charleston, all averaged over the time interval *dt*, which in the case of this calculation is one day. The parameter dS/dt indicates the change in reservoir storage over the time interval *dt*.

The resulting daily water budgets for the March 1973 and May 2003 floods are shown in Table 4 and Table 5. The water budget analyses are included in Attachment 1-6.

Table 4: Daily Water Budget for the March 1973 Flood.

	Hiwassee River at Charleston	Watts Bar Dam Discharge	Chickamauga Dam			Local Runoff
			End-of-day Storage	Change in Storage	Discharge	
	I		*S*	ΔS	*O*	*L*
Date	cfs	cfs	1,000 dsf[1]	cfs	cfs	cfs
13-Mar-1973			221.5			
14-Mar-1973	5,500	21,400	221.1	-330	28,500	1,270
15-Mar-1973	6,320	35,200	238.3	17,130	41,000	16,610
16-Mar-1973	31,000	114,700	379.5	141,190	116,700	112,190
17-Mar-1973	54,000	180,400	435.2	55,730	215,900	37,230
18-Mar-1973	38,000	134,000	389.9	-45,330	219,000	1,670
19-Mar-1973	21,000	96,100	323.0	-66,870	182,900	-1,070

Table 5: Daily Water Budget for the May 2003 Flood.

	Hiwassee River at Charleston	Watts Bar Dam Discharge	Chickamauga Dam			Local Runoff
			End-of-day Storage	Change in Storage	Discharge	
	I		*S*	ΔS	*O*	*L*
Date	cfs	cfs	1,000 dsf	cfs	cfs	cfs
3-May-2003			312.7			
4-May-2003	2,500	8,700	302.1	-10,570	22,521	748
5-May-2003	3,920	25,354	346.8	44,620	42,149	57,498
6-May-2003	37,700	87,227	407.6	60,790	142,194	78,053
7-May-2003	62,700	134,632	425.8	18,200	213,404	34,270
8-May-2003	58,200	139,700	417.6	-8,150	214,906	8,856
9-May-2003	38,300	139,724	402.7	-14,950	200,276	7,299
10-May-2003	16,900	120,930	366.9	-35,750	173,781	204

7.3.2 Baseflows

Baseflows were subtracted from the flood flows to obtain direct runoff hydrographs for the March 1973 and May 2003 floods.

[1] A dsf is defined as the volume of water resulting from a flow of 1 cfs for one day (86,400 seconds). This is equal to 86,400 cubic feet of water, or about 1.9835 acre-feet.

The daily baseflows were estimated by linearly interpolating between the daily local flows preceding and following the floods. Due to the noisiness of the calculated daily local flows, further refinement of the baseflows beyond these simple estimates was deemed impractical. The baseflow separation computations and resulting daily local direct runoff values are shown in Table 6 and Table 7.

Table 6: Baseflow Separation for the March 1973 Flood.

Date	Local runoff *L* cfs	Baseflow cfs	Local direct runoff cfs
14-Mar-1973	1,270	1,270	0
15-Mar-1973	16,610	1,370	15,240
16-Mar-1973	112,190	1,470	110,720
17-Mar-1973	37,230	1,570	35,660
18-Mar-1973	1,670	1,670	0
		Volume, ac-ft	320,569
		Depth, inches	**5.059**

Table 7: Baseflow Separation for the May 2003 Flood.

Date	Local runoff *L* cfs	Baseflow cfs	Local direct runoff cfs
4-May-2003	748	748	0
5-May-2003	57,498	657	56,841
6-May-2003	78,053	567	77,486
7-May-2003	34,270	476	33,794
8-May-2003	8,856	385	8,471
9-May-2003	7,299	295	7,004
10-May-2003	204	204	0
		Volume, ac-ft	364,157
		Depth, inches	**5.747**

The resulting local direct runoff amounts for the March 1973 and May 2003 floods are equivalent to depths of 5.059 inches and 5.747 inches, respectively, over the 1,188.1 mi^2 water budget area. These depths were calculated using the expressions shown beneath Table 2. The local direct runoff depths represent the basin-wide average excess rainfall, P_{eff}, that resulted from the March 1973 and May 2003 storms respectively, over Subbasins 44B and 45. The baseflow separation calculations are shown in Attachment 1-6.

Due to the uncertain nature of the daily baseflow estimates, no attempt was made to disaggregate them into sub-daily values. Rather, the daily values are reported for each hour. The baseflows were distributed to Subbasins 44B and 45 in proportion to their drainage areas.

7.3.3 Additional Reservoir Runoff

The calculated water budgets for the March 1973 and May 2003 floods provide total volumes of direct runoff originating from the combined area of Subbasins 44B and 45. Because the water budgets were calculated using a mass balance approach that considers all inflows, outflows, and changes in storage, they implicitly include direct runoff from rain falling on the Chickamauga Reservoir water surface. The reservoir runoff would result in a nearly instant response at the basin outlet, due to the absence of any overland flow or stream channel travel time and would be equal to the rain falling on the reservoir. The reservoir runoff volume considered in the unit hydrograph convolution is the excess rainfall determined for the total basin. Therefore, the remaining rainfall on the reservoir, over and above that computed in the unit hydrograph convolution, must be considered. This "additional" reservoir runoff was computed separately for the March 1973 and May 2003 floods.

The depth of additional reservoir runoff, P_{RRO}, considered in this computation is equal to the difference between the rainfall depth on the reservoir and the basin-wide excess rainfall depth, shown in Table 6 and Table 7. The rainfall depth on the reservoir was obtained from Reference 12 for the March 1973 storm and from the NWS gridded precipitation for the May 2003 storm. The volume of additional reservoir runoff is equal to the product of P_{RRO} and the surface area of Chickamauga Reservoir, which was determined based on the reservoir elevation data and the relationship shown in Figure 4.

The additional reservoir runoff volume calculations are shown in Section 7.4.1 and in Attachment 1-6. The resulting hourly runoff series are shown in the "2003 Reservoir" and "1973 Reservoir" worksheets in Attachment 1-1.

7.4 Excess Rainfall Hyetographs

The excess rainfall hyetograph is the input to the basin model that is converted into direct runoff at the basin outlet via convolution with the unit hydrograph. This is developed from the observed rainfall hyetograph by the application of a loss rate function which accounts for the hydrologic abstractions of evaporation and transpiration, interception, depression storage, and infiltration (Reference 5). Excess rainfall is also known as "runoff" or "effective rainfall;" all three terms refer to the same quantity.

The TVA uses the FLDHYDRO computer program (Reference 4) to estimate excess precipitation from a given rain storm for use with the UH for runoff prediction. Reference 4 provides detailed information concerning the operation of the FLDHYDRO program. The TVA created this program to implement the Antecedent Precipitation Index (API)/Runoff Index (RI) methodology developed by the United States Weather Bureau (USWB) and described in Reference 14. In this method, antecedent precipitation data are used to define the basin state at the beginning of the storm through the API. Seasonal, empirical relationships (the RI component) are employed to account for expected seasonal variation in runoff resulting from observed seasonal variations in evapotranspiration.

7.4.1 FLDHYDRO Operation

The excess rainfall hyetographs for Subbasins 44B and 45 were computed for the March 1973 and May 2003 storms using the FLDHYDRO program and the available rainfall data. Several steps were performed to determine the depth of additional reservoir runoff, P_{RRO}, and to adjust the excess rainfall depths to account for the inclusion of P_{RRO} in the water balance. These steps are described below and the corresponding results are shown in Table 8.

