Attachment 02.04.03-08AQ
TVA letter dated February 3, 2010
RAI Response

ASSOCIATED ATTACHMENTS/ENCLOSURES:

Attachment 02.04.03-8E: Guntersville Dam Watershed (Subbasins 49 and 50) Unit Hydrograph Validation

(49 Pages including Cover Sheet)

NPG CALCULATION COVERSHEET/CCRIS UPDATE

REV A EDMS/RIMS NO.	EDMS TYPE:	EDMS ACCESSION NO (N/A for REV. 0)
L58 090603 002	calculations(nuclear)	L58 091230 035

Calc Title: Guntersville Dam Watershed (Subbasins 49 and 50) Unit Hydrograph Validation

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT	CN	NUC	GEN	CEB	CDQ000020080059	0	1	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
clstokes	615-252-4343	CEB	See Page 8	☐ Yes ☒ No

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
Carrie L. Stokes *Carrie L Stokes*	12/11/09	Mark Crisp *Mark Crisp*	12/11/09
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
Mark Crisp *Mark Crisp*	12/11/09	K.R. Spates *K.R. Spates*	12/23/09

STATEMENT OF PROBLEM/ABSTRACT

Validate existing unit hydrographs for the subbasins of the Guntersville Dam watershed (Subbasins 49 and 50) using the 1973 and 2003 floods of record.

*EDCN 22404A (SQN), EDCN 54018A (WBN), 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)

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REV A EDMS/RIMS NO.	EDMS TYPE:	EDMS ACCESSION NO (N/A for REV. 0)
L58 090603 002	calculations(nuclear)	N/A

Calc Title: Guntersville Dam Watershed (Subbasins 49 and 50) 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	CDQ000020060059	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
THJACKSO	(301) 228-8323	Bechtel (CEB)	Design Review	☐ Yes ☒ No

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
Thomas H. Jackson	5-6-09	Nicholas D. Martin	5-6-09
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
Robert E. Swain	5/6/2009	CJT K.R. Sparks	6/3/09

STATEMENT OF PROBLEM/ABSTRACT

Validate existing unit hydrographs for the subbasins of the Guntersville Dam watershed (Subbasins 49 and 50) using the 1973 and 2003 floods of record.

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)

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NPG CALCULATION COVERSHEET/CCRIS UPDATE

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	REV
	CN	NUC	GEN	CEB	CDQ000020080059	1

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	EN	WBN	CEB	54018	
A	P	EN	SQN	CEB	22404	
A	P	CO	GEN	CEB	FLDHYDRO 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:

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
PREPARER PHONE NO.	EDMS ACCESSION NO.		

NPG CALCULATION RECORD OF REVISION

CALCULATION IDENTIFIER CDQ000020080059

Title Guntersville Dam Watershed (Subbasins 49 and 50) Unit Hydrograph Validation

Revision No.	DESCRIPTION OF REVISION
0	Initial issue (46 Pages)
1	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 includes 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 1 through 8 with the forms from the NEDP-2 Revision in effect at the time of calculations issuance. Significant changes in Revision 1 are noted with a right margin revision bar. Administrative changes and typos are excluded. Pages Added: 1a, 8a Pages Replaced: 1-8 & 10 Total pages of calculation hard copy for Revision 1= 48

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NPG COMPUTER INPUT FILE STORAGE INFORMATION SHEET

Document	CDQ000020080059	Rev. 1	Plant: GEN

Subject: Guntersville Dam Watershed (Subbasins 49 and 50) 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.)

See listing of electronically attached spreadsheets and input/output files on the two following pages

☐ Microfiche/eFiche

ELECTRONIC FILE ATTACHMENTS			
Document: CDQ000020080059	Rev. 1	Plant: GEN	
Subject: Subbasin 49 and 50 (Guntersville Dam Watershed) Unit Hydrograph Validation			

Electronic Attachment	Name of File or Folder	File Location
Supporting Spreadsheets		
Attachment 1-1	Convolution 1973_B49.xls	Attached to PDF
Attachment 1-2	Convolution 1973_B50.xls	Attached to PDF
Attachment 1-3	Convolution 2003_B49.xls	Attached to PDF
Attachment 1-4	Convolution 2003_B50.xls	Attached to PDF
Attachment 1-5	FLDHDYRO Processing.xls	Attached to PDF
Attachment 1-6	GriddedPrecipitationDataAllSubasins2003.xls	Attached to PDF
Attachment 1-7	GuntersvilleReservoir_Mass Balance 1973.xls	Attached to PDF
Attachment 1-8	GuntersvilleReservoir_Mass Balance 2003.xls	Attached to PDF
Attachment 1-9	GuntersvilleReservoir_Precipitation over water.xls	Attached to PDF
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Attachment 1-11	nickajack_rev0.xls	Attached to PDF
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Attachment 1-13	Precipitation_2003_B50.xls	Attached to PDF
Attachment 1-14	SB 49 & 50 Precip 1973.xls	Attached to PDF
Attachment 1-15	SB 49 & 50 Base Flow 1973 & 2003.xls	Attached to PDF
Attachment 1-16	SB 49 & 50 Total Local Inflow Hydrographs 1973 & 2003.xls	Attached to PDF
Attachment 1-17	SequatchieRiverProcessing.xls	Attached to PDF
Attachment 1-18	SOCH Model Runs for March 1973.xls	Attached to PDF
Attachment 1-19	SOCH Model Runs for May 2003.xls	Attached to PDF
Attachment 1-20	Validated Unit Hydrograph Ordinates for SB 49 & 50.xls	Attached to PDF
FLDHYDRO Files		
Attachment 2-1	Mar1973_GuntLocals_Fldhydro.dat	Attached to PDF
Attachment 2-2	Mar1973_GuntLocals_Fldhydro.out	Attached to PDF
Attachment 2-3	May2003_GuntLocals_Fldhydro.dat	Attached to PDF
Attachment 2-4	May2003_GuntLocals_Fldhydro.out	Attached to PDF
Attachment 2-5	SequatchieNrWhitwell.txt	Attached to PDF

NPG CALCULATION VERIFICATION FORM

Calculation Identifier CDQ000020080059 Revision 1

Method of verification used:

1. Design Review ☒
2. Alternate Calculation ☐
3. Qualification Test ☐

Verifier Mark W Crisp Date 12/11/09

Comments:

This calculation was revised to address 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. The verification is inclusive of work completed prior to this revision.

Storm hydrographs in this document were produced by reverse reservoir routing. The resulting hydrographs were averaged and/or smoothed to avoid drastic slope changes in the hydrograph that are typically caused by imperfections in the gaged data. This is an acceptable practice, but the final hydrograph volume should have been checked against the original data to ensure a proper volume balance. This verification process included a check of this volume balance and no notable discrepancies were found.

CDQ 59, Subbasin 49, Guntersville Dam: The inflow hydrographs were obtained by Reverse Reservoir Routing using daily flow and storage values. When compared to the original reservoir release and storage data, the inflow hydrographs are slightly lower in volume. For the March 1973 storm, the inflow hydrograph is lower in volume by 0.96%. For the May 2003 storm, the inflow hydrograph is lower in volume by 0.36%.

FLDHYDRO input files for this calculation were developed with a check volume used to calibrate the modeled. This is an acceptable practice, but the FLDHYDRO output calibrated with a check volume should have been compared to FLDHYDRO output for the same storm that was not calibrated with a check volume. This comparison allows better selection of storms that have runoff and environmental characteristics most compatible with the FLDHYDRO program. This verification process included a comparison of FLDHYDRO runs calibrated with check volumes and FLDHYDRO runs that were not calibrated with check volumes, no notable discrepancies were found.

NPG CALCULATION VERIFICATION FORM

Calculation Identifier CDQ000020080059 Revision 0

Method of verification used:

1. Design Review ☒
2. Alternate Calculation ☐
3. Qualification Test ☐

Verifier Bob Swain Date 4/29/2009

Comments:

The calculation entitled, "Guntersville Dam Watershed (Subbasins 49 and 50) 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. The unit hydrographs for Subbasins 49 and 50 were revised in 1973. However, the original calculations supporting the development of the unit hydrographs could not be found. It is unknown whether or not the March 1973 flood was used to develop the unit hydrographs; therefore, the March 1973 flood along with the May 2003 flood were used for unit hydrograph validation.

2. The unit hydrograph ordinates were adjusted to incorporate GIS calculated drainage areas by linear scaling to obtain a flood volume of one inch of runoff.

3. The reservoir surface area used for the calculation, which is based on water surface elevation 595, was checked against the reservoir elevations during the 1973 and 2003 storms. The small range of reservoir elevations during the storms allowed use of a constant reservoir surface area for the reservoir runoff computations.

The calculation presents the development of initial simulated flows from Subbasins 49 and 50 for floods that occurred in March 1973 and May 2003, which were used in the calibration of the SOCH model. The comparison between the observed and simulated flows and water surface elevations at several locations supports the conclusion that the unit hydrographs developed for Subbasins 49 and 50 have been indirectly validated against floods that occurred in March 1973 and May 2003.

1 Purpose

The Tennessee Valley Authority's (TVA) 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 12) 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 a similar future PMF and dam break analysis for the Browns Ferry Nuclear Power 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 1960s, 1970s, and early 1980s, utilizing observed rainfall and stream flow and reservoir headwater and discharge data, and are being validated by checking their performance in reproducing recent floods.

This calculation presents the validation of the unit hydrographs (UH) developed by the TVA for Subbasins 49 and 50, which comprise the local inflow areas for runoff entering the Tennessee River between Guntersville and Nickajack Dams, as shown in Figure 1.

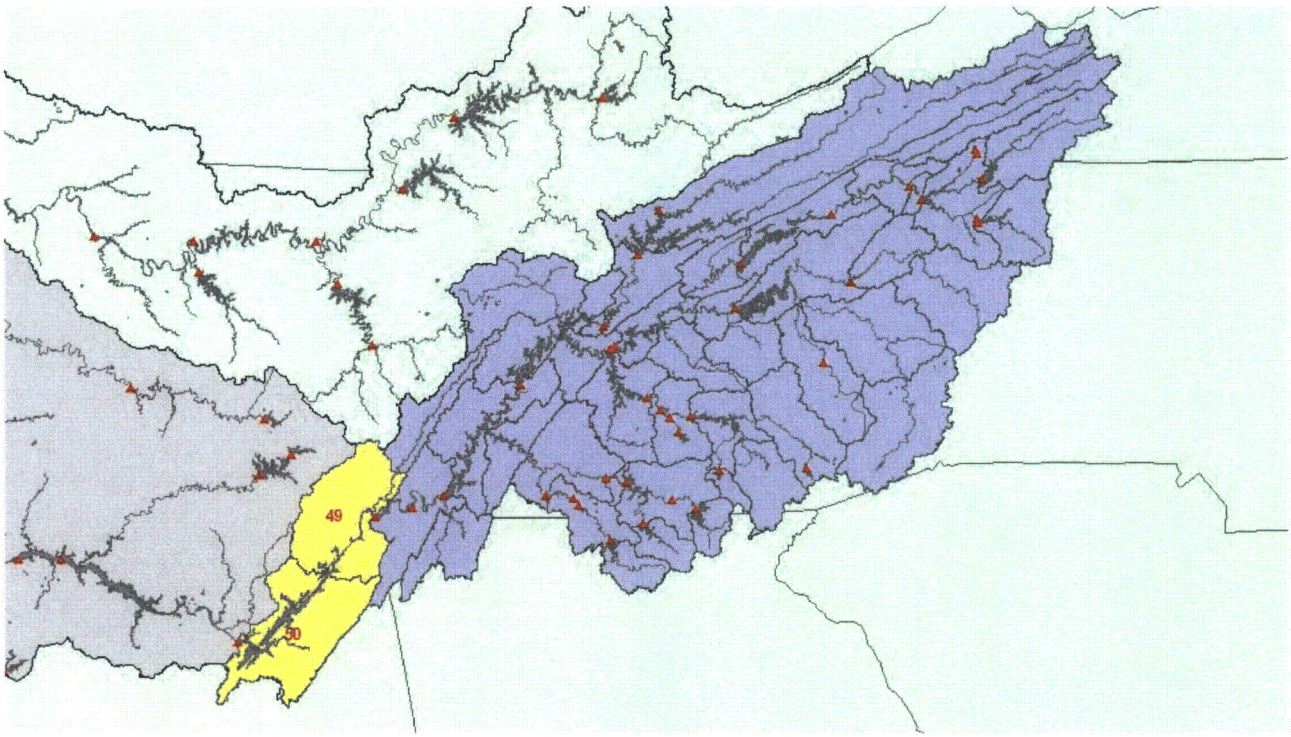

Figure 1: Location of the Two Guntersville Dam Subbasins within the Tennessee River Watershed

2 References

1. American Nuclear Society, American National Standard for Determining Design Basis Flooding at Power Reactor Sites, ANSI/ANS-2.8-1992, 1992.
2. Chow, V.T., D.R. Maidment, and L.W. Mays, *Applied Hydrology*, McGraw-Hill Book Company, 1988.
3. Kohler, M.A., and R.K. Linsley, Predicting the Runoff from Storm Rainfall, *Research Paper No. 34*, U.S. Department of Commerce, September 1951.
4. Linsley, R.K., Kohler, M.A., and J.L.H.Paulhus, *Hydrology for Engineers*, McGraw-Hill Book Company, 1982.
5. Tennessee Valley Authority, *UNITGRPH-FLDHYDRO-TRBROUTE-CHANROUT User Documentation*, Version 1.0, March 2009 (EDMS L58 090325 001)
6. Tennessee Valley Authority, Unit Area 49, Guntersville North Local, File Book Reference (EDMS L58 081223 800)
7. Tennessee Valley Authority, Unit Area 50, Guntersville South Local, File Book Reference (EDMS L58 081223 801)
8. Tennessee Valley Authority, Bihourly Stream Flow Data for the Sequatchie River near Whitwell (EDMS L58 090219 800).
9. Tennessee Valley Authority, Observed Daily Outflow and Headwater Elevation Data for Guntersville and Nickajack Dams, inter alia; electronic data transmitted by TVA to Bechtel, November 2008 in spreadsheets guntersville_rev0.xls and nickajack_rev0.xls RFI 25447-000-GRI-GEX-00053 Rev 1 (EDMS L58 090311 802).
10. Tennessee Valley Authority, Calculation #CDQ000020080041 Rev 1, SOCH Model Calibration, Guntersville
11. Tennessee Valley Authority, Calculation #CDQ000020080055, Processing and Validation of National Weather Service's NEXRAD Stage III Hourly Precipitation Data for Hydrologic and Hydraulic Analysis of Watersheds, Revision 3
12. Tennessee Valley Authority, Bellefonte Nuclear Plant - White Paper, Hydrologic Analysis, Revision 1, July 25, 2008 (EDMS No. L58 080730001) FOR INFORMATION ONLY
13. Tennessee Valley Authority, Office of Environment & Research, Geographic Information & Engineering, "Drainage Areas above Guntersville," June 18, 2008 Drawing #6GIE 301 E 200801 R0D
14. Tennessee Valley Authority, Bellefonte Units 3 and 4 Hydrology Project Request for Information Response Information Continuation Sheet RFI#25447-000-GRI-GEX-00069 Rev 1 (EDMS L58 090429 801).
15. Tennessee Valley Authority, *Simulated Open Channel Hydraulics (SOCH) User's Manual*, Version 1.0
16. Tennessee Valley Authority, Basin Average Hourly Precipitation data provided in FLDHYDRO input files (RFI 25447-000-GRI-GEX-00038, Rev 0, EDMS No. L58 081028 001).
17. Tennessee Valley Authority, Bellefonte Units 3 and 4 Hydrology Project Request for Information Response Information Continuation Sheet RFI#25447-000-GRI-GEX-00072 Rev 0 (EDMS L58 090416 800).
18. U.S. Geological Survey, Daily Mean Stream Flow Data for the Sequatchie River near Whitwell (October 1, 1920 through September 30, 1994).
19. U.S. Nuclear Regulatory Commission, Standard Review Plan 2.4.3, Probable Maximum Flood (PMF) on Streams and Rivers, NUREG-0800, Revision 4, March 2007.
20. Viessman, W., J.W. Knapp, G.L. Lewis, and T.E. Harbaugh, *Introduction to Hydrology, Second Edition,* Harper & Row, Publishers, 1977.