1. The excess rainfall depths, P_{eff}, were obtained from Table 6 and Table 7. These are 5.059 inches for the March 1973 storm and 5.747 inches for the May 2003 storm.
2. The P_{eff} values were input as CHKVOL values to FLDHYDRO, which was run for each storm (March 1973 and May 2003) to obtain preliminary excess rainfall predictions. The resulting predicted area weighted average excess rainfall depths for these storms are 5.063 and 5.767 inches for the March 1973 and May 2003 storms, respectively. The FLDHYDRO input and output files for these preliminary runs are included as electronic Attachments 3-1 to 3-4.
3. The additional reservoir runoff, P_{RRO}, was estimated for each flood as the difference between the rainfall on Chickamauga Reservoir (shown in Table 8), and the predicted excess rainfall depths. For March 1973, this yields $P_{RRO} = 7.19 - 5.06 = 2.13$; for May 2003, it is $P_{RRO} = 9.64 - 5.77 = 3.87$ (note: 9.64 and 5.77 are the weighted-average NWS gridded rainfall and estimated excess rainfall depths for the May 2003 storm in Subbasins 44B and 45). The reservoir area of 55.44 square miles shown in Table 8 is an approximate value used only for this water budget estimation; in calculating the additional reservoir runoff series, the area varies in time according to the reservoir elevation data.
4. These P_{RRO} values were distributed across the 1,188.1 mi^2 water budget area and subtracted from the water budget depths (Step 1) to obtain adjusted CHKVOL values of 4.960 and 5.566 inches for the March 1973 and May 2003 storms, respectively.
5. The FLDHYDRO program was re-run using the adjusted CHKVOL values from Step 4. The revised FLDHYDRO results and the P_{RRO} values from Step 3 were area-weighted across the water budget area and compared with the initial water budget values from Step 1. The FLDHYDRO input and output files for these final runs are included as Attachments 3-5 to 3-8.
6. The initial P_{RRO} values from Step 4 were revised based on the revised excess rainfall results from Step 5.

Table 8: Steps Used to Determine CHKVOL Values and Reservoir Runoff Depths.

Step	Storm / Flood	March 1973				May 2003			
	Subbasin	44B	45	reservoir	44B+45	44B	45	reservoir	44B+45
	Area, mi^2	396.0	792.1	55.44	1,188.1	396.0	792.1	55.44	1,188.1
	Rainfall, in.	7.97	7.07	7.19		9.84	9.54	9.64	
1	CHKVOL from water budget, in.				5.059				5.747
2	Initial FLDHYDRO runoff, in.	5.63	4.78		5.063	6.08	5.61		5.767
3	P_{RRO}, or reservoir runoff, in.			2.13	0.099			3.87	0.181
4	Adjusted CHKVOL, in.				4.960				5.566
5	Revised FLDHYDRO runoff, in.	5.46	4.61		4.893	5.91	5.44		5.597
6	Revised P_{RRO}, in.			2.30	0.107			4.04	0.189
Sum of results from Steps 5 and 6					5.000				5.785

Following the above water budget analysis, the Chickamauga Reservoir additional runoff series were computed. For the March 1973 storm, the reservoir runoff was computed using FLDHYDRO with an input CHKVOL value of 4.960 inches (from Step 4). For the May 2003 storm, the reservoir runoff was obtained by area-weighting the rainfall and excess rainfall results for Subbasins 44B and 45 that FLDHYDRO produced in Step 5. The methods used for the two floods were not the same because rainfall data that is specific to Chickamauga Reservoir is available for the March 1973 storm, but not for the May 2003 storm. In both cases, the hourly reservoir runoff was set equal to the hourly difference between the rainfall and the excess rainfall. The reservoir surface area was varied hourly according to the water surface elevation and the elevation-area relationship shown in Figure 4. The FLDHYDRO input and output files for the March 1973 reservoir runoff computation are included as Attachments 3-9 and 3-10.

7.4.2 FLDHYDRO Results

Figure 7 to Figure 10 provide plots of the FLDHYDRO results for the March 1973 and May 2003 storms in Subbasins 44B and 45. The sum of the hourly losses and hourly runoff values shown in these figures is equal to the hourly rainfall depths that were input to FLDHYDRO. It may be seen from these figures that the percentage of rainfall that becomes runoff tends to increase over the course of each storm. The FLDHYDRO results are also shown on the"1973 Rainfall" and "2003 Rainfall" tabs in Attachment 1-1.

Figure 7: FLDHYDRO Calculated Hourly Rainfall Losses and Runoff for the March 1973 Storm in Subbasin 44B.

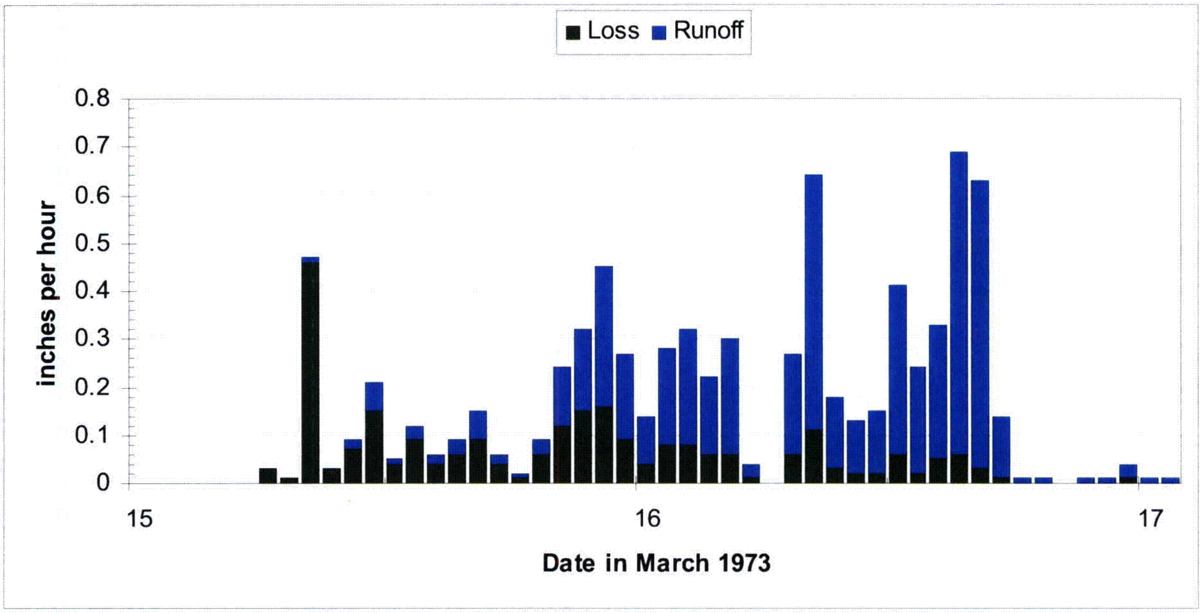


Figure 8: FLDHYDRO Calculated Hourly Rainfall Losses and Runoff for the March 1973 Storm in Subbasin 45.

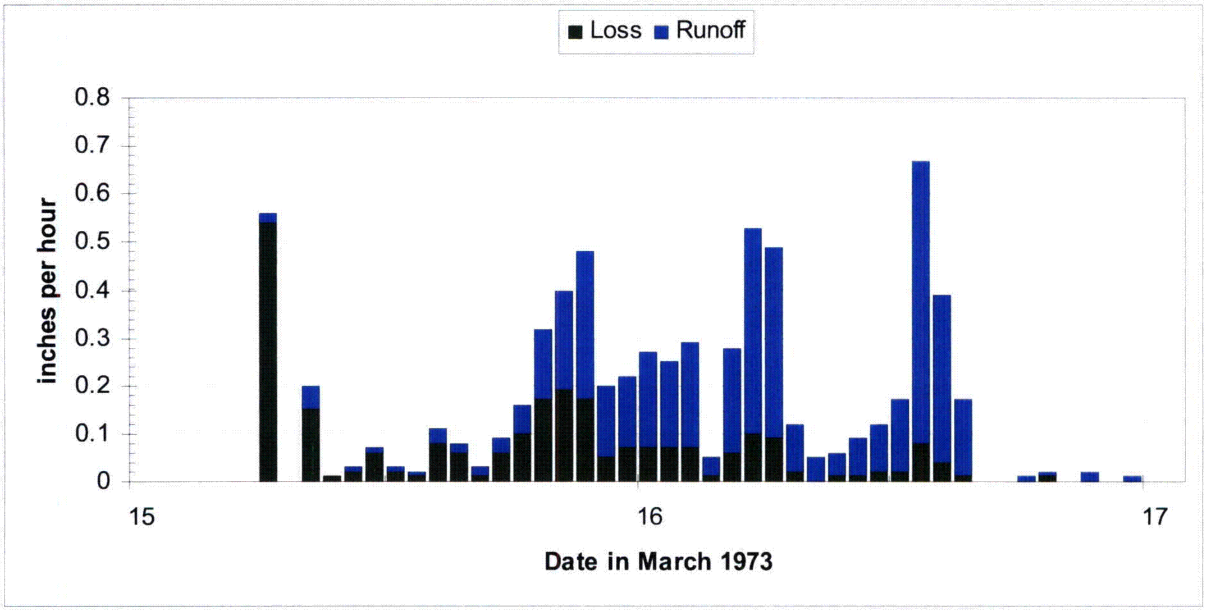


Figure 9: FLDHYDRO Calculated Hourly Rainfall Losses and Runoff for the May 2003 Storm in Subbasin 44B.

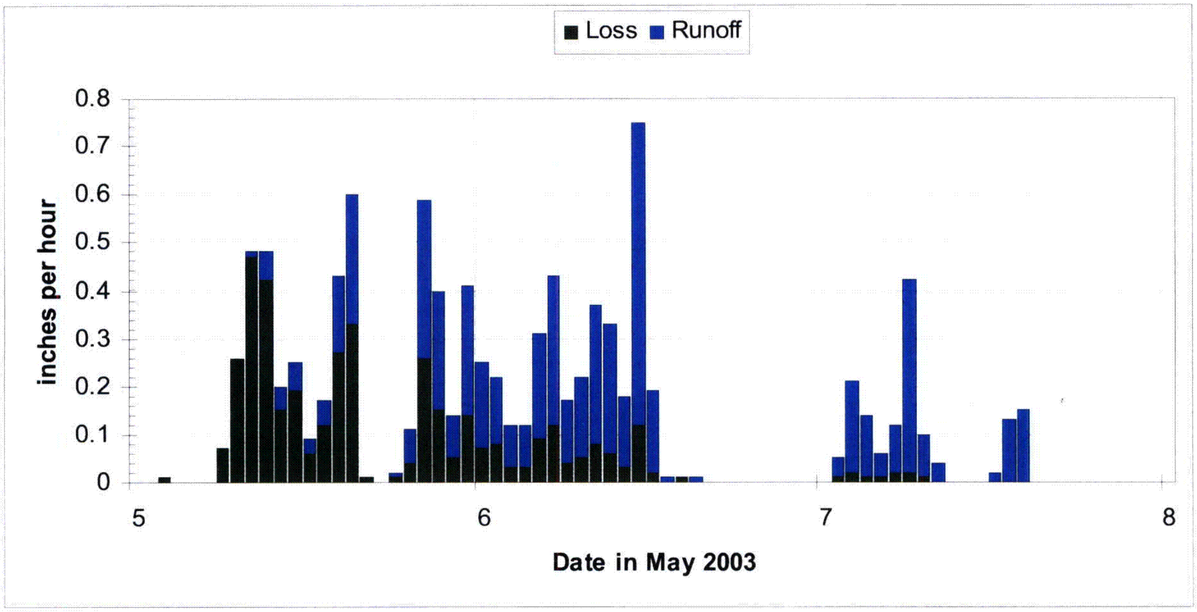
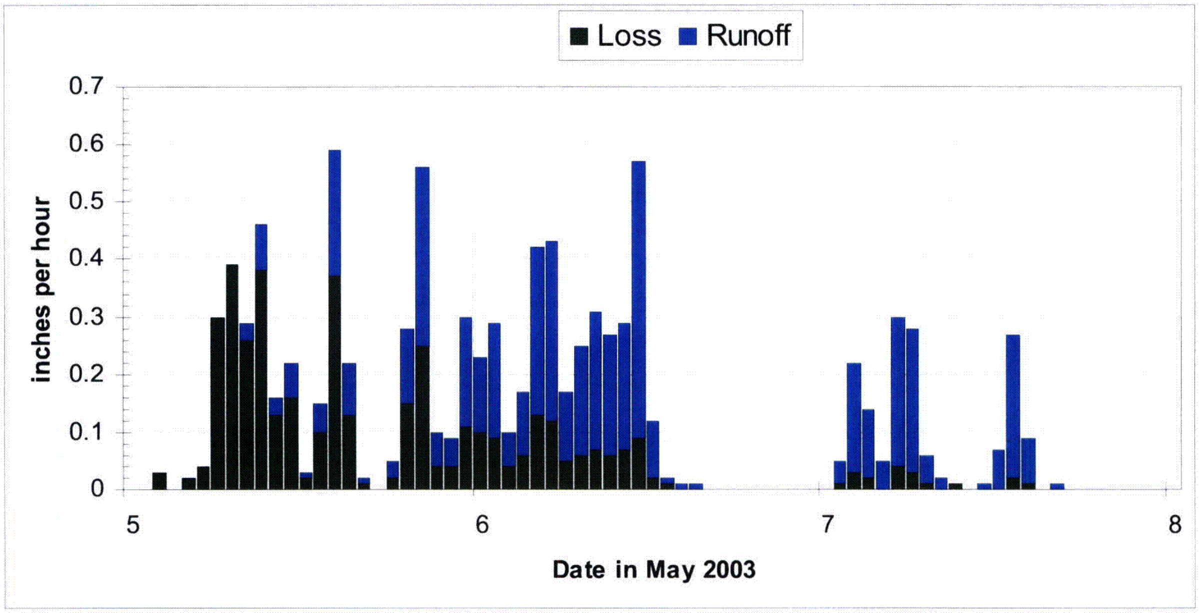


Figure 10: FLDHYDRO Calculated Hourly Rainfall Losses and Runoff for the May 2003 Storm in Subbasin 45.



The hourly excess rainfall series shown in Figure 7 to Figure 10 were aggregated to six-hour values for use in the unit hydrograph convolutions.

7.5 Direct Runoff and Baseflow Hydrographs

The unit hydrographs for Subbasins 44B and 45 were convoluted with the six-hour excess rainfall series to obtain the initial direct runoff hydrographs from these subbasins for the March 1973 and May 2003 floods. The resulting initial direct runoff hydrographs, as well as the baseflow hydrographs from Section 7.3.2, are plotted in Figure 11 to Figure 14.

Figure 11: Direct Runoff and Baseflow Hydrographs from Subbasin 44B, Hiwassee River at Mouth, for the March 1973 Flood.