3 Assumptions

3.1 General Assumptions

None

3.2 Unverified Assumptions

None

4 Background

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 2, 4, and 20).

The direct runoff hydrograph (i.e. stream flow minus base flow) can be calculated from a series of M excess rainfall inputs of any depth and the K ordinates of the unit hydrograph using the process of "convolution." The N = K + M -1 ordinates of the direct runoff hydrograph are given by the discrete convolution equation, which states that the direct runoff Q_n at a given time n is obtained from the excess runoff P_m and the unit hydrograph ordinate U_{n-m+1} (where $U_i = 0$ for all i = n – m + 1 > K) as follows (Reference 2):

$$Q_n = \sum_{m=1}^{n \le M} P_m U_{n-m+1} \tag{1}$$

The reverse process, called deconvolution, can be used to derive the ordinates of the unit hydrograph (U), from excess rainfall (P) and direct runoff (Q) derived from observed data.

Unit hydrograph theory is applicable under the following conditions (References 2 and 4):

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

The methodology used for unit hydrograph validation follows that described in ANSI/ANS-2.8-1992 (Reference 1). This document is included as a reference in the NRC's Standard Review Plan for Section 2.4.3, Probable Maximum Flood on Streams and Rivers (Reference 19). With regard to verifying runoff models, ANSI/ANS-2.8-1992 indicates 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."

In the Guntersville watershed, reverse reservoir routing, which is based on the assumption of a level storage pool, cannot be utilized because the pronounced backwater effects associated with the large dam and mild bed slopes of the main stem of the Tennessee River make the level pool assumption untenable. For this reason, dynamic stream flow modeling must be utilized to develop reliable stream flow hydrographs on the main stem of the river.

For the Guntersville watershed calculations, the required dynamic modeling was carried out using the Simulated Open Channel Hydraulic Model (SOCH) developed by the TVA (Reference 15), which outputs the stage and discharge hydrographs for specified locations in the model for each run. The simulated stage and discharge hydrographs simulated in SOCH were compared with the corresponding observed series to effect an indirect validation of the TVA unit hydrographs, as described below.

The SOCH model for this calculation includes the backwater reach of the Tennessee River between Nickajack Dam (TRM 424.7) and Guntersville Dam (TRM 349.0). Inputs to the model include observed upstream inflows from the main stem and a tributary (i.e. the Sequatchie River and Nickajack Dam outflow series), local inflow hydrographs for the drainage area between dams (i.e. Subbasins 49 and 50), and rainfall over the reservoir area.

The local inflow hydrographs are developed by convolution of the TVA unit hydrographs with effective rainfall developed for each subbasin using observed rainfall from two large storms for Guntersville Reservoir, which occurred in March 1973 and the May 2003. The simulation of the 2003 flood provided the opportunity to check whether changes in watershed characteristics over the intervening years might have altered the rainfall-runoff response of the watershed to such an extent as to invalidate the original TVA unit hydrographs.

The validation procedure included the following steps:

1. Develop a daily mass balance for the combined Subbasin 49 and 50 areas and determine total direct local inflow over the duration of the flood.
2. Obtain rainfall data for Subbasins 49 and 50 for the periods of interest and determine effective rainfall using FLDHYDRO (Reference 5). Input to FLDHYDRO includes observed daily antecedent rainfall and observed hourly rainfall for the duration of the flood. Observed rainfall data for the 1973 storm were obtained from TVA point gage data preserved in FLDHYDRO input files; rainfall for the 2003 storm was obtained from NWS gridded one-hour rainfall data sets.
3. Use the local direct runoff volumes calculated in Step 1 as the CHKVOL input in FLDHYDRO to ensure that the effective rainfall volumes calculated by FLDHYDRO approximately equals the observed runoff volumes.
4. Use convolution to convert the effective rainfall series obtained in Step 3 into direct local runoff hydrographs.
5. Add base flow calculated in FLDHYDRO to the direct local runoff hydrographs to obtain initial total local inflow hydrographs, and provide to TVA for input to the SOCH model.
6. Calculate the flow series for the volumes of precipitation falling directly on the reservoir area and provide as input to the SOCH model.
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.

Detailed discussions of these procedures are provided in following sections of this calculation.

6 Design Input Data

The input data necessary for validating the local inflow unit hydrographs include:

- Unit hydrograph ordinates and durations for Subbasins 49 and 50
- Observed discharge records for the Sequatchie River at Whitwell
- Observed outflows from Guntersville Dam and from Nickajack Dam and the corresponding headwater elevations
- The stage-volume relationships for the two reservoirs
- Observed rainfall data associated with the selected validation floods

Each of these inputs is described in more detail in the following subsections.

6.1 Subbasin Areas

The local inflow area for the reach of the Tennessee River between the Nickajack Dam (TRM 424.7) and Guntersville Dam (TRM 349.0) includes an area of approximately 2,199 square miles, which is divided by the TVA into two subbasins at TRM 394.5 for hydrologic modeling, as shown in Figure 2.

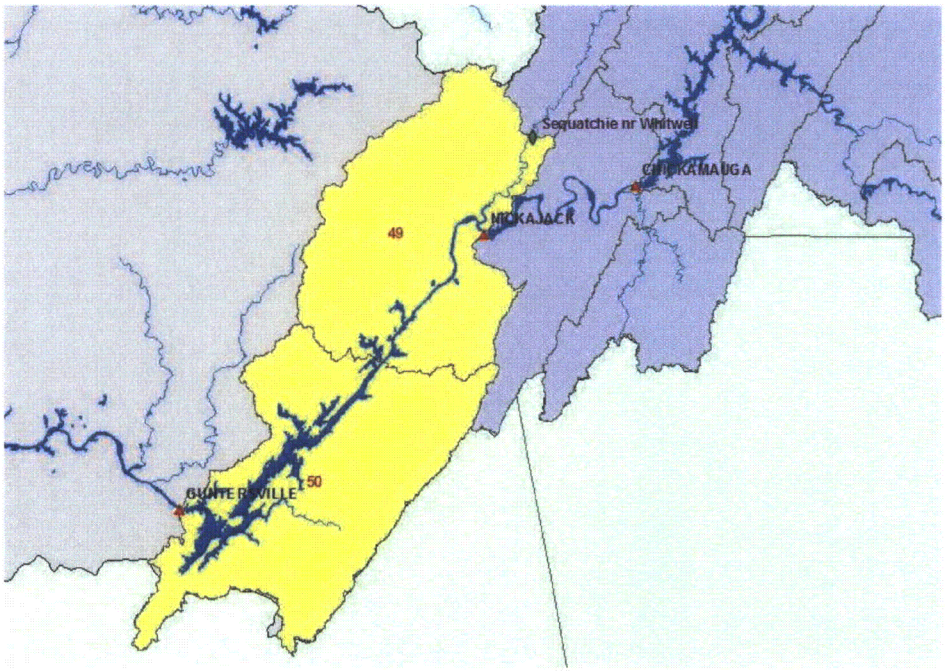

Figure 2: Guntersville Local Inflow Subbasins (Shown in Yellow)

The total areas of each subbasin calculated by the TVA using Geographic Information System (GIS) software in 2008 (Reference 13) are provided in the third column of Table 1. The reservoir area associated with each of these subbasins, as measured in GIS for a water surface elevation of 595 ft MSL is provided in the fourth column of the table.

The original unit hydrograph calculations are based on the "dry land" areas shown in the fifth column of Table 1, which exclude the reservoir water surface. Subtracting the reservoir areas from the total subbasin areas (both measured in GIS) gives the dry land areas that should be used for the unit hydrograph calculation, shown in the sixth column of the table. A comparison of the original and newly calculated dry land areas shows a very small but non-negligible difference for both of the subbasins. The unit hydrograph ordinates for each subbasin were corrected for this error in the current calculation, as described in Section 6.2.

Table 1: Guntersville Local Inflow Subbasin Areas (in square miles)

Basin ID	Subbasin Name	GIS-basis		TVA UH areas	Corrected UH Areas **	% difference
		Total Basin	Reservoir *			
49	Guntersville North Local	1044.1	17.0	1041.0	1027.1	1.35%
50	Guntersville South Local	1154.9	86.0	1047.0	1068.9	-2.05%
	Total	2199.0	103.0	2088.0		

* Reservoir Area for W.S. Elev. 595 MSL

** Required area = GIS measured areas - reservoir surface areas

6.2 Unit Hydrographs

The response of a watershed to one inch of rainfall is simulated with a unit hydrograph, as described in Section 4. The original unit hydrographs were revised for the two Guntersville local inflow subbasins in 1973 by the TVA's River Operations Group. The calculations have not been found, but in recent years the TVA has operationally validated the unit hydrographs by checking that using them as input to the SOCH model can reproduce historical flood flows (References 6 and 7).

The unit hydrographs for Subbasins 49 and 50 were developed on the basis of the non-reservoir area of each catchment (i.e. discounting the reservoir surface area). Because new dry land areas were calculated for each of the subbasins as a result of recent GIS studies (see previous section and Reference 13), the ordinates of each of the unit hydrographs have been adjusted by a linear scale factor to provide a total runoff depth of one inch (as shown in Attachment 1-20 to this calculation). The revised hydrographs for Subbasins 49 and 50 are plotted in Figure 3.

Key parameters associated with the original TVA and the revised unit hydrographs are presented in Table 2. As shown in the final column of the table, the volume of runoff is one inch for each unit hydrograph, as required by theory. The volume determination is based on the calculation of area under the unit hydrograph, as shown in Table 3.

Table 2: TVA Unit Hydrograph Parameters for the Guntersville Local Inflow Subbasins

Subbasin		Effective Duration, hours	Time Step, hours	Number of ordinates	Qpeak, cfs	Peak Time, hours	Area, sq. mi.	Volume, acft	Volume inches
49	Original	6	3	47	22,400	15	1041.0	55,550	1.001
	Revised	6	3	47	22,089	15	1027.1	54,779	1.000
50	Original	6	3	45	22,500	15	1047.0	55,860	1.000
	Revised	6	3	45	22,963	15	1068.9	57,008	1.000

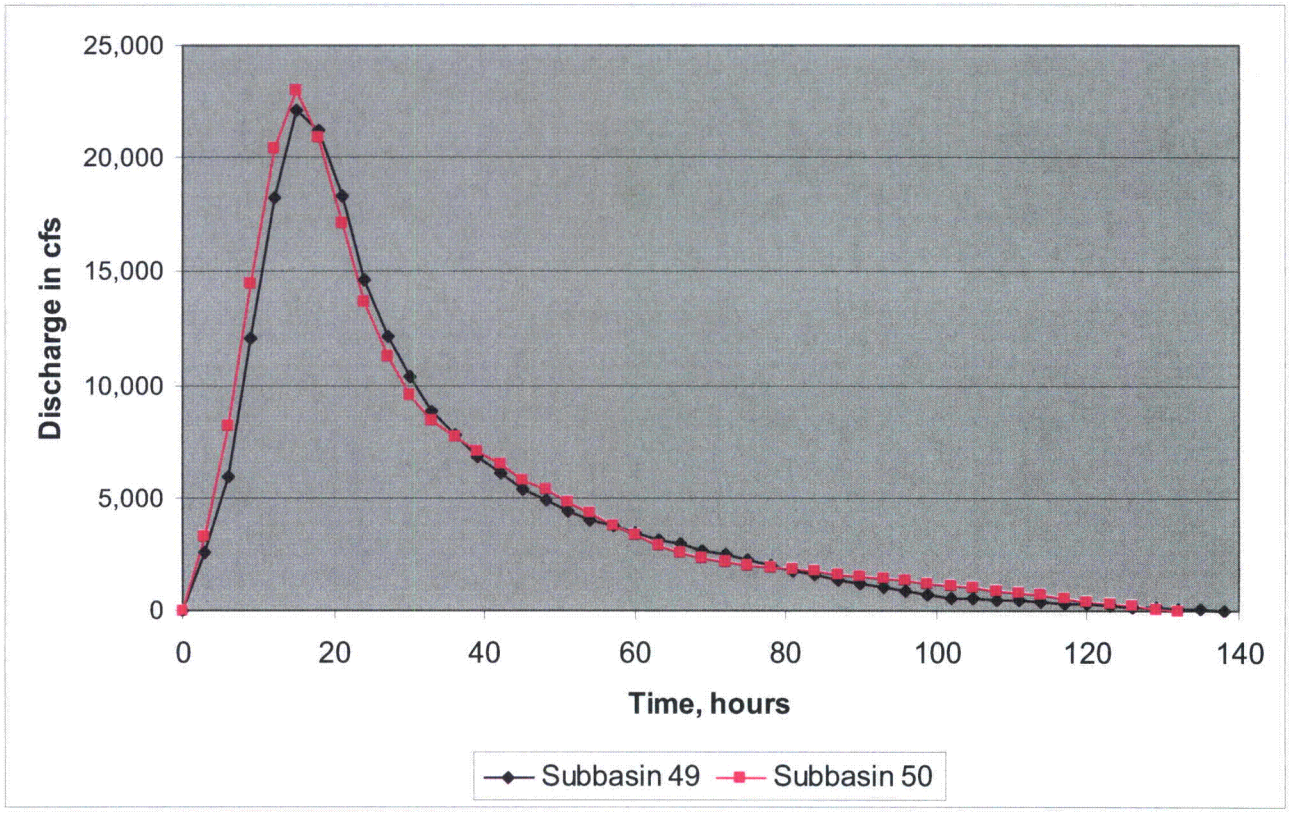

Figure 3: Six-hour Unit Hydrographs for Subbasins 49 and 50 (Guntersville North and South Locals Using Adjusted Subbasin Areas)

Table 3: Ordinates and Volume Calculations for Six-hour Unit Hydrographs for Subbasins 49 and 50 - Guntersville North and South Local (Calculation Notes on Following Page)

Subbasin 49

Time, hrs	Discharge, cfs/in	Average Q, cfs/in (1)	Wedge volume, acft (2)
0	0	1,282	318
3	2,564	4,240	1,051
6	5,917	8,974	2,225
9	12,031	15,137	3,753
12	18,243	20,166	5,000
15	22,089	21,645	5,367
18	21,202	19,772	4,902
21	18,342	16,468	4,083
24	14,595	13,362	3,313
27	12,129	11,242	2,787
30	10,354	9,615	2,384
33	8,875	8,333	2,066
36	7,790	7,297	1,809
39	6,804	6,459	1,601
42	6,114	5,769	1,430
45	5,424	5,177	1,284
48	4,931	4,684	1,161
51	4,438	4,240	1,051
54	4,043	3,895	966
57	3,747	3,599	892
60	3,451	3,304	819
63	3,156	3,057	758
66	2,958	2,810	697
69	2,663	2,564	636
72	2,465	2,342	581
75	2,219	2,096	520
78	1,972	1,874	465
81	1,775	1,676	416
84	1,578	1,479	367
87	1,381	1,282	318
90	1,183	1,109	275
93	1,035	961	238
96	888	814	202
99	740	666	165
102	592	567	141
105	542	518	128
108	493	468	116
111	444	419	104
114	394	370	92
117	345	320	79
120	296	271	67
123	247	222	55
126	197	173	43
129	148	123	31
132	99	74	18
135	49	25	6
138	0	0	0
Total volume, acft =			54,779
Basin Area, sq. mi. =			1027.1
Total volume, inches (3) =			1.000

Subbasin 50

Time, hrs	Discharge, cfs/in	Average Q, cfs/in (1)	Wedge volume, acft (2)
0	0	1,633	405
3	3,266	5,715	1,417
6	8,164	11,328	2,809
9	14,492	17,452	4,327
12	20,411	21,687	5,377
15	22,963	21,942	5,440
18	20,921	19,033	4,719
21	17,145	15,410	3,821
24	13,676	12,451	3,087
27	11,226	10,410	2,581
30	9,593	9,032	2,239
33	8,471	8,113	2,012
36	7,756	7,399	1,834
39	7,042	6,787	1,683
42	6,532	6,174	1,531
45	5,817	5,588	1,385
48	5,358	5,077	1,259
51	4,797	4,567	1,132
54	4,337	4,057	1,006
57	3,776	3,572	886
60	3,368	3,113	772
63	2,858	2,704	671
66	2,551	2,449	607
69	2,347	2,271	563
72	2,194	2,118	525
75	2,041	1,990	493
78	1,939	1,888	468
81	1,837	1,786	443
84	1,735	1,684	418
87	1,633	1,582	392
90	1,531	1,480	367
93	1,429	1,378	342
96	1,327	1,276	316
99	1,225	1,174	291
102	1,123	1,072	266
105	1,021	970	240
108	919	867	215
111	816	765	190
114	714	638	158
117	561	485	120
120	408	357	89
123	306	255	63
126	204	153	38
129	102	51	13
132	0	0	0
Total volume, acft =			57,008
Basin Area, sq. mi. =			1068.9
Total volume, inches (3) =			1.000

Notes:

1) $Q_{ave} = 0.5(Q_t + Q_{t-1})$

2) $Volume = Qave \frac{ft^3}{sec} * 3600 \frac{sec}{hr} * 3hr * \frac{1acft}{43560\,ft^3}$

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

Effective rainfall hyetographs developed for each subbasin are convoluted with the unit hydrographs, and the calculated direct runoff is used as input to a SOCH model simulation of the Tennessee River between Nickajack and Guntersville Dams for the 1973 and 2003 storms of record. The comparison of the observed and simulated discharge and water surface elevations at specific cross sections within the reach, as discussed in Section 7.4, is used to provide an indirect validation of the unit hydrographs.

6.3 Observed Stream Flow

Average daily flows for the Sequatchie River near Whitwell are required as an upstream input to the local area water budget. These flows were obtained from two sources:

- Daily observed stream flows were obtained from the USGS (Reference 18) for the period from October 1, 1920 through September 30, 1994 from which the values for the 1973 flood were selected. The USGS data file, "SequatchieNrWhitwell.txt" is provided as Attachment 2-5.
- Bi-hourly observed in-channel stream flow series were obtained from the TVA for the 2003 flood (Reference 8) and were processed to provide average daily flows (see tab labeled "2003 24-hour flow series" in the spreadsheet "SequatchieRiverProcessing.xls," provided as Attachment 1-17).

6.4 Observed Dam Outflows and Headwater Elevations

The daily total discharge from Nickajack Dam is used as the second upstream input for the local inflow water budget. Daily discharge values were obtained from the TVA (Reference 9) in the spreadsheet "nickajack_rev0.xls," provided with this calculation as Attachment 1-11.

Inflows to the downstream end of Guntersville Reservoir are obtained by a solution of the daily water budget for the reservoir, as presented in Section 7.1. The daily starting stage and daily total outflow (including spills and turbine discharges) from the Guntersville Dam used for the calculation were obtained from the TVA (Reference 9) in the spreadsheet "guntersville_rev0.xls," which is provided as Attachment 1-10 to this calculation.

6.5 Stage-Volume Relationship

It was not necessary to consult the stage-volume relationship for the Guntersville Reservoir in this calculation. The storage volume measured for the starting stage for each day was provided by the TVA directly in the spreadsheet "guntersville_rev0.xls," as discussed above.

6.6 Observed Rainfall

Basin average hourly rainfall depths for the 1973 flood were obtained from the TVA in FLDHYDRO input files (Reference 16) and are provided in the spreadsheet "SB 49 & 50 Precip 1973.xls", provided as Attachment 1-14 to this calculation.

Basin average hourly rainfall depths for the 2003 flood were developed from National Weather Service (NWS) gridded precipitation data sets. NWS NEXRAD Stage III hourly precipitation data were obtained from the Lower Mississippi River Forecast Center (LMRFC) from January 1997 to April 2008 for unit hydrograph validation. A Microsoft.Net utility was developed to generate radar-based Mean Areal Precipitation (MAPX) time series for each of the subbasins (Reference 11).

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 11 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.

Observed average basin rainfall for the May 2003 storm was obtained from Reference 11. The hourly precipitation series developed from NWS gridded data for use in the calculation are provided in the spreadsheet "GriddedPrecipitationDataAllSubbasins2003.xls" (Attachment 1-6)

The conversion of the time base of the precipitation time series to Central Time for the May 2003 storm, and unit conversion and reformatting required for input to FLDHYDRO (see Section 7.2) are carried out in the following spreadsheets, provided as electronic attachments to this calculation:

- Precipitation_2003_B49.xls (Attachment 1-12)
- Precipitation_2003_B50.xls (Attachment 1-13)

7 Computations and Analysis

Computations required for the development of the local inflow hydrographs for input to the SOCH model and the use of SOCH model output for validation of the TVA unit hydrographs are presented in the following sections.

7.1 Determination of local inflow volumes

Because of data limitations, the direct runoff volume cannot be determined for each subbasin separately, so the total direct volume is determined for the total period of the flood using a daily water budget as shown schematically in Figure 4.

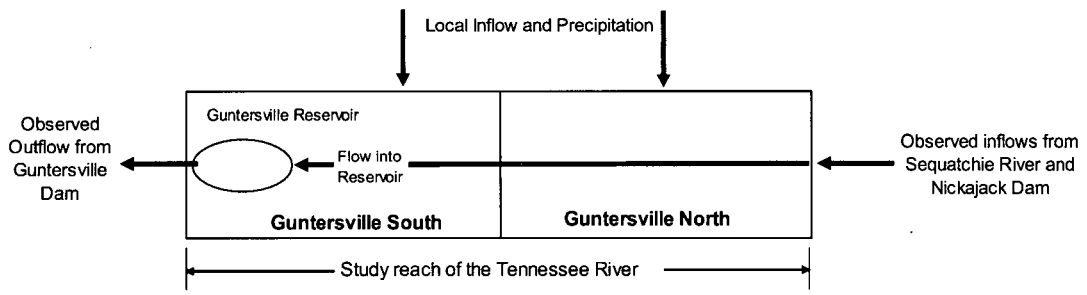

Figure 4: Mass Balance Schematic for the Guntersville Reach of the Tennessee River

The volume of local inflow is determined from a mass balance developed for the study reach (i.e. the Tennessee River between the Nickajack and Guntersville Dams). The mass balance for the reach can be written as:

Total Flow into Reservoir = Sequatchie flow + Nickajack outflow + Total Local inflow

The flow into Guntersville Reservoir is obtained from a mass balance on the reservoir at the downstream end of the study reach as: Daily Inflow = Total measured outflow for the period + change in storage over the period, i.e. Σ Qin = Σ Qout + Δ Storage. Daily inflows and reservoir storage volumes were provided by the TVA for the 1973 and 2003 floods in the spreadsheet "Guntersville_rev0.xls" as discussed in Sections 6.4 and 6.5.

With the inflow to the reservoir known, it is possible to solve the mass balance over the reach for the local inflow volume, i.e. Local Inflow = Flow into Reservoir – Nickajack outflow – Sequatchie flow.

This calculation is carried in Tables 4 and 5 for each day of the 1973 and 2003 floods, respectively (see Attachments 1-7 and 1-8).

Table 4: Surface Water Flows into and out of Study Reach for the March 1973 Flood

Date	HW 1973	Total Q 1973	Storage Volume	Guntersville Daily Average Inflows	Nickajack Daily Average Discharge	Sequatchie Daily Average Flows	Observed Guntersville Local	Baseflow Separation	Est. Guntersville Local Surface Runoff
	(ft)	(cfs)	1000*(cfs-day)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
11-Mar-73	593.70	47,900	476.29		32,100	2,030			
12-Mar-73	594.16	47,900	494.05	65,660	38,400	3,290	23,970		
13-Mar-73	594.27	50,300	494.03	50,280	35,600	2,250	12,430		
14-Mar-73	593.79	57,300	480.74	44,010	34,100	1,670	8,240	8,240	0
15-Mar-73	594.06	68,500	500.13	87,890	47,800	2,190	37,900	10,650	27,250
16-Mar-73	594.00	182,500	638.17	320,540	144,900	19,500	156,140	13,060	143,080
17-Mar-73	595.40	253,000	755.93	370,760	233,700	20,500	116,560	15,470	101,090
18-Mar-73	595.42	295,800	761.58	301,450	248,500	12,500	40,450	17,880	22,570
19-Mar-73	594.95	304,400	703.33	246,150	218,500	7,360	20,290	20,290	0
20-Mar-73	594.48	266,500	610.49	173,660	162,700	4,030	6,930		
21-Mar-73	594.62	196,200	563.19	148,900	118,600	4,120	26,180		
22-Mar-73	594.24	147,200	536.79	120,800	101,800	3,740	15,260		
23-Mar-73	594.12	124,500	526.93	114,640	97,500	2,700	14,440		
24-Mar-73	594.00	119,300	521.21	113,580	98,400	2,090	13,090		
25-Mar-73	593.74	119,000	510.72	108,510	94,700	1,990	11,820		
26-Mar-73	593.76	110,100	507.63	107,010	89,000	1,950	16,060		
27-Mar-73	593.80	101,600	505.45	99,420	83,600	1,710	14,110		

Total surface runoff, in DSF (summation of last column in table) 293,990

Table 5: Surface Water Flows into and out of Study Reach for May 2003 Flood

Date	HW 1973	Total Q 1973	Storage Volume	Guntersville Daily Average Inflows	Nickajack Daily Average Discharge	Sequatchie Daily Average Flows	Observed Guntersville Local	Baseflow Separation	Est. Guntersville Local Surface Runoff
	(ft)	(cfs)	(1000cfs-day)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
01-May-03	594.40	39,692	499.10		30,056	601			
02-May-03	594.56	39,326	504.04	44,269	34,380	596	9,293		
03-May-03	594.63	34,893	499.71	30,563	22,935	521	7,107		
04-May-03	594.29	28,803	494.19	23,278	17,586	502	5,190	5,190	0
05-May-03	594.57	36,286	508.01	50,110	33,191	2,163	14,756	6,039	8,717
06-May-03	594.84	151,579	658.96	302,531	145,107	22,798	134,626	6,888	127,738
07-May-03	594.57	266,685	733.98	341,702	243,498	25,646	72,558	7,737	64,821
08-May-03	594.86	288,578	758.74	313,337	258,901	17,625	36,811	8,586	28,225
09-May-03	594.57	300,481	721.61	263,347	234,297	10,924	18,126	9,435	8,691
10-May-03	594.70	270,259	668.67	217,322	200,850	6,188	10,284	10,284	0
11-May-03.	594.45	237,287	618.96	187,582	165,058	3,462	19,062		
12-May-03	594.14	199,744	561.27	142,048	134,740	2,882	4,426		
13-May-03	593.98	145,134	544.90	128,770	126,692	2,291	-213		
14-May-03	594.12	126,128	529.61	110,837	99,540	1,866	9,431		
15-May-03	594.23	107,128	519.98	97,492	87,689	1,453	8,350		
16-May-03	594.43	83,208	522.59	85,822	77,706	1,167	6,949		
17-May-03	594.45	83,196	519.45	80,051	68,438	1,119	10,494		

Total surface runoff, in DSF (summation of last column in table) 238,192

The base flow separation shown in the second-to-last column in Tables 4 and 5 is accomplished with a straight-line assumption, as shown in Figures 5 and 6.