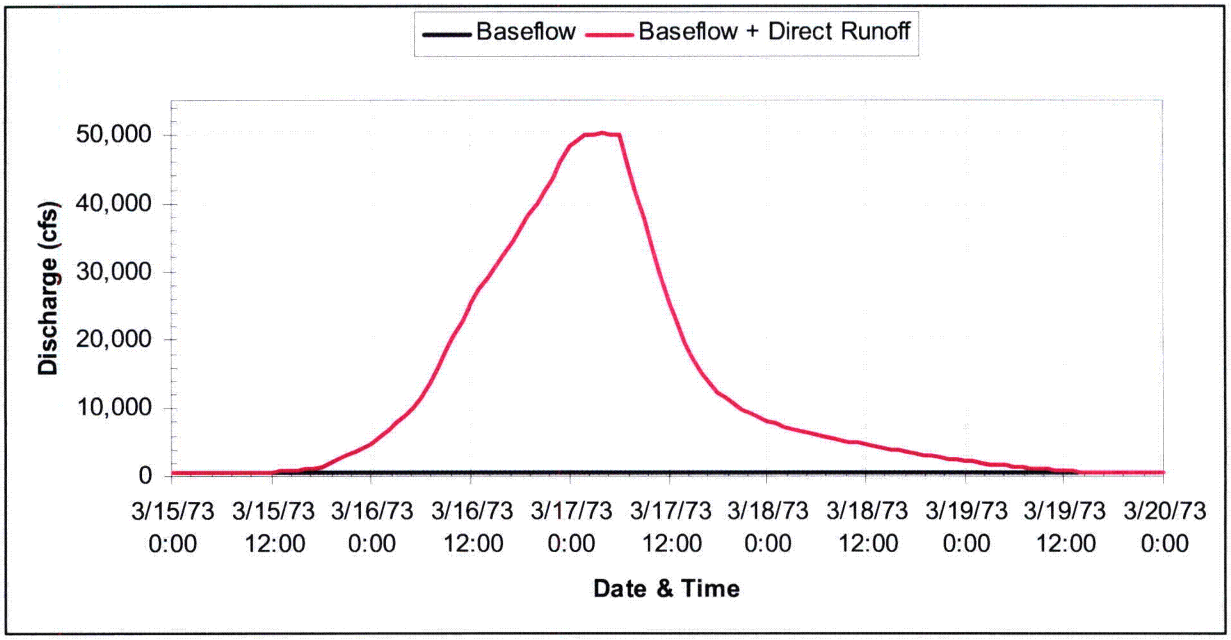


Figure 12: Direct Runoff and Baseflow Hydrographs from Subbasin 45, Chickamauga Dam Local, for the March 1973 Flood.

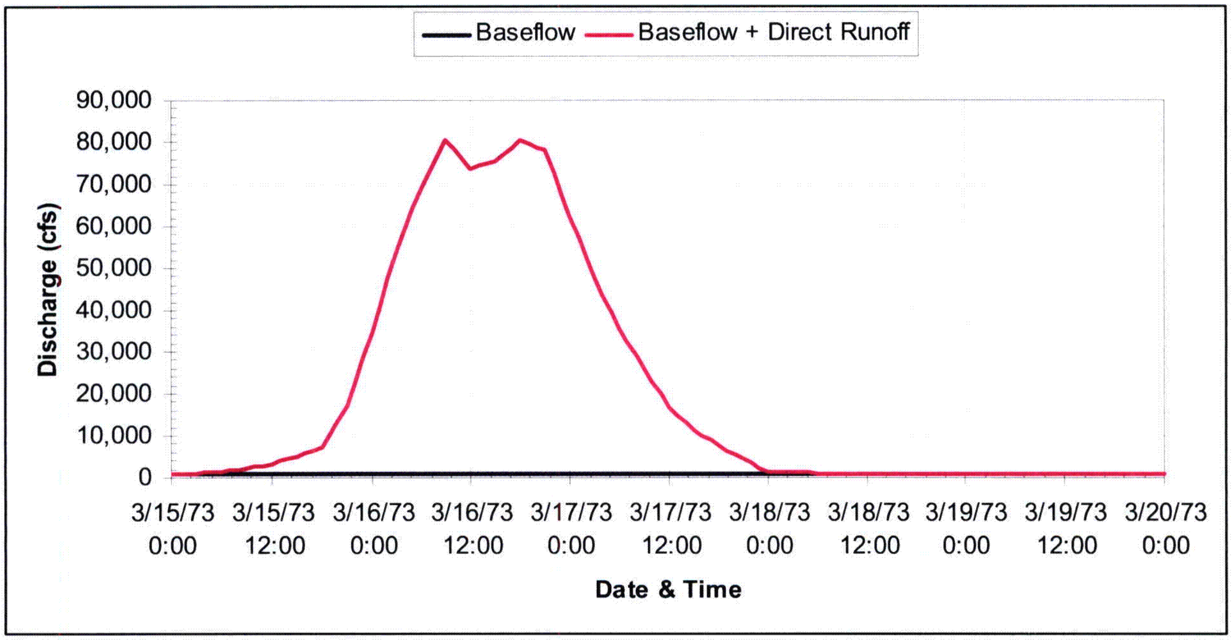


Figure 13: Direct Runoff and Baseflow Hydrographs from Subbasin 44B, Hiwassee River at Mouth, for the May 2003 Flood.