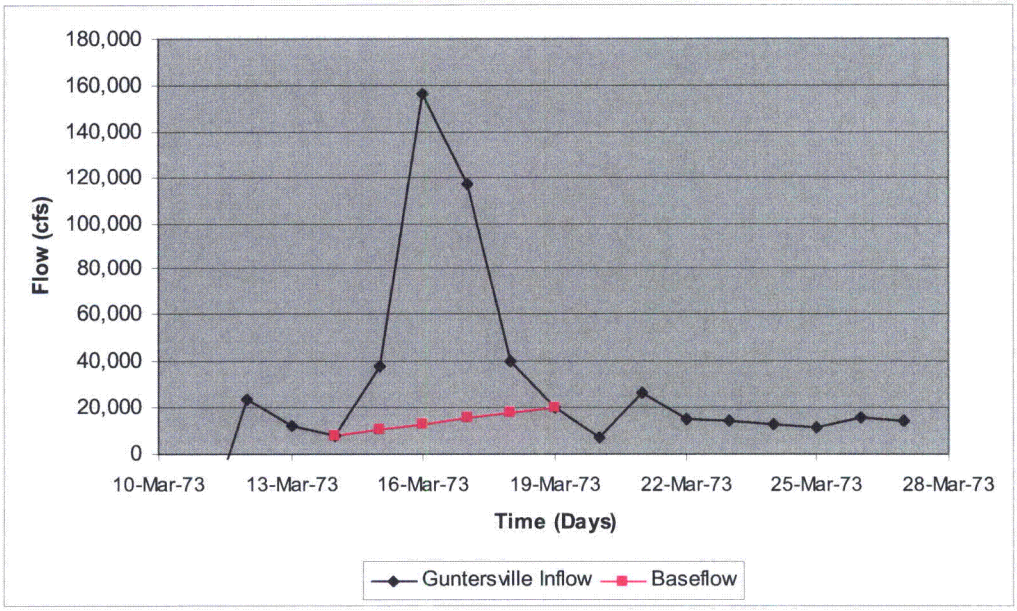

Figure 5: Base Flow Separation at Guntersville for March 1973 Flood

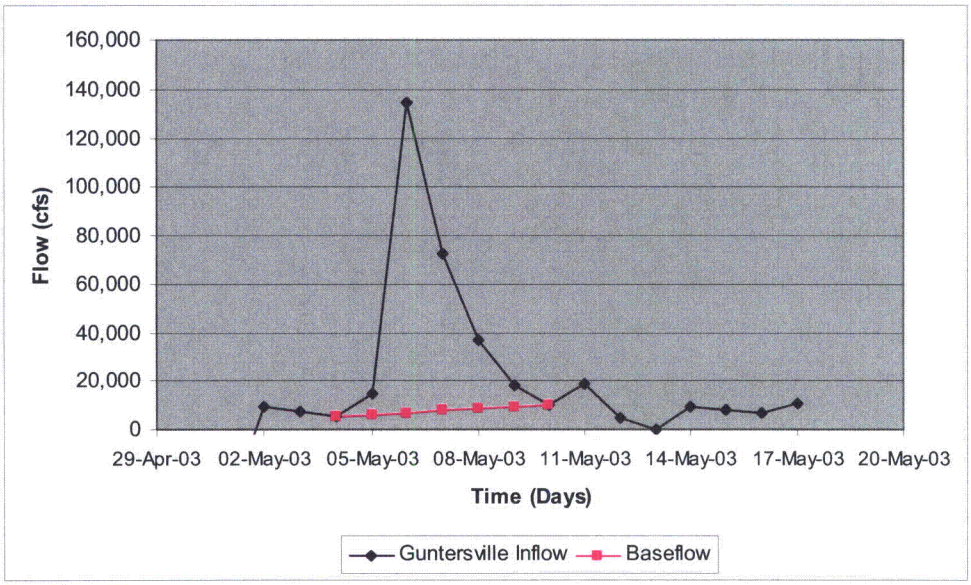

Figure 6: Base Flow Separation at Guntersville for May 2003 Flood

Subtracting the base flow from the stream flow calculated at Guntersville gives the runoff volume in DSF (second-foot-days, i.e. 1 cfs x 86,400 seconds per day) including runoff originating within the basin and rain falling directly on the reservoir. The volume of the rainfall over the reservoir is removed to provide the direct runoff volume from the land area of the subbasin.

The volume of rainfall is determined from the sum of the basin average rainfall depth over Subbasin 49 for the north reservoir area plus the basin average rainfall depth for Subbasin 50 over the south reservoir area. The reservoir is divided into north and south sections based on transects provided by the TVA, as shown in Table 6, with surface areas based on a constant water surface elevation of 595 feet (Reference 17).

Considering the fact that the total range in the water surface elevation is between 593.79 and 595.42 in 1973 and between 594.29 and 594.86 feet in 2003, as can be seen Tables 4 and 5, the assumption of a constant water surface elevation introduces minimal error into the mass balance.

Table 6: Surface Area (in acres) per Transect of Guntersville Reservoir (Reference 17)

	Section	River Mile Range	Elevation 595 feet	Elevation 620 feet	Elevation 640 feet	Elevation 660 feet
North Reservoir Sections (Subbasin 49)	Section 01 - 02	TRM 424.70 - 422.60	370	5,128	14,756	22,199
	Section 02 - 03	TRM 422.60 - 420.49	347	1,849	2,289	2,612
	Section 03 - 04	TRM 420.49 - 418.39	344	3,744	6,578	8,090
	Section 04 - 05	TRM 418.39 - 416.28	316	1,731	2,269	2,633
	Section 05 - 06	TRM 416.28 - 414.19	507	3,378	5,278	6,437
	Section 06 - 07	TRM 414.19 - 412.08	393	1,395	1,886	2,276
	Section 07 - 08	TRM 412.08 - 409.98	637	1,995	2,382	2,669
	Section 08 - 09	TRM 409.98 - 407.88	512	3,578	5,788	7,503
	Section 09 - 10	TRM 407.88 - 405.77	365	1,914	2,349	2,530
	Section 10 - 11	TRM 405.77 - 403.67	323	2,021	2,281	2,437
	Section 11 - 12	TRM 403.67 - 401.57	363	2,188	2,531	2,774
	Section 12 - 13	TRM 401.57 - 399.47	2,096	17,045	27,147	32,531
	Section 13 - 14	TRM 399.47 - 397.36	714	2,261	2,935	3,485
	Section 14 - 15	TRM 397.36 - 395.26	1,388	2,356	2,588	2,778
	Section 15 - 16	TRM 395.26 - 393.16 *	2,370	11,559	15,841	18,142
	Total Area, acres		11,045	62,141	96,898	119,095
	Total Area, sq. mi.		17	97	151	186

* Approximately 2/3 of the surface area along reach Section 15-16 area is upstream of TRM 394.5, accounted for in North Reservoir area

Table 6, continued

	Section	River Mile Range	Elevation 595 feet	Elevation 620 feet	Elevation 640 feet	Elevation 660 feet
South Reservoir Sections (Subbasin 50)	Section 15 - 16	TRM 395.26 - 393.16 *	1,167	5,693	7,802	8,936
	Section 16 - 17	TRM 393.16 - 391.06	599	928	1,024	1,085
	Section 17 - 18	TRM 391.06 - 388.95	676	913	1,037	1,182
	Section 18 - 19	TRM 388.95 - 386.85	1,523	1,935	2,107	2,266
	Section 19 - 20	TRM 386.85 - 384.74	1,068	1,280	1,345	1,415
	Section 20 - 21	TRM 384.74 - 382.64	1,308	1,437	1,515	1,571
	Section 21 - 22	TRM 382.64 - 380.54	3,421	14,054	31,230	40,474
	Section 22 - 23	TRM 380.54 - 378.44	1,572	2,055	2,536	2,867
	Section 23 - 24	TRM 378.44 - 376.34	4,623	15,498	22,358	25,115
	Section 24 - 25	TRM 376.34 - 374.23	2,290	3,160	3,605	3,840
	Section 25 - 26	TRM 374.23 - 372.13	4,862	6,980	8,532	9,543
	Section 26 - 27	TRM 372.13 - 370.03	2,374	3,433	4,088	4,511
	Section 27 - 28	TRM 370.03 - 367.92	1,817	2,380	2,605	2,707
	Section 28 - 29	TRM 367.92 - 365.82	2,212	2,861	3,172	3,402
	Section 29 - 30	TRM 365.82 - 363.72	1,755	2,246	2,507	2,627
	Section 30 - 31	TRM 363.72 - 361.62	4,703	7,109	8,620	9,737
	Section 31 - 32	TRM 361.62 - 359.51	1,896	2,279	2,554	2,787
	Section 32 - 33	TRM 359.51 - 357.41	4,085	6,985	8,659	10,063
	Section 33 - 34	TRM 357.41 - 355.31	8,424	13,757	17,328	20,200
	Section 34 - 35	TRM 355.31 - 353.21	1,181	1,372	1,498	1,649
	Section 35 - 36	TRM 353.21 - 351.10	2,340	3,487	4,082	4,550
	Section 36 - 37	TRM 351.10 - 349.00	980	980	980	980
	Total Area, acres		54,877	94,205	130,359	151,488
	Total Area, sq. mi.		86	147	204	237

* Approximately 1/3 of the surface area along reach Section 15-16 area is downstream of TRM 394.5, accounted for in South Reservoir area

The volume of precipitation over the basins is calculated from observed rainfall depths, accounting for rainfall over the land and reservoir separately. The areas used in the calculation of the rainfall volumes and the basin average depths of runoff are summarized in Table 7.

Table 7: Reference Areas for Mass Balance Calculation

AREA	Area, sq. mi.
Guntersville North Local	1,027
Guntersville South Local	1,069
Guntersville Lake Surface North *	17
Guntersville Lake Surface South *	86

* Based on contour data at Elevation 595 ft

The daily rainfall depths used for the runoff volume calculation are summed from the hourly rainfall series output in the following FLDHYDRO output files, discussed further in Section 7.2:

- Mar1973_Guntlocals_Fldhydro.out (Attachment 2-2)
- May2003_Guntlocals_Fldhydro.out (Attachment 2-4)

The daily rainfall depths for the March 1973 and May 2003 storms are summarized in Table 8.

Table 8: Rainfall Depths, in Inches, Used for Runoff Calculation

	Basin average daily precipitation depth, inches	
Date	Subbasin 49	Subbasin 50
March 15, 1973	3.77	2.43
March 16, 1973	4.35	2.57
Total	8.12	5.00
May 5, 2003	2.66	2.41
May 6, 2003	3.76	3.86
May 7, 2003	1.58	0.73
Total	8.00	7.00

The calculation of the local area runoff depth over the land mass of the subbasin is summarized in Table 9 (see Attachments 1-7 and 1-8). The direct runoff volume, in inches, calculated in Table 9 was used as the CHKVOL input values for FLDHYDRO for the March 1973 and May 2003 floods, as described in Section 7.2.

Table 9: Calculation of Runoff Depth over the Land Area of Subbasins 49 and 50

Volume description	March 1973	May 2003
Volume of rainfall on North Lake Surface, cubic feet (1)	320,694,528	315,955,200
Volume of rainfall on South Lake Surface cubic feet (1)	998,976,000	1,398,566,400
Lake Surface Runoff Volume, DSF (2)	15,274	19,844
Guntersville SRO Volume, DSF (3)	293,990	238,192
Without lake SRO Volume, DSF (4)	278,716	218,348
Without lake SRO Volume, inches of RO (5)	4.95	3.87

1) Reservoir area (mi^2) * PPT depth in inches * 1ft/12" * $(5280\ ft/mi)^2$

2) Total volume of PPT on reservoir ÷ 86,400 sec/day

3) Sum of daily average total flows (last column of Table 4 or 5)

4) Subtract rainfall volume from total volume

5) Inches of runoff = 12 in/ft * Volume in DSF * 86,400 sec/day ÷ $(5,280\ ft/mi)^2$

7.2 Calculation of Effective Precipitation

The effective (or excess) rainfall hyetograph is the series that is convoluted with the unit hydrograph to provide the direct runoff for each subbasin. 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 20).

Effective rainfall is obtained from observed rainfall data with the FLDHYDRO program (Reference 5). The FLDHYDRO program was developed by the TVA to implement the Antecedent Precipitation Index (API)/Runoff Index (RI) methodology developed by the United States Weather Bureau (USWB), as described in Reference 3. In brief, the method uses the API for a given day, which is calculated on the basis of a recession constant normally reported to range from 0.85 to 0.98 (Reference 20, page 101). A recession constant of 0.9 is assumed for this calculation. The API is used to obtain a RI that has been determined for the Tennessee River Valley region as a function of precipitation, location, and season. The RI is then used to obtain precipitation losses for each increment of rainfall.