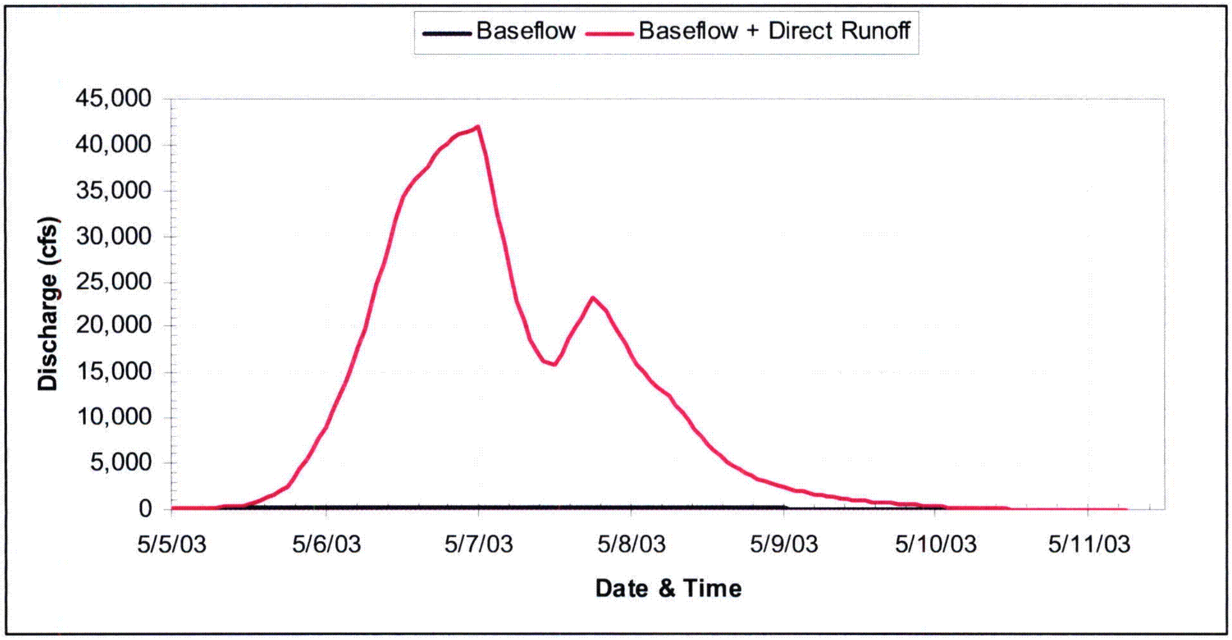
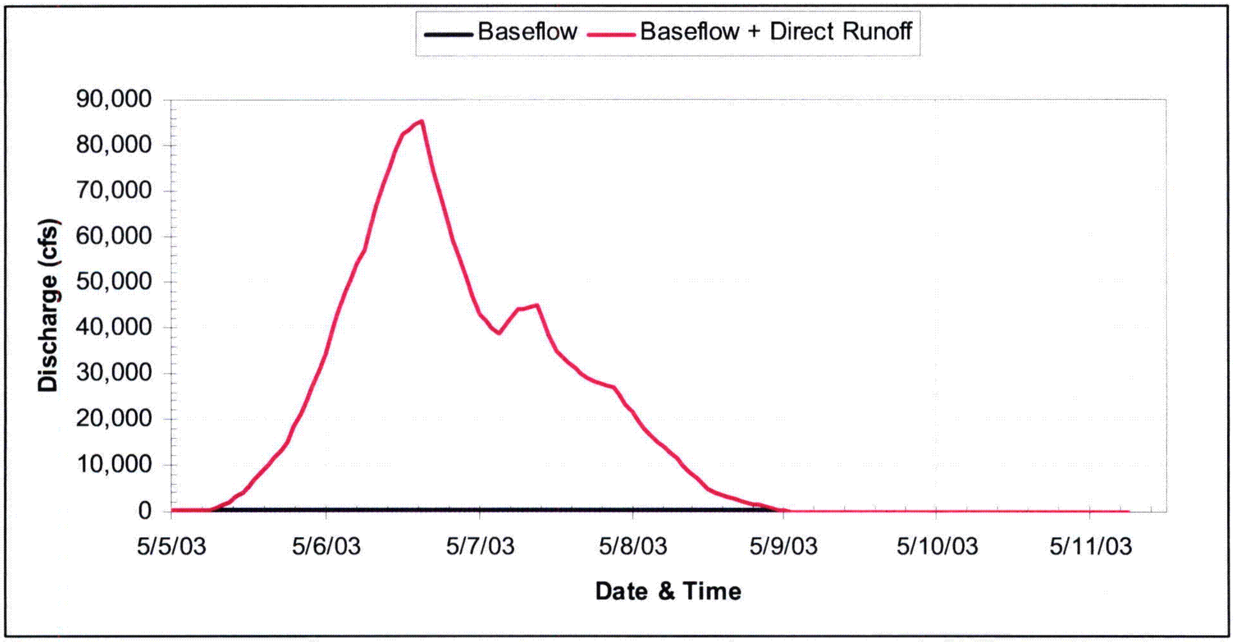


Figure 14: Direct Runoff and Baseflow Hydrographs from Subbasin 45, Chickamauga Dam Local, for the May 2003 Flood.



The unit hydrograph convolutions were performed in an Excel spreadsheet; calculations and resulting hydrographs are in the "1973 Convolutions" and "2003 Convolutions" tabs in Attachment 1-1. Mass balance checks of the simulated runoff volumes resulting from the unit hydrograph convolutions are summarized in Table 9. This table indicates that the simulated runoff resulting from the convolutions consistently underestimates the input excess rainfall by 1.6% in Subbasin 45. The reason for this small discrepancy is due to the GIS drainage area of 792.1 square miles, which is slightly larger than the original area estimate of 780 square miles for which the unit hydrograph was derived.

Table 9: Volume Checks for the Unit Hydrograph Convolution Results.

Subbasin	44B	45	Total
Area, mi^2	396.0	792.1	1,188.1
March 1973 flood:			
Excess Rainfall, in.	5.45	4.61	4.890
Simulated Runoff, in.	5.455	4.536	4.842
Difference, %	0.1%	-1.6%	-1.0%
May 2003 flood:			
Excess Rainfall, in.	5.91	5.44	5.597
Simulated Runoff, in.	5.915	5.353	5.540
Difference, %	0.1%	-1.6%	-1.0%

7.6 Additional Reservoir Runoff Hydrographs

The computed initial additional runoff hydrographs from Chickamauga Reservoir are shown in Figure 15 and Figure 16. These runoff series were determined using the methods described in Section 7.3.3 and at the end of Section 7.4.1.

Figure 15: Additional Chickamauga Reservoir Runoff from the March 1973 Flood.

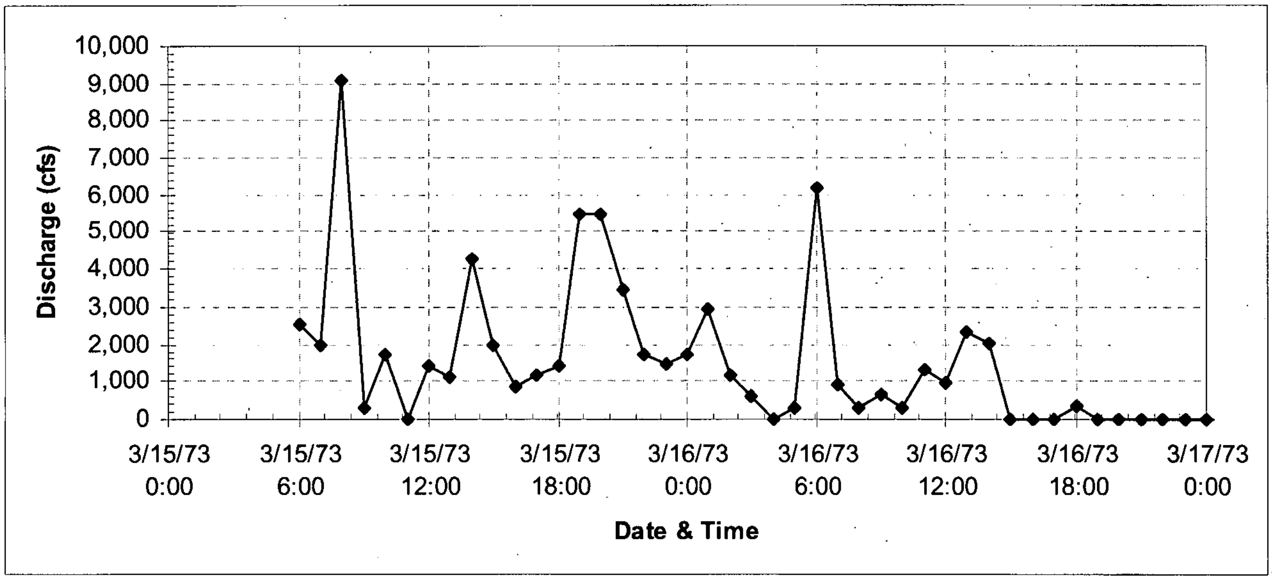
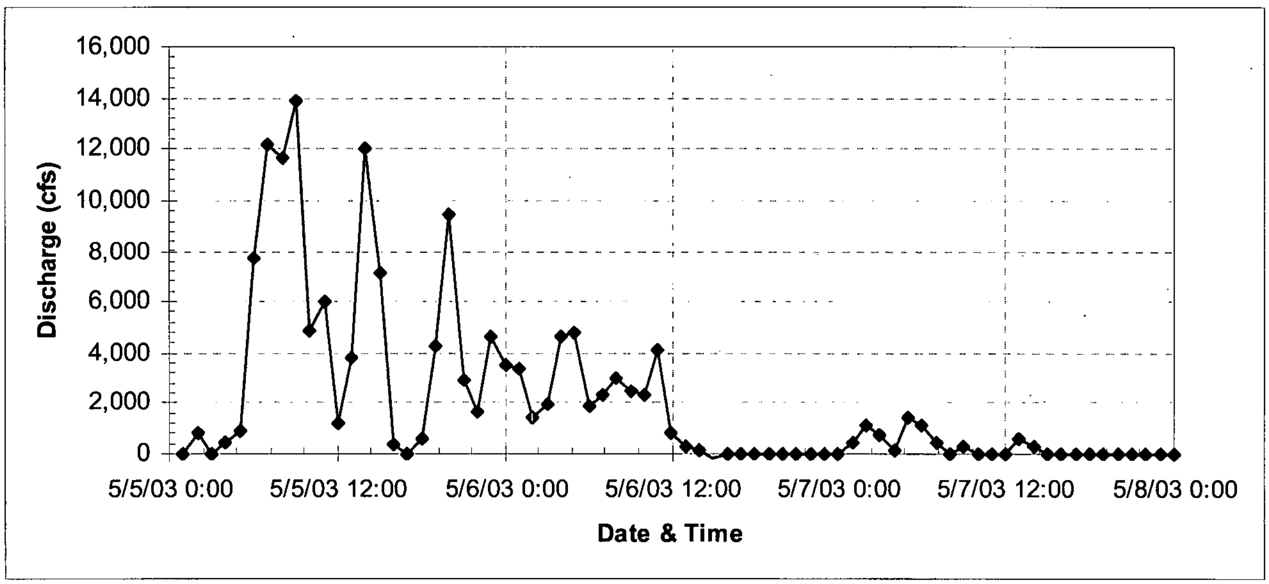