The use of the loss function is discussed in the TVA White Paper (Reference 12), and the methodology is described in detail in the USWB publication (References 3 and 4). Input to FLDHYDRO is via a column delimited batch file. Input includes:

- Hourly precipitation gage readings for a maximum of 30 recording gages and daily precipitation readings for a maximum of 100 non-recording gages (For the gridded precipitation data sets, daily precipitation depths were calculated by summing hourly rainfall depths.)
- Indices to relate each non-recording gage record to a recording gage record for interpolation
- Thiessen coefficients to weight gage records for the calculation of basin average precipitation depths (not used for gridded precipitation data)
- Depth of runoff for the period of rainfall

For this calculation, input for each run included the following data and "flags":

- NARFE = 1 to obtain a printout of flood hydrographs only
- NRI = 1 for the number of Runoff Indices to be used per basin
- NCPTS = 1 for the number of sites for surface runoff volume check (set to zero if a runoff check volume is not supplied)
- NSUBW = 2 for number of sub-watersheds (Subbasin 49 and 50)
- NREC = 2 for the number of recorders (using only one time series per basin as one "recorder")
- NSTNS = 2 for total number of stations (i.e. no non-recording stations used)
- STAB = 2 when API areas vary with watershed
- ITDGR = 0 for the hour at which each gage is read
- NAMSTA = The name of each recording gage (name of subbasin for this application)
- BEGDR = The starting date (entered in MMDDYY format)

- BEGTR = Time at which the first hour of rainfall has been recorded (between 01 to 24)
- NHR = The number of hourly readings for the storm
- SHRAIN = The time series of hourly rainfall readings (in 10F8.0 format) obtained from processing of NWS gridded rainfall
- NDRAPI = The number of days of antecedent rainfall listed before the storm
- API = The initial API at the beginning of the antecedent daily rainfall series (setting this value to 1.0 is sufficient when a month of data is used because the initial condition has negligible impact on the final API for a sufficiently long series)
- APRAIN = The time series of daily rainfall readings (in 10F8.0 format) obtained from the sum of hourly rainfall data for approximately one month prior to the start of the hourly rainfall
- BAREA = The subbasin area in square miles
- APITYPE = The API zone with SE = 1, E = 2, NE = 3, N = 4, W = 5, and S = 6. Subbasin 49 is assumed to be in the N zone; Subbasin 50 is assumed to be in the S zone (see Figure 7).
- NSPW = 1 for number of rainfall stations for each sub-watershed (for gridded data there are no Thiessen weighting factors)
- NUMVOL = Number of watersheds above surface runoff volume check point
- CHKVOL = The volume of surface runoff in inches (calculated from outflow hydrographs after base flow separation)

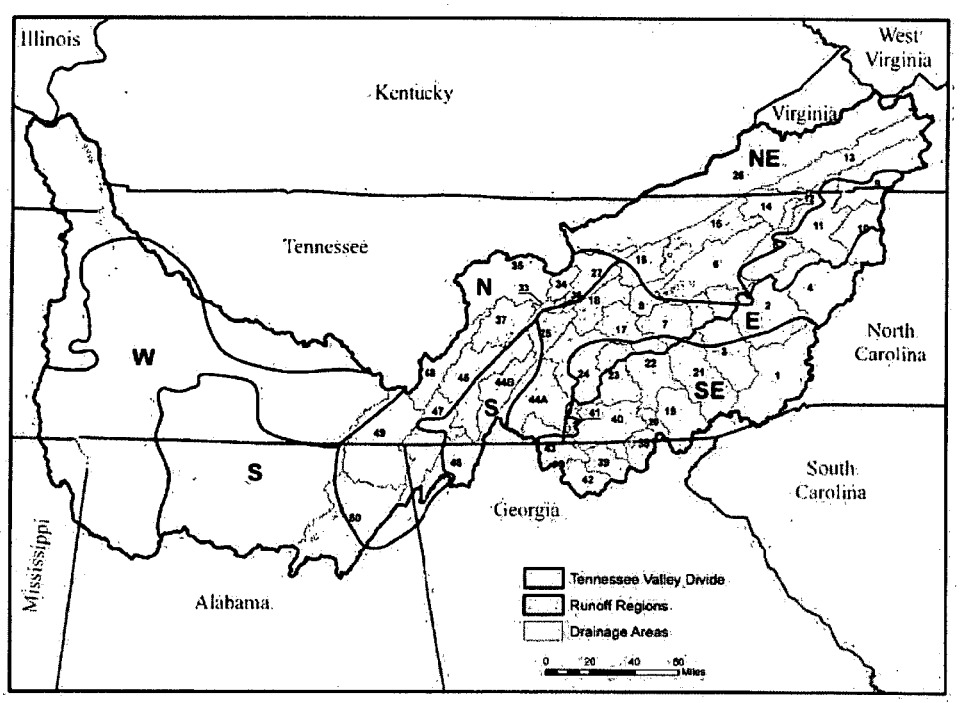

Figure 7: API Regions for Application of TVA FLDHYDRO Program

Input data and parameters for running FLDHYDRO to get effective basin average rainfall for the dry land areas of Subbasins 49 and 50 were written to the following batch input files and included as attachments to this calculation:

- Attachment 2-1 Mar1973_GuntLocals_Fldhydro.dat
- Attachment 2-3 May2003_GuntLocals_Fldhydro.dat

The corresponding FLDHYDRO output files are also provided as attachments:

- Attachment 2-2 Mar1973_GuntLocals_Fldhydro.out
- Attachment 2-4 May2003_GuntLocals_Fldhydro.out

FLDHYDRO can also carry out the convolution of the unit hydrograph with the effective rainfall. The input files for the FLDHYDRO runs were set up in this manner, but convolution was done in a spreadsheet for this calculation because the convolution routines in FLDHYDRO had not been validated at the time of execution.

The output for each basin provides an echo of data input and tabulated cumulative rainfall and effective rainfall (runoff) depths. The cumulative effective rainfall depth series were converted to incremental time series for input to HEC-HMS in the spreadsheet "FLDHYDRO processing.xls," provided as Attachment 1-5 to this calculation.

The cumulative precipitation and excess rainfall depths for the two validation runs for each of the subbasins are plotted in Figures 8 to 11 (compare with Table 8). The use of the excess rainfall, or runoff, time series as input to the convolution calculation is described in the next section.

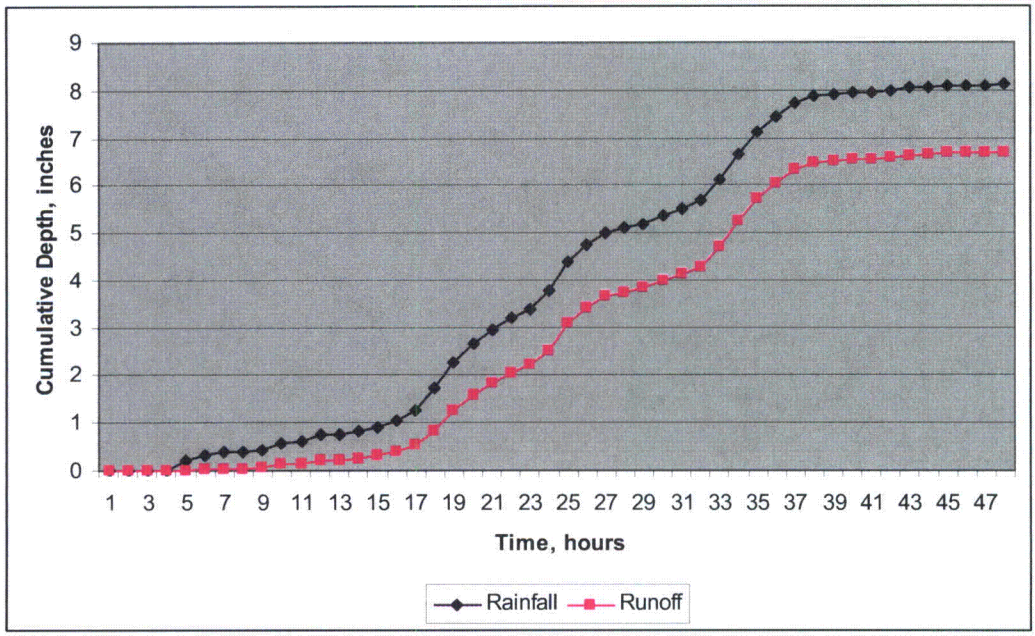

Figure 8: Cumulative Precipitation and Runoff Series for March 1973 Event in Subbasin 49

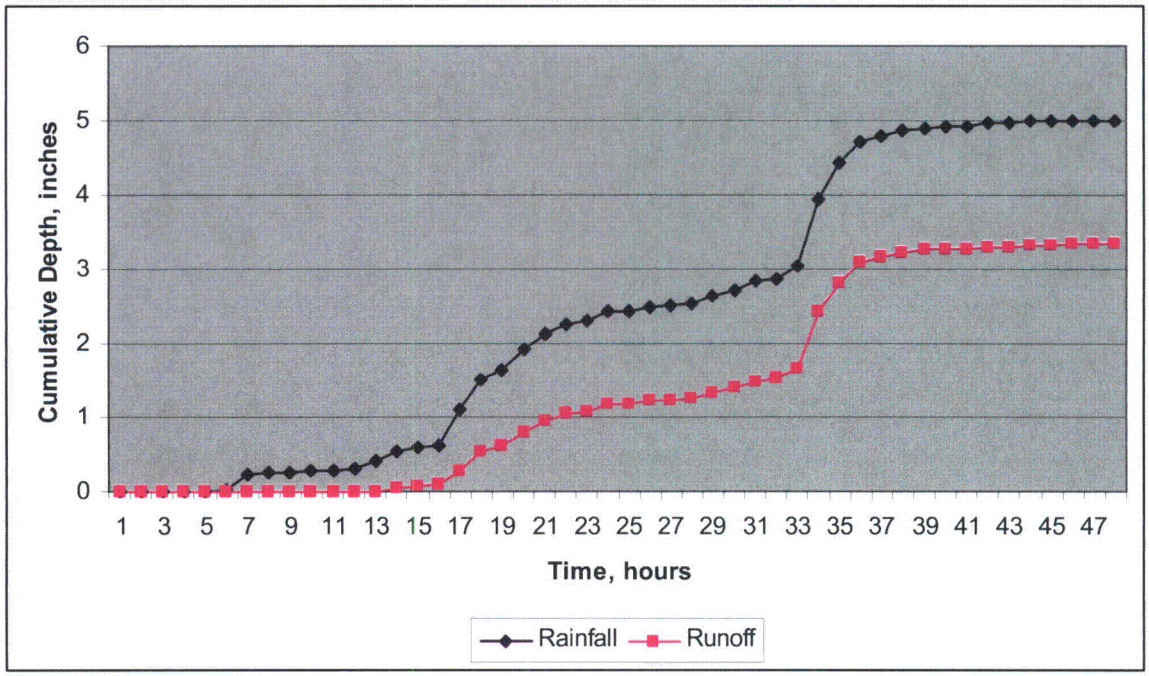

Figure 9: Cumulative Precipitation and Runoff Series for March 1973 Event in Subbasin 50

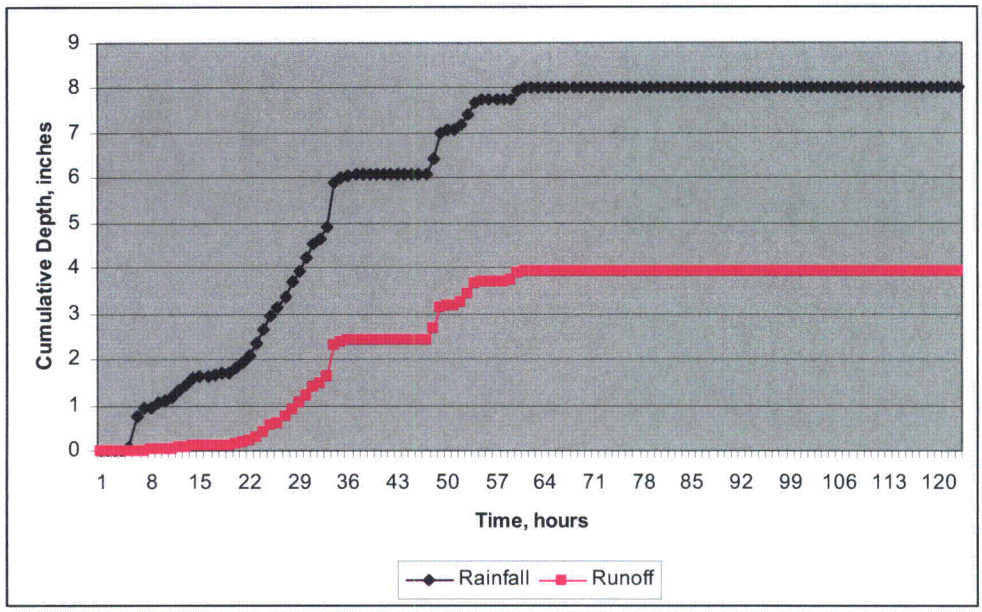

Figure 10: Cumulative Precipitation and Runoff Series for May 2003 Event in Subbasin 49

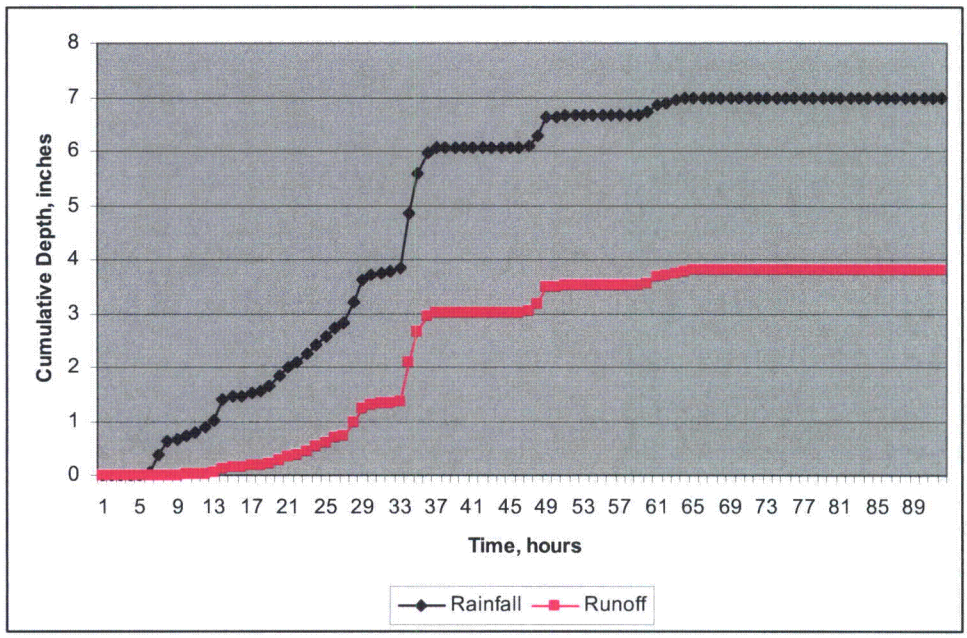

Figure 11: Cumulative Precipitation and Runoff series for May 2003 Event in Subbasin 50

7.3 Development of Local Inflow Hydrographs

Local inflow hydrographs were developed for input to the SOCH model of the Tennessee River between Guntersville and Nickajack Dams for the March 1973 and May 2003 floods, as described below.

7.3.1 Convolution of Dry Land Hydrographs

Hydrographs for the local runoff from each of the subbasins are developed by convolution of the TVA unit hydrograph ordinates with the effective rainfall time series as developed in FLDHYDRO using standard engineering procedures, as summarized in Section 4 (see References 2 and 4).

The convolutions for Subbasins 49 and 50 are provided in Tables 10 and 11, respectively, for the March 1973 flood and in Tables 12 and 13, respectively, for the May 2003 flood.