Figure 16: Additonal Chickamauga Reservoir Runoff from the May 2003 Flood.



The initial additional reservoir runoff calculations are presented in the "1973 Reservoir" and "2003 Reservoir" worksheets in Attachment 1-1.

7.7 SOCH Model Input

Four time series were provided for use in the SOCH models for the March 1973 and the May 2003 validation runs. These inputs are as follows:

- Total direct runoff for Subbasin 44B,
- Total direct runoff for Subbasin 45,
- Losses and runoff for Subbasin 44B,
- Losses and runoff for Subbasin 45.

The time series were developed in spreadsheets in Attachment 1-1. Plots of the component time series are provided as Figures 7 through 14 in Sections 7.4 and 7.5.

7.8 SOCH Model Output and Unit Hydrograph Validation

The component time series presented in Sections 7.4 and 7.5 of this calculation were used as inputs to a SOCH model of the reach of the Tennessee River between Watts Bar and Chickamauga Dams. Additional inputs to the model include observed discharge series for the Hiwassee River and outflow from Watts Bar Dam as upstream boundary conditions. (See Figure 3.)

For the March 1973 event, simulated and observed water surface elevations were compared at three gage locations: TRM 485.2, 523.2, and 529.9. For the May 2003 event, simulated and observed water surface elevations were compared at two gage locations: TRM 484.7 and 529.9. Observed stages were included at TRM 471.0 for reference. Simulated and observed discharges were compared at TRM 471.0 for both historic floods.

As described in Calculation CDQ000020080039 Rev 0 (Reference 15), local inflows to Chickamauga Reservoir from Subbasin 45 and to the Hiwassee River from Subbasin 44B were combined with the observed data (Watts Bar observed discharge and tailwater elevation, Chickamauga observed discharge and headwater elevation, and the Hiwassee River observed discharge) for the March 1973 and May 2003 events and conservatively reproduced the observed elevations at gage locations along the reservoir for the historic floods. These comparisons are shown in Figures 17 through 20. As a result, the unit hydrographs developed for basins 44B and 45 were validated and deemed adequate for use in developing flood inflows for other events, including PMF. Data and simulation results for the aforementioned figures are provided in Attachments 4-1 and 4-2.

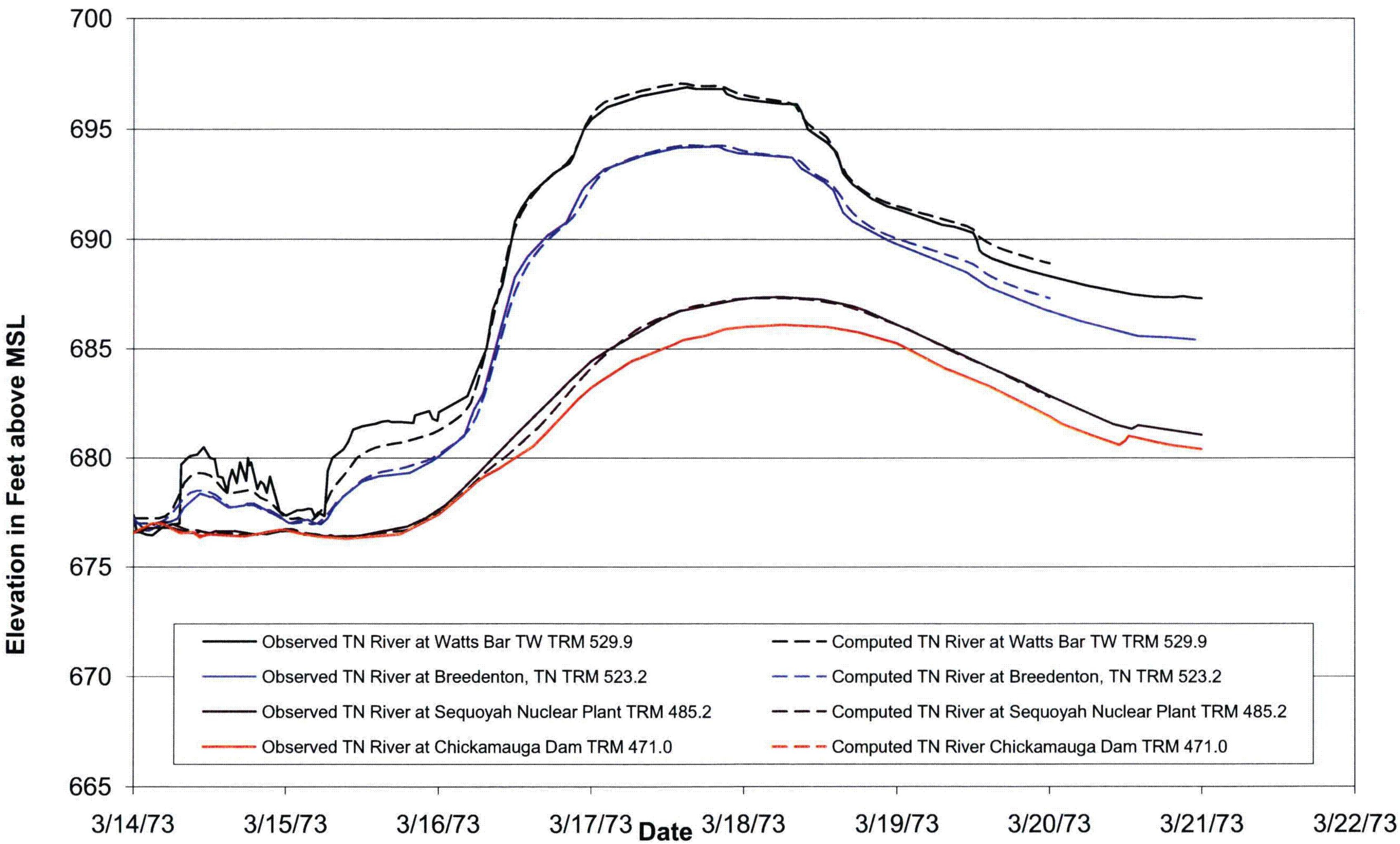


Figure 17: Observed and Simulated Stage Hydrographs for the Tennessee River between Watts Bar and Chickamauga Dams, March 1973.