The calculations, including the conversion of one-hour rainfall depths to 6-hour depths to coincide with the duration of the unit hydrographs are presented in the following spreadsheets, which are provided as attachments to this calculation:

- Convolution 1973_B49.xls (Attachment 1-1)
- Convolution 1973_B50.xls (Attachment 1-2)
- Convolution 2003_B49.xls (Attachment 1-3)
- Convolution 2003_B50.xls (Attachment 1-4)

Table 10: Subbasin 49 Convolution for March 1973 Flood

Date	Time	6hr UH	Rainfall Excess, inches								Q
	hrs	cfs/in	0.02	0.20	0.62	1.69	1.47	2.04	0.55	0.12	cfs
March 15, 1973	0	0	0								0
March 15, 1973	3	2,564	51								51
March 15, 1973	6	5,917	118	0							118
March 15, 1973	9	12,031	241	513							753
March 15, 1973	12	18,243	365	1,183	0						1,548
March 15, 1973	15	22,089	442	2,406	1,590						4,438
March 15, 1973	18	21,202	424	3,649	3,668	0					7,741
March 15, 1973	21	18,342	367	4,418	7,459	4,333					16,577
March 15, 1973	24	14,595	292	4,240	11,311	9,999	0				25,842
March 16, 1973	27	12,129	243	3,668	13,695	20,332	3,769				41,707
March 16, 1973	30	10,354	207	2,919	13,145	30,831	8,698	0			55,800
March 16, 1973	33	8,875	178	2,426	11,372	37,331	17,685	5,230			74,221
March 16, 1973	36	7,790	156	2,071	9,049	35,831	26,818	12,070	0		85,994
March 16, 1973	39	6,804	136	1,775	7,520	30,998	32,471	24,543	1,410		98,853
March 16, 1973	42	6,114	122	1,558	6,420	24,665	31,166	37,216	3,254	0	104,402
March 16, 1973	45	5,424	108	1,361	5,503	20,499	26,963	45,062	6,617	308	106,419
March 16, 1973	48	4,931	99	1,223	4,830	17,499	21,454	43,251	10,034	710	99,099
March 17, 1973	51	4,438	89	1,085	4,219	14,999	17,830	37,417	12,149	1,444	89,231
March 17, 1973	54	4,043	81	986	3,791	13,166	15,221	29,773	11,661	2,189	76,867
March 17, 1973	57	3,747	75	888	3,363	11,499	13,046	24,744	10,088	2,651	66,353
March 17, 1973	60	3,451	69	809	3,057	10,333	11,452	21,123	8,027	2,544	57,413
March 17, 1973	63	3,156	63	749	2,751	9,166	10,002	18,105	6,671	2,201	49,709
March 17, 1973	66	2,958	59	690	2,507	8,333	8,988	15,892	5,695	1,751	43,915
March 17, 1973	69	2,663	53	631	2,323	7,499	7,973	13,881	4,881	1,456	38,697
March 17, 1973	72	2,465	49	592	2,140	6,833	7,248	12,472	4,285	1,243	34,861
March 18, 1973	75	2,219	44	533	1,956	6,333	6,523	11,064	3,742	1,065	31,261
March 18, 1973	78	1,972	39	493	1,834	5,833	5,943	10,058	3,363	935	28,499
March 18, 1973	81	1,775	36	444	1,651	5,333	5,508	9,053	2,983	817	25,824
March 18, 1973	84	1,578	32	394	1,528	5,000	5,074	8,248	2,712	734	23,721
March 18, 1973	87	1,381	28	355	1,376	4,500	4,639	7,644	2,441	651	21,633
March 18, 1973	90	1,183	24	316	1,223	4,166	4,349	7,041	2,224	592	19,933
March 18, 1973	93	1,035	21	276	1,101	3,750	3,914	6,437	2,061	533	18,092
March 18, 1973	96	888	18	237	978	3,333	3,624	6,035	1,898	485	16,608
March 19, 1973	99	740	15	207	856	3,000	3,262	5,432	1,736	450	14,956
March 19, 1973	102	592	12	178	734	2,666	2,899	5,029	1,627	414	13,559
March 19, 1973	105	542	11	148	642	2,333	2,609	4,526	1,464	379	12,113
March 19, 1973	108	493	10	118	550	2,000	2,319	4,023	1,356	355	10,732
March 19, 1973	111	444	9	108	459	1,750	2,029	3,621	1,220	320	9,516
March 19, 1973	114	394	8	99	367	1,500	1,740	3,219	1,085	296	8,312
March 19, 1973	117	345	7	89	336	1,250	1,522	2,816	976	266	7,263
March 19, 1973	120	296	6	79	306	1,000	1,305	2,414	868	237	6,214
March 20, 1973	123	247	5	69	275	917	1,087	2,112	759	213	5,437
March 20, 1973	126	197	4	59	245	833	870	1,811	651	189	4,661
March 20, 1973	129	148	3	49	214	750	797	1,509	569	166	4,057
March 20, 1973	132	99	2	39	183	667	725	1,207	488	142	3,453
March 20, 1973	135	49	1	30	153	583	652	1,106	407	124	3,056
March 20, 1973	138	0	0	20	122	500	580	1,006	325	107	2,660
March 20, 1973	141			10	92	417	507	905	298	89	2,318
March 20, 1973	144			0	61	333	435	805	271	71	1,976
March 21, 1973	147				31	250	362	704	244	65	1,656
March 21, 1973	150				0	167	290	604	217	59	1,336
March 21, 1973	153					83	217	503	190	53	1,047
March 21, 1973	156					0	145	402	163	47	757
March 21, 1973	159						72	302	136	41	551
March 21, 1973	162						0	201	108	36	345
March 21, 1973	165							101	81	30	212
March 21, 1973	168							0	54	24	78
March 22, 1973	171								27	18	45
March 22, 1973	174								0	12	12
March 22, 1973	177									6	6
March 22, 1973	180									0	0
March 22, 1973	183										0

Table 11: Subbasin 50 Convolution for March 1973 Flood

Date	Time	6hr UH	Rainfall Excess (inches)								Q
	hrs	cfs	0.00	0.00	0.53	0.64	0.24	1.68	0.23	0.03	cfs
March 15, 1973	0	0	0								0
March 15, 1973	3	3,266	0								0
March 15, 1973	6	8,164	0	0							0
March 15, 1973	9	14,492	0	0							0
March 15, 1973	12	20,411	0	0	0						0
March 15, 1973	15	22,963	0	0	1,731						1,731
March 15, 1973	18	20,921	0	0	4,327	0					4,327
March 15, 1973	21	17,145	0	0	7,681	2,090					9,771
March 15, 1973	24	13,676	0	0	10,818	5,225	0				16,043
March 16, 1973	27	11,226	0	0	12,170	9,275	784				22,229
March 16, 1973	30	9,593	0	0	11,088	13,063	1,959	0			26,111
March 16, 1973	33	8,471	0	0	9,087	14,696	3,478	5,487			32,748
March 16, 1973	36	7,756	0	0	7,248	13,390	4,899	13,716	0		39,253
March 16, 1973	39	7,042	0	0	5,950	10,973	5,511	24,346	751		47,532
March 16, 1973	42	6,532	0	0	5,084	8,752	5,021	34,291	1,878	0	55,027
March 16, 1973	45	5,817	0	0	4,489	7,185	4,115	38,577	3,333	98	57,797
March 16, 1973	48	5,358	0	0	4,111	6,140	3,282	35,148	4,695	245	53,620
March 16, 1973	51	4,797	0	0	3,732	5,421	2,694	28,804	5,281	435	46,368
March 17, 1973	54	4,337	0	0	3,462	4,964	2,302	22,975	4,812	612	39,127
March 17, 1973	57	3,776	0	0	3,083	4,507	2,033	18,860	3,943	689	33,115
March 17, 1973	60	3,368	0	0	2,840	4,180	1,862	16,117	3,145	628	28,771
March 17, 1973	63	2,858	0	0	2,542	3,723	1,690	14,231	2,582	514	25,282
March 17, 1973	66	2,551	0	0	2,299	3,429	1,568	13,031	2,206	410	22,943
March 17, 1973	69	2,347	0	0	2,001	3,070	1,396	11,830	1,948	337	20,583
March 17, 1973	72	2,194	0	0	1,785	2,776	1,286	10,973	1,784	288	18,892
March 17, 1973	75	2,041	0	0	1,515	2,417	1,151	9,773	1,620	254	16,729
March 17, 1973	78	1,939	0	0	1,352	2,155	1,041	9,001	1,502	233	15,285
March 18, 1973	81	1,837	0	0	1,244	1,829	906	8,058	1,338	211	13,587
March 18, 1973	84	1,735	0	0	1,163	1,633	808	7,287	1,232	196	12,319
March 18, 1973	87	1,633	0	0	1,082	1,502	686	6,344	1,103	175	10,891
March 18, 1973	90	1,531	0	0	1,028	1,404	612	5,658	998	161	9,861
March 18, 1973	93	1,429	0	0	974	1,306	563	4,801	868	144	8,656
March 18, 1973	96	1,327	0	0	920	1,241	527	4,286	775	130	7,878
March 18, 1973	99	1,225	0	0	865	1,176	490	3,943	657	113	7,245
March 18, 1973	102	1,123	0	0	811	1,110	465	3,686	587	101	6,761
March 18, 1973	105	1,021	0	0	757	1,045	441	3,429	540	86	6,298
March 19, 1973	108	919	0	0	703	980	416	3,258	505	77	5,938
March 19, 1973	111	816	0	0	649	914	392	3,086	469	70	5,581
March 19, 1973	114	714	0	0	595	849	367	2,915	446	66	5,238
March 19, 1973	117	561	0	0	541	784	343	2,743	423	61	4,895
March 19, 1973	120	408	0	0	487	718	318	2,572	399	58	4,553
March 19, 1973	123	306	0	0	433	653	294	2,400	376	55	4,211
March 19, 1973	126	204	0	0	379	588	269	2,229	352	52	3,869
March 19, 1973	129	102	0	0	297	523	245	2,057	329	49	3,500
March 19, 1973	132	0	0	0	216	457	220	1,886	305	46	3,131
March 20, 1973	135			0	162	359	196	1,715	282	43	2,757
March 20, 1973	138			0	108	261	171	1,543	258	40	2,382
March 20, 1973	141				54	196	135	1,372	235	37	2,028
March 20, 1973	144				0	131	98	1,200	211	34	1,674
March 20, 1973	147					65	73	943	188	31	1,300
March 20, 1973	150					0	49	686	164	28	927
March 20, 1973	153						24	514	129	24	692
March 20, 1973	156						0	343	94	21	458
March 20, 1973	159							171	70	17	259
March 21, 1973	162							0	47	12	59
March 21, 1973	165								23	9	33
March 21, 1973	168								0	6	6
March 21, 1973	171									3	3
March 21, 1973	174									0	0

Table 12: Subbasin 49 Convolution for May 2003 Flood

Date	Time	6hr UH	Rainfall Excess (inches)											Q
	hrs	cfs	0.00	0.06	0.07	0.30	0.78	1.21	0.01	0.26	0.97	0.22	0.05	cfs
May 5, 2003	0	0	0											0
May 5, 2003	3	2,564	0											0
May 5, 2003	6	5,917	0	0										0
May 5, 2003	9	12,031	0	154										154
May 5, 2003	12	18,243	0	355	0									355
May 5, 2003	15	22,089	0	722	179									901
May 5, 2003	18	21,202	0	1,095	414	0								1,509
May 5, 2003	21	18,342	0	1,325	842	769								2,937
May 5, 2003	24	14,595	0	1,272	1,277	1,775	0							4,324
May 6, 2003	27	12,129	0	1,101	1,546	3,609	2,000							8,256
May 6, 2003	30	10,354	0	876	1,484	5,473	4,615	0						12,448
May 6, 2003	33	8,875	0	728	1,284	6,627	9,384	3,102						21,125
May 6, 2003	36	7,790	0	621	1,022	6,360	14,230	7,159	0					29,392
May 6, 2003	39	6,804	0	533	849	5,503	17,230	14,557	26					38,696
May 6, 2003	42	6,114	0	467	725	4,378	16,537	22,074	59	0				44,241
May 6, 2003	45	5,424	0	408	621	3,639	14,307	26,728	120	667				46,490
May 6, 2003	48	4,931	0	367	545	3,106	11,384	25,654	182	1,538	0			42,777
May 7, 2003	51	4,438	0	325	476	2,663	9,461	22,194	221	3,128	2,487			40,955
May 7, 2003	54	4,043	0	296	428	2,337	8,076	17,659	212	4,743	5,739	0		39,491
May 7, 2003	57	3,747	0	266	380	2,041	6,923	14,676	183	5,743	11,670	564		42,447
May 7, 2003	60	3,451	0	243	345	1,834	6,076	12,529	146	5,512	17,696	1,302	0	45,683
May 7, 2003	63	3,156	0	225	311	1,627	5,307	10,739	121	4,769	21,426	2,647	128	47,300
May 7, 2003	66	2,958	0	207	283	1,479	4,769	9,426	104	3,795	20,566	4,014	296	44,938
May 7, 2003	69	2,663	0	189	262	1,331	4,230	8,233	89	3,154	17,792	4,860	602	40,742
May 7, 2003	72	2,465	0	178	242	1,213	3,846	7,398	78	2,692	14,157	4,664	912	35,379
May 8, 2003	75	2,219	0	160	221	1,124	3,461	6,563	68	2,308	11,765	4,035	1,104	30,809
May 8, 2003	78	1,972	0	148	207	1,035	3,154	5,966	61	2,025	10,044	3,211	1,060	26,911
May 8, 2003	81	1,775	0	133	186	947	2,923	5,369	54	1,769	8,609	2,668	917	23,576
May 8, 2003	84	1,578	0	118	173	888	2,692	4,892	49	1,590	7,557	2,278	730	20,966
May 8, 2003	87	1,381	0	107	155	799	2,461	4,534	44	1,410	6,600	1,953	606	18,670
May 8, 2003	90	1,183	0	95	138	740	2,308	4,176	40	1,282	5,931	1,714	518	16,941
May 8, 2003	93	1,035	0	83	124	666	2,077	3,818	37	1,154	5,261	1,497	444	15,161
May 8, 2003	96	888	0	71	110	592	1,923	3,580	35	1,051	4,783	1,345	390	13,879
May 9, 2003	99	740	0	62	97	533	1,731	3,222	32	974	4,304	1,193	340	12,487
May 9, 2003	102	592	0	53	83	473	1,538	2,983	30	897	3,922	1,085	306	11,370
May 9, 2003	105	542	0	44	72	414	1,385	2,685	27	820	3,635	976	271	10,330
May 9, 2003	108	493	0	36	62	355	1,231	2,386	25	769	3,348	889	247	9,347
May 9, 2003	111	444	0	33	52	311	1,077	2,148	22	692	3,061	824	222	8,441
May 9, 2003	114	394	0	30	41	266	923	1,909	20	641	2,870	759	202	7,661
May 9, 2003	117	345	0	27	38	222	808	1,670	18	577	2,583	694	187	6,823
May 9, 2003	120	296	0	24	35	178	692	1,432	16	513	2,391	651	173	6,103
May 10, 2003	123	247	0	21	31	163	577	1,253	14	462	2,152	586	158	5,415
May 10, 2003	126	197	0	18	28	148	462	1,074	12	410	1,913	542	148	4,754
May 10, 2003	129	148	0	15	24	133	423	895	10	359	1,722	488	133	4,202
May 10, 2003	132	99	0	12	21	118	385	716	9	308	1,530	434	123	3,656
May 10, 2003	135	49	0	9	17	104	346	656	7	269	1,339	391	111	3,249
May 10, 2003	138	0	0	6	14	89	308	597	6	231	1,148	347	99	2,843
May 10, 2003	141			3	10	74	269	537	5	192	1,004	304	89	2,488
May 10, 2003	144			0	7	59	231	477	5	154	861	260	79	2,133
May 11, 2003	147				3	44	192	418	4	141	717	228	69	1,817
May 11, 2003	150				0	30	154	358	4	128	574	195	59	1,502
May 11, 2003	153					15	115	298	3	115	526	163	52	1,288
May 11, 2003	156					0	77	239	3	103	478	130	44	1,074
May 11, 2003	159						38	179	2	90	430	119	37	896
May 11, 2003	162						0	119	2	77	383	108	30	719
May 11, 2003	165							60	1	64	335	98	27	585
May 11, 2003	168							0	1	51	287	87	25	451
May 12, 2003	171								0	38	239	76	22	376
May 12, 2003	174								0	26	191	65	20	302
May 12, 2003	177									13	143	54	17	228
May 12, 2003	180									0	96	43	15	154
May 12, 2003	183										48	33	12	93
May 12, 2003	186										0	22	10	32
May 12, 2003	189											11	7	18
May 12, 2003	192											0	5	5
May 13, 2003	195												2	2
May 13, 2003	198												0	0

Table 13: Subbasin 50 Convolution for May 2003 Flood

Date	Time	6hr UH	Rainfall Excess											Q
	hrs	cfs	0.00	0.04	0.15	0.34	0.77	1.65	0.07	0.17	0.32	0.06	0.23	cfs
May 5, 2003	0	0	0											0
May 5, 2003	3	3,266	0											0
May 5, 2003	6	8,164	0	0										0
May 5, 2003	9	14,492	0	131										131
May 5, 2003	12	20,411	0	327	0									327
May 5, 2003	15	22,963	0	580	490									1,070
May 5, 2003	18	20,921	0	816	1,225	0								2,041
May 5, 2003	21	17,145	0	919	2,174	1,110								4,203
May 5, 2003	24	13,676	0	837	3,062	2,776	0							6,674
May 6, 2003	27	11,226	0	686	3,444	4,927	2,515							11,572
May 6, 2003	30	9,593	0	547	3,138	6,940	6,287	0						16,912
May 6, 2003	33	8,471	0	449	2,572	7,807	11,159	5,389						27,376
May 6, 2003	36	7,756	0	384	2,051	7,113	15,717	13,471	0					38,736
May 6, 2003	39	7,042	0	339	1,684	5,829	17,681	23,912	229					49,674
May 6, 2003	42	6,532	0	310	1,439	4,650	16,110	33,678	572	0				56,758
May 6, 2003	45	5,817	0	282	1,271	3,817	13,202	37,888	1,014	555				58,029
May 6, 2003	48	5,358	0	261	1,163	3,262	10,530	34,520	1,429	1,388	0			52,554
May 7, 2003	51	4,797	0	233	1,056	2,880	8,644	28,290	1,607	2,464	1,045			46,219
May 7, 2003	54	4,337	0	214	980	2,637	7,387	22,565	1,465	3,470	2,613	0		41,330
May 7, 2003	57	3,776	0	192	873	2,394	6,522	18,523	1,200	3,904	4,637	196		38,441
May 7, 2003	60	3,368	0	173	804	2,221	5,972	15,829	957	3,557	6,532	490	0	36,535
May 7, 2003	63	2,858	0	151	719	1,978	5,422	13,977	786	2,915	7,348	870	751	34,916
May 7, 2003	66	2,551	0	135	651	1,822	5,029	12,798	672	2,325	6,695	1,225	1,878	33,228
May 7, 2003	69	2,347	0	114	566	1,631	4,479	11,619	593	1,908	5,487	1,378	3,333	31,109
May 7, 2003	72	2,194	0	102	505	1,475	4,126	10,777	543	1,631	4,376	1,255	4,695	29,485
May 8, 2003	75	2,041	0	94	429	1,284	3,693	9,598	493	1,440	3,592	1,029	5,281	26,934
May 8, 2003	78	1,939	0	88	383	1,145	3,340	8,841	457	1,319	3,070	821	4,812	24,274
May 8, 2003	81	1,837	0	82	352	972	2,908	7,914	407	1,197	2,711	674	3,943	21,159
May 8, 2003	84	1,735	0	78	329	867	2,593	7,157	375	1,110	2,482	576	3,145	18,712
May 8, 2003	87	1,633	0	73	306	798	2,200	6,231	336	989	2,253	508	2,582	16,277
May 8, 2003	90	1,531	0	69	291	746	1,965	5,557	304	911	2,090	465	2,206	14,604
May 8, 2003	93	1,429	0	65	276	694	1,807	4,715	264	815	1,862	423	1,948	12,869
May 8, 2003	96	1,327	0	61	260	659	1,690	4,210	236	737	1,715	392	1,784	11,744
May 9, 2003	99	1,225	0	57	245	625	1,572	3,873	200	642	1,535	349	1,620	10,717
May 9, 2003	102	1,123	0	53	230	590	1,493	3,620	179	573	1,388	321	1,502	9,949
May 9, 2003	105	1,021	0	49	214	555	1,414	3,368	164	486	1,208	288	1,338	9,085
May 9, 2003	108	919	0	45	199	520	1,336	3,199	154	434	1,078	260	1,232	8,457
May 9, 2003	111	816	0	41	184	486	1,257	3,031	143	399	914	227	1,103	7,785
May 9, 2003	114	714	0	37	168	451	1,179	2,863	136	373	816	202	998	7,223
May 9, 2003	117	561	0	33	153	416	1,100	2,694	129	347	751	171	868	6,663
May 9, 2003	120	408	0	29	138	382	1,022	2,526	121	330	702	153	775	6,176
May 10, 2003	123	306	0	22	122	347	943	2,357	114	312	653	141	657	5,670
May 10, 2003	126	204	0	16	107	312	864	2,189	107	295	621	132	587	5,230
May 10, 2003	129	102	0	12	84	278	786	2,021	100	278	588	122	540	4,808
May 10, 2003	132	0	0	8	61	243	707	1,852	93	260	555	116	505	4,401
May 10, 2003	135			4	46	191	629	1,684	86	243	523	110	469	3,984
May 10, 2003	138			0	31	139	550	1,516	79	226	490	104	446	3,579
May 10, 2003	141				15	104	432	1,347	71	208	457	98	423	3,156
May 10, 2003	144				0	69	314	1,179	64	191	425	92	399	2,733
May 11, 2003	147					35	236	926	57	173	392	86	376	2,280
May 11, 2003	150					0	157	674	50	156	359	80	352	1,828
May 11, 2003	153						79	505	39	139	327	73	329	1,491
May 11, 2003	156						0	337	29	121	294	67	305	1,153
May 11, 2003	159							168	21	95	261	61	282	889
May 11, 2003	162							0	14	69	229	55	258	626
May 11, 2003	165								7	52	180	49	235	523
May 11, 2003	168								0	35	131	43	211	419
May 12, 2003	171									17	98	34	188	337
May 12, 2003	174									0	65	24	164	254
May 12, 2003	177										33	18	129	180
May 12, 2003	180										0	12	94	106
May 12, 2003	183											6	70	77
May 12, 2003	186											0	47	47
May 12, 2003	189												23	23
May 12, 2003	192												0	0

7.3.2 Flow Series for Rainfall on Reservoirs

The hourly average flow series for rainfall on the reservoirs is developed by dividing the total volume of rain falling each hour [volume/hour] by 3,600 [seconds/hour]. The volume of rainfall falling each hour is obtained as the product of total surface area and the measured rainfall for each subbasin (17 square miles for Subbasin 49 and 86 square miles for Subbasin 50).

Calculations are presented in the spreadsheet "Guntersville_Precipitation over water.xls," provided as Attachment 1-9 to this calculation, and summarized in Tables 14 and 15.

Table 14: Calculation of Flow Series for Rainfall over Reservoir for March 1973 Storm

North Reservoir				
Date and Time	Time, hours	Precipitation, in inches over Subbasin 49		Q (ft3/s)
		Cumulative	Increment	
March 15, 1973	0	0.00		
March 15, 1973	1	0.00	0.00	0
March 15, 1973	2	0.00	0.00	0
March 15, 1973	3	0.00	0.00	0
March 15, 1973	4	0.00	0.00	0
March 15, 1973	5	0.20	0.20	2,194
March 15, 1973	6	0.32	0.12	1,316
March 15, 1973	7	0.38	0.06	658
March 15, 1973	8	0.41	0.03	329
March 15, 1973	9	0.45	0.04	439
March 15, 1973	10	0.57	0.12	1,316
March 15, 1973	11	0.62	0.05	549
March 15, 1973	12	0.75	0.13	1,426
March 15, 1973	13	0.76	0.01	110
March 15, 1973	14	0.83	0.07	768
March 15, 1973	15	0.91	0.08	878
March 15, 1973	16	1.05	0.14	1,536
March 15, 1973	17	1.27	0.22	2,414
March 15, 1973	18	1.72	0.45	4,937
March 15, 1973	19	2.27	0.55	6,034
March 15, 1973	20	2.66	0.39	4,279
March 15, 1973	21	2.94	0.28	3,072
March 15, 1973	22	3.20	0.26	2,852
March 15, 1973	23	3.40	0.20	2,194
March 15, 1973	24	3.77	0.37	4,059
March 16, 1973	25	4.38	0.61	6,692
March 16, 1973	26	4.74	0.36	3,949
March 16, 1973	27	5.01	0.27	2,962
March 16, 1973	28	5.11	0.10	1,097
March 16, 1973	29	5.19	0.08	878
March 16, 1973	30	5.36	0.17	1,865
March 16, 1973	31	5.51	0.15	1,646
March 16, 1973	32	5.68	0.17	1,865
March 16, 1973	33	6.11	0.43	4,717
March 16, 1973	34	6.66	0.55	6,034
March 16, 1973	35	7.14	0.48	5,266
March 16, 1973	36	7.45	0.31	3,401
March 16, 1973	37	7.73	0.28	3,072
March 16, 1973	38	7.88	0.15	1,646
March 16, 1973	39	7.91	0.03	329
March 16, 1973	40	7.95	0.04	439
March 16, 1973	41	7.97	0.02	219
March 16, 1973	42	8.00	0.03	329
March 16, 1973	43	8.05	0.05	549
March 16, 1973	44	8.08	0.03	329
March 16, 1973	45	8.09	0.01	110
March 16, 1973	46	8.10	0.01	110
March 16, 1973	47	8.11	0.01	110
March 16, 1973	48	8.12	0.01	110

South Reservoir				
Date and Time	Time, hours	Precipitation, in inches over Subbasin 50		Q (ft3/s)
		Cumulative	Increment	
March 15, 1973	0	0.00		
March 15, 1973	1	0.00	0.00	0
March 15, 1973	2	0.00	0.00	0
March 15, 1973	3	0.00	0.00	0
March 15, 1973	4	0.00	0.00	0
March 15, 1973	5	0.00	0.00	0
March 15, 1973	6	0.02	0.02	1,110
March 15, 1973	7	0.23	0.21	11,655
March 15, 1973	8	0.26	0.03	1,665
March 15, 1973	9	0.26	0.00	0
March 15, 1973	10	0.27	0.01	555
March 15, 1973	11	0.28	0.01	555
March 15, 1973	12	0.30	0.02	1,110
March 15, 1973	13	0.40	0.10	5,550
March 15, 1973	14	0.55	0.15	8,325
March 15, 1973	15	0.58	0.03	1,665
March 15, 1973	16	0.62	0.04	2,220
March 15, 1973	17	1.10	0.48	26,639
March 15, 1973	18	1.52	0.42	23,309
March 15, 1973	19	1.65	0.13	7,215
March 15, 1973	20	1.92	0.27	14,985
March 15, 1973	21	2.13	0.21	11,655
March 15, 1973	22	2.25	0.12	6,660
March 15, 1973	23	2.31	0.06	3,330
March 15, 1973	24	2.43	0.12	6,660
March 16, 1973	25	2.43	0.00	0
March 16, 1973	26	2.48	0.05	2,775
March 16, 1973	27	2.51	0.03	1,665
March 16, 1973	28	2.53	0.02	1,110
March 16, 1973	29	2.63	0.10	5,550
March 16, 1973	30	2.72	0.09	4,995
March 16, 1973	31	2.85	0.13	7,215
March 16, 1973	32	2.88	0.03	1,665
March 16, 1973	33	3.05	0.17	9,435
March 16, 1973	34	3.96	0.91	50,504
March 16, 1973	35	4.43	0.47	26,084
March 16, 1973	36	4.72	0.29	16,095
March 16, 1973	37	4.80	0.08	4,440
March 16, 1973	38	4.87	0.07	3,885
March 16, 1973	39	4.91	0.04	2,220
March 16, 1973	40	4.92	0.01	555
March 16, 1973	41	4.92	0.00	0
March 16, 1973	42	4.97	0.05	2,775
March 16, 1973	43	4.97	0.00	0
March 16, 1973	44	4.99	0.02	1,110
March 16, 1973	45	4.99	0.00	0
March 16, 1973	46	5.00	0.01	555
March 16, 1973	47	5.00	0.00	0
March 16, 1973	48	5.00	0.00	0

Table 15: Calculation of Flow Series for Rainfall over Reservoir for May 2003 Storm