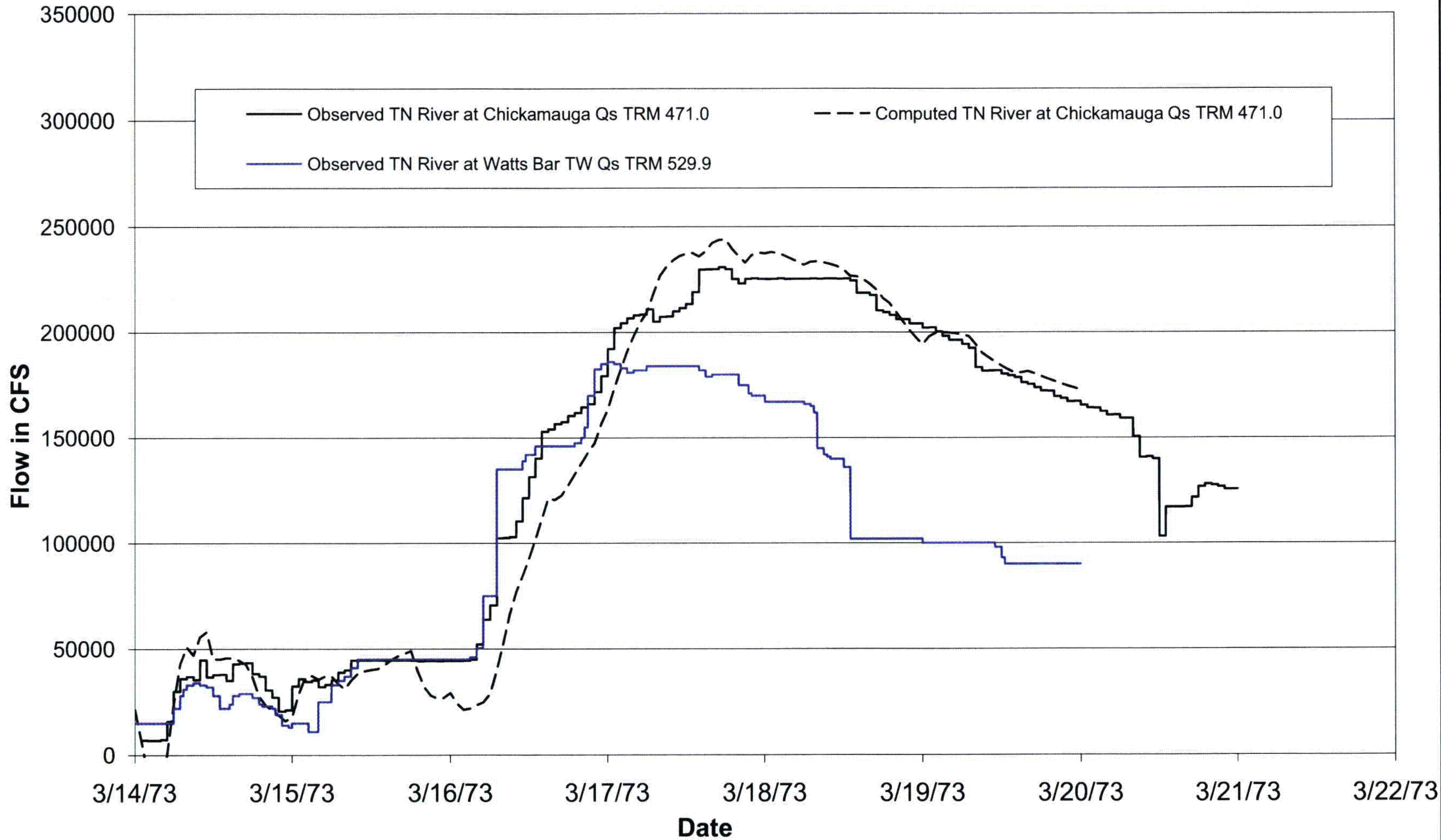


Figure 18: Observed and Simulated Discharge Hydrographs for the Tennessee River at Chickamauga Dam, March 1973.

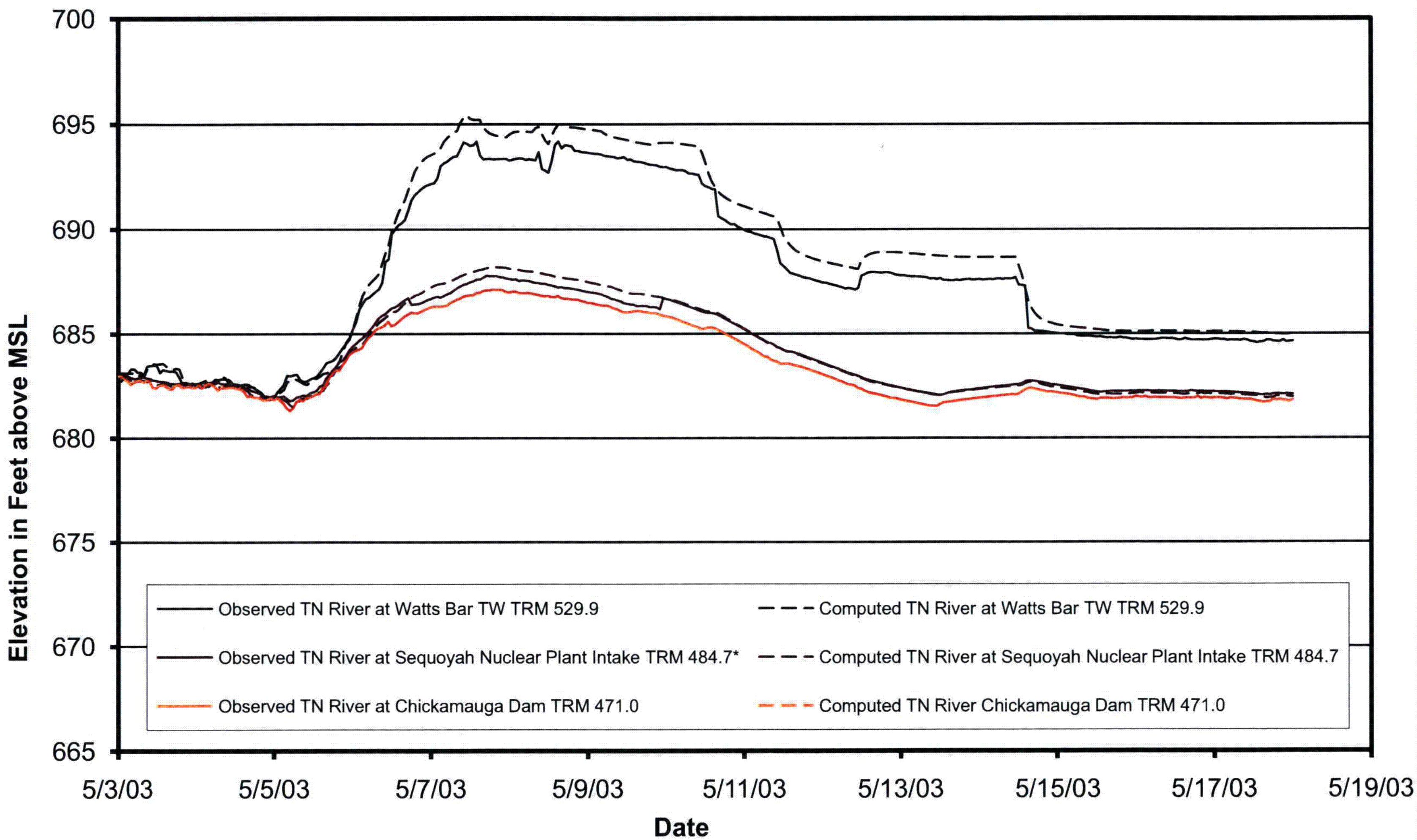


Figure 19: Observed and Simulated Stage Hydrographs for Tennessee River between Watts Bar and Chickamauga Dams, May 2003.

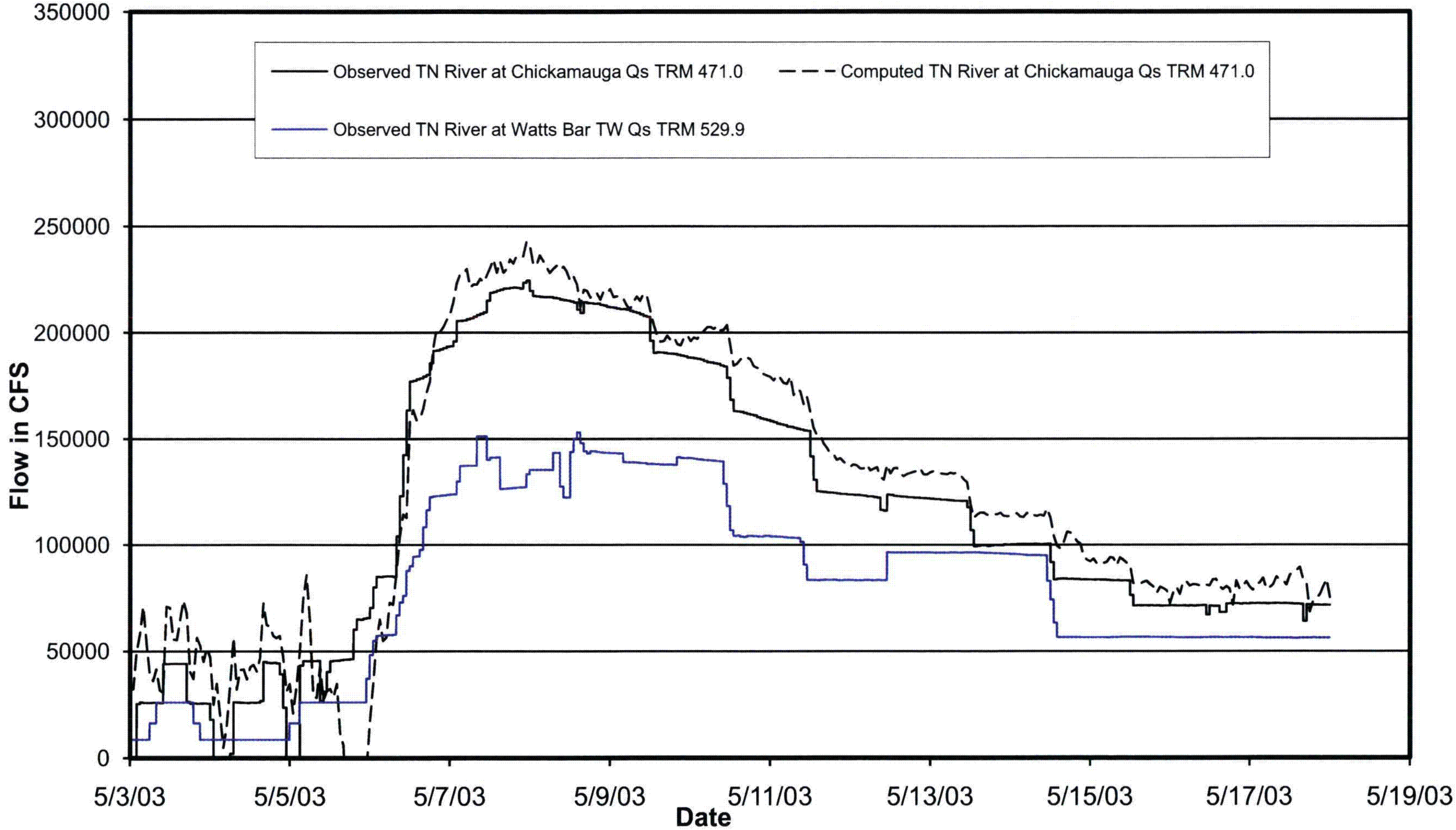


Figure 20: Observed and Simulated Discharge Hydrographs for the Tennessee River at Chickamauga Dam, May 2003.

8 Conclusions

Unit hydrographs for subbasins 44B and 45 for the simulation of local inflow to the Tennessee River between Watts Bar and Chickamauga Dams were developed by TVA previously. In compliance with NRC requirements, the unit hydrographs were indirectly validated in this calculation for two events: the floods of March 1973 and May 2003.

The usual procedure for validating local unit hydrographs is to use them to develop flow series for observed rainfall inputs and compare them with check series developed from reverse reservoir routing and hydrograph separation, as required. Because of the mild slopes and significant backwater on the main stem of the Tennessee River, however, reverse reservoir routing cannot be used to develop inflow series for Chickamauga Reservoir. Therefore, it was necessary to validate the unit hydrographs indirectly. Local runoff hydrographs were developed from observed rainfall series for use as input to the SOCH model simulation of the reach of the Tennessee River between Watts Bar and Chickamauga Dams for the two validation runs.

8.1 Unit Hydrograph Validation

The original unit hydrographs for Subbasins 44B and 45 were indirectly validated for the March 1973 and May 2003 floods in this calculation and are provided in Table 10 and Table 11 (Attachment 4-3). Since the stage and discharge hydrographs simulated in the SOCH model runs utilizing local inputs developed with the unit hydrographs conservatively predict observed data, it is concluded that the original unit hydrographs adequately describe the response of the local catchment areas between the reservoirs and are valid for use in hydrologic studies to determine PMF.

Table 10: Validated 6-hour Unit Hydrograph Ordinates for Subbasin 44B

Ordinate no.	*t*, hours	*Q*, cfs
1	0	0
2	2	493
3	4	1,084
4	6	1,773
5	8	2,857
6	10	4,334
7	12	6,403
8	14	10,344
9	16	13,791
10	18	16,870
11	20	14,777
12	22	11,821
13	24	8,570
14	26	6,009
15	28	4,236
16	30	3,152
17	32	2,660
18	34	2,216
19	36	1,872
20	38	1,675
21	40	1,527
22	42	1,379
23	44	1,281
24	46	1,182
25	48	1,084
26	50	985
27	52	896
28	54	808
29	56	719
30	58	640
31	60	562
32	62	483
33	64	404
34	66	335
35	68	266
36	70	197
37	72	128
38	74	59
39	76	20
40	78	0

Table 11: Validated 6-hour Unit Hydrograph Ordinates for Subbasin 45

Ordinate no.	*t*, hours	*Q*, cfs
1	0	0
2	3	7,500
3	6	23,500
4	9	32,000
5	12	25,250
6	15	21,000
7	18	17,500
8	21	14,000
9	24	11,000
10	27	7,500
11	30	5,500
12	33	2,900
13	36	0