North Reservoir				
Date and Time	Time, hours	Precipitation, in inches over Subbasin 49		Q (ft3/s)
		Cumulative	Increment	
May 5, 2003	0	0.00		
May 5, 2003	1	0.00	0.00	0
May 5, 2003	2	0.00	0.00	0
May 5, 2003	3	0.00	0.00	0
May 5, 2003	4	0.00	0.00	0
May 5, 2003	5	0.08	0.08	878
May 5, 2003	6	0.75	0.67	7,350
May 5, 2003	7	0.94	0.19	2,084
May 5, 2003	8	0.96	0.02	219
May 5, 2003	9	1.05	0.09	987
May 5, 2003	10	1.08	0.03	329
May 5, 2003	11	1.19	0.11	1,207
May 5, 2003	12	1.33	0.14	1,536
May 5, 2003	13	1.45	0.12	1,316
May 5, 2003	14	1.59	0.14	1,536
May 5, 2003	15	1.61	0.02	219
May 5, 2003	16	1.62	0.01	110
May 5, 2003	17	1.66	0.04	439
May 5, 2003	18	1.69	0.03	329
May 5, 2003	19	1.71	0.02	219
May 5, 2003	20	1.82	0.11	1,207
May 5, 2003	21	1.94	0.12	1,316
May 5, 2003	22	2.07	0.13	1,426
May 5, 2003	23	2.34	0.27	2,962
May 5, 2003	24	2.66	0.32	3,511
May 6, 2003	25	2.95	0.29	3,181
May 6, 2003	26	3.12	0.17	1,865
May 6, 2003	27	3.37	0.25	2,743
May 6, 2003	28	3.69	0.32	3,511
May 6, 2003	29	3.95	0.26	2,852
May 6, 2003	30	4.22	0.27	2,962
May 6, 2003	31	4.54	0.32	3,511
May 6, 2003	32	4.65	0.11	1,207
May 6, 2003	33	4.91	0.26	2,852
May 6, 2003	34	5.89	0.98	10,751
May 6, 2003	35	6.03	0.14	1,536
May 6, 2003	36	6.05	0.02	219
May 6, 2003	37	6.07	0.02	219
May 6, 2003	38	6.08	0.01	110
May 6, 2003	39	6.08	0.00	0
May 6, 2003	40	6.08	0.00	0
May 6, 2003	41	6.08	0.00	0
May 6, 2003	42	6.08	0.00	0
May 6, 2003	43	6.08	0.00	0
May 6, 2003	44	6.08	0.00	0
May 6, 2003	45	6.08	0.00	0
May 6, 2003	46	6.08	0.00	0
May 6, 2003	47	6.08	0.00	0
May 6, 2003	48	6.42	0.34	3,730
May 7, 2003	49	7.00	0.58	6,363
May 7, 2003	50	7.07	0.07	768
May 7, 2003	51	7.08	0.01	110
May 7, 2003	52	7.19	0.11	1,207
May 7, 2003	53	7.42	0.23	2,523
May 7, 2003	54	7.68	0.26	2,852
May 7, 2003	55	7.74	0.06	658
May 7, 2003	56	7.74	0.00	0
May 7, 2003	57	7.74	0.00	0
May 7, 2003	58	7.74	0.00	0
May 7, 2003	59	7.77	0.03	329
May 7, 2003	60	7.94	0.17	1,865
May 7, 2003	61	8.00	0.06	658
May 7, 2003	62	8.00	0.00	0
May 7, 2003	63	8.00	0.00	0
May 7, 2003	64	8.00	0.00	0
May 7, 2003	65	8.00	0.00	0
May 7, 2003	66	8.00	0.00	0
May 7, 2003	67	8.00	0.00	0
May 7, 2003	68	8.00	0.00	0

South Reservoir				
Date and Time	Time, hours	Precipitation, in inches over Subbasin 50		Q (ft3/s)
		Cumulative	Increment	
May 5, 2003	0	0.00		
May 5, 2003	1	0.00	0.00	0
May 5, 2003	2	0.00	0.00	0
May 5, 2003	3	0.00	0.00	0
May 5, 2003	4	0.00	0.00	0
May 5, 2003	5	0.00	0.00	0
May 5, 2003	6	0.07	0.07	3,885
May 5, 2003	7	0.37	0.30	16,650
May 5, 2003	8	0.62	0.25	13,875
May 5, 2003	9	0.66	0.04	2,220
May 5, 2003	10	0.74	0.08	4,440
May 5, 2003	11	0.80	0.06	3,330
May 5, 2003	12	0.89	0.09	4,995
May 5, 2003	13	1.01	0.12	6,660
May 5, 2003	14	1.41	0.40	22,199
May 5, 2003	15	1.45	0.04	2,220
May 5, 2003	16	1.46	0.01	555
May 5, 2003	17	1.52	0.06	3,330
May 5, 2003	18	1.55	0.03	1,665
May 5, 2003	19	1.66	0.11	6,105
May 5, 2003	20	1.84	0.18	9,990
May 5, 2003	21	2.00	0.16	8,880
May 5, 2003	22	2.09	0.09	4,995
May 5, 2003	23	2.24	0.15	8,325
May 5, 2003	24	2.41	0.17	9,435
May 6, 2003	25	2.56	0.15	8,325
May 6, 2003	26	2.72	0.16	8,880
May 6, 2003	27	2.83	0.11	6,105
May 6, 2003	28	3.22	0.39	21,644
May 6, 2003	29	3.61	0.39	21,644
May 6, 2003	30	3.72	0.11	6,105
May 6, 2003	31	3.76	0.04	2,220
May 6, 2003	32	3.77	0.01	555
May 6, 2003	33	3.84	0.07	3,885
May 6, 2003	34	4.85	1.01	56,054
May 6, 2003	35	5.60	0.75	41,624
May 6, 2003	36	5.97	0.37	20,535
May 6, 2003	37	6.05	0.08	4,440
May 6, 2003	38	6.05	0.00	0
May 6, 2003	39	6.05	0.00	0
May 6, 2003	40	6.05	0.00	0
May 6, 2003	41	6.05	0.00	0
May 6, 2003	42	6.05	0.00	0
May 6, 2003	43	6.05	0.00	0
May 6, 2003	44	6.05	0.00	0
May 6, 2003	45	6.05	0.00	0
May 6, 2003	46	6.05	0.00	0
May 6, 2003	47	6.09	0.04	2,220
May 6, 2003	48	6.27	0.18	9,990
May 7, 2003	49	6.63	0.36	19,980
May 7, 2003	50	6.64	0.01	555
May 7, 2003	51	6.66	0.02	1,110
May 7, 2003	52	6.67	0.01	555
May 7, 2003	53	6.67	0.00	0
May 7, 2003	54	6.67	0.00	0
May 7, 2003	55	6.67	0.00	0
May 7, 2003	56	6.67	0.00	0
May 7, 2003	57	6.67	0.00	0
May 7, 2003	58	6.67	0.00	0
May 7, 2003	59	6.67	0.00	0
May 7, 2003	60	6.74	0.07	3,885
May 7, 2003	61	6.87	0.13	7,215
May 7, 2003	62	6.90	0.03	1,665
May 7, 2003	63	6.94	0.04	2,220
May 7, 2003	64	6.99	0.05	2,775
May 7, 2003	65	7.00	0.01	555
May 7, 2003	66	7.00	0.00	0
May 7, 2003	67	7.00	0.00	0
May 7, 2003	68	7.00	0.00	0

7.3.3 Base Flow

Base flow must be added back to the runoff from the land area and reservoir to get the total local inflow for Subbasins 49 and 50 as input to the SOCH model. The base flow ordinates series are determined by a straight line drawn between the points of tangency of the rising and falling limbs of the direct runoff hydrograph for the March 1973 and May 2003 floods as shown graphically in Figures 5 and 6, respectively. For convenience, this was done in FLDHYDRO by providing the starting and ending base flow discharges divided by the basin area, i.e. cfs/mi^2, as the parameters BBSFLW and EBSFLW (Reference 5). These parameters are provided in Table 16 for reference and can be seen in the input files for FLDHYDRO runs, provided as Attachments 2-1 and 2-3.

Table 16: Base Flow Input Parameters for FLDHYDRO Calculation of Base Flow Ordinates

	FLDHYDRO Parameter	March 1973	May 2003
Start of runoff	BBSFLW	3.931	2.476
End of runoff	EBSFLW	9.680	4.906

FLDHYDRO starts the flood hydrograph at the first hour of excess rainfall, which may not coincide with the first hour of the convolution. The base flow output from FLDHYDRO is adjusted to have the same time step as the convolution in the spreadsheet "SB 49& 50 Base Flow 1973 & 2003.xls," provided as Attachment 1-15 to this calculation.

7.3.4 SOCH Model Input Provided to TVA

Four time series were provided to the TVA for use in the SOCH models for the March 1973 and the May 2003 validation runs, as follows:

- Total direct runoff from Subbasin 49
- Total direct runoff from Subbasin 50
- Runoff resulting from rainfall on the north reservoir
- Runoff resulting from rainfall on the south reservoir

These time series were developed in the spreadsheet "SB 49 & 50 Total Local Inflow Hydrographs 1973&2003.xls," provided as Attachment 1-16 to this calculation.

Plots of the component time series provided to the TVA for use in the SOCH model are provided as Figures 12 and 13 for Subbasins 49 and 50 for the March 1973 flood and Figures 14 and 15 for Subbasins 49 and 50 for the May 2003 flood, respectively.

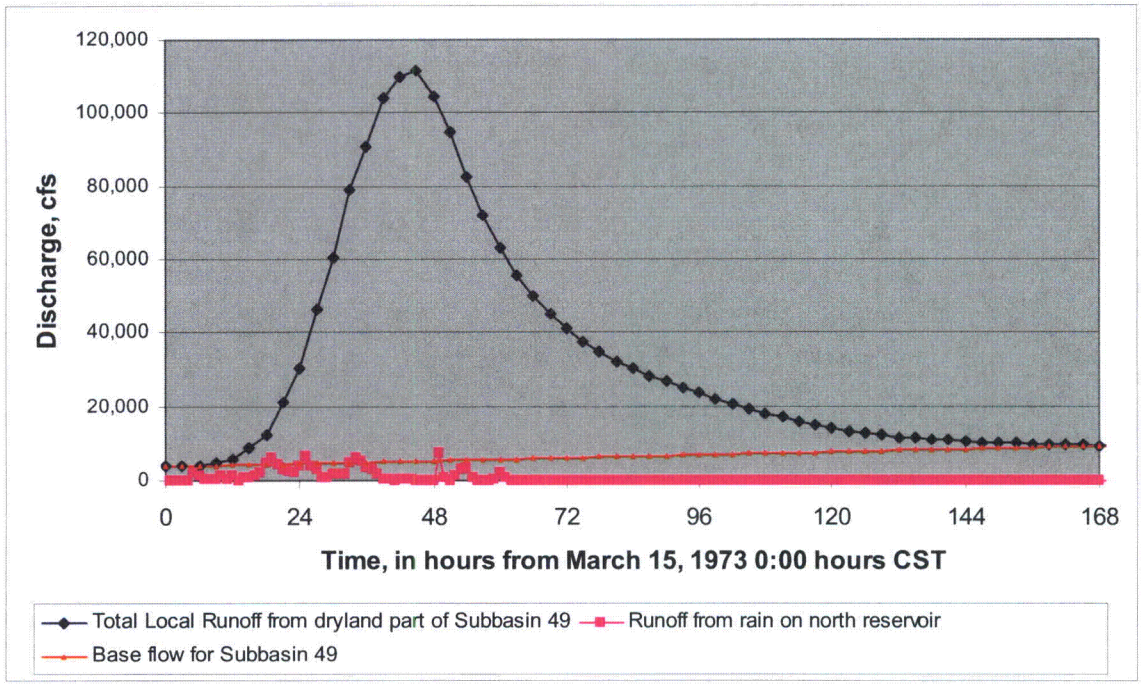

Figure 12: SOCH Model Inputs for Subbasin 49 for the March 1973 Simulation

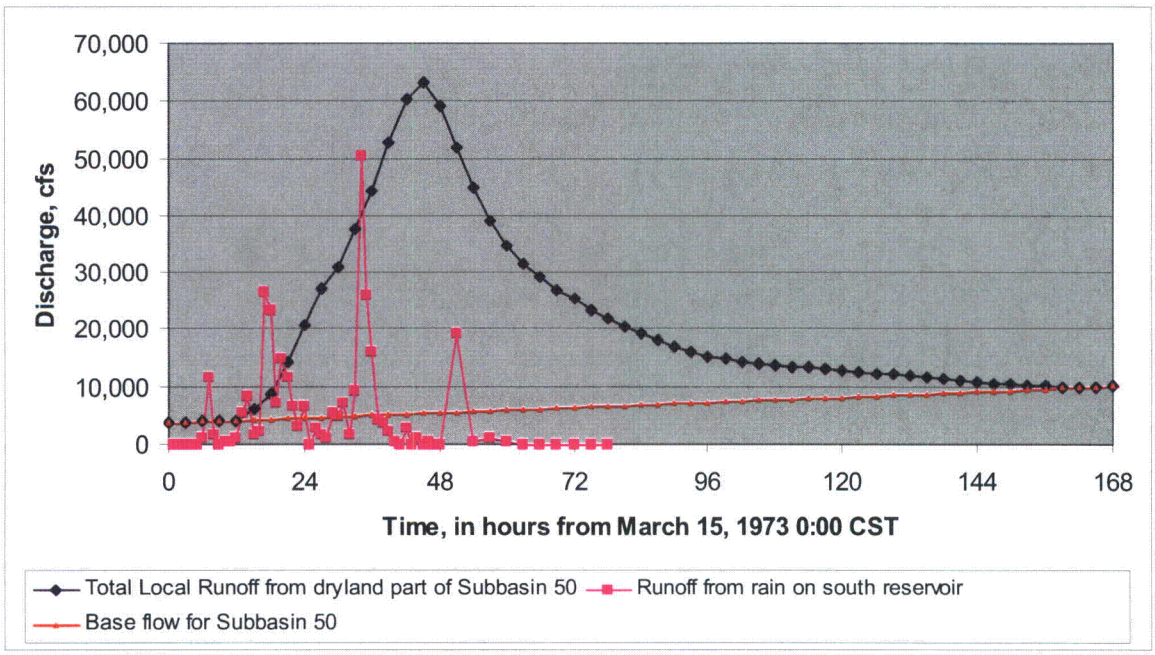

Figure 13: SOCH Model Inputs for Subbasin 50 for the March 1973 Simulation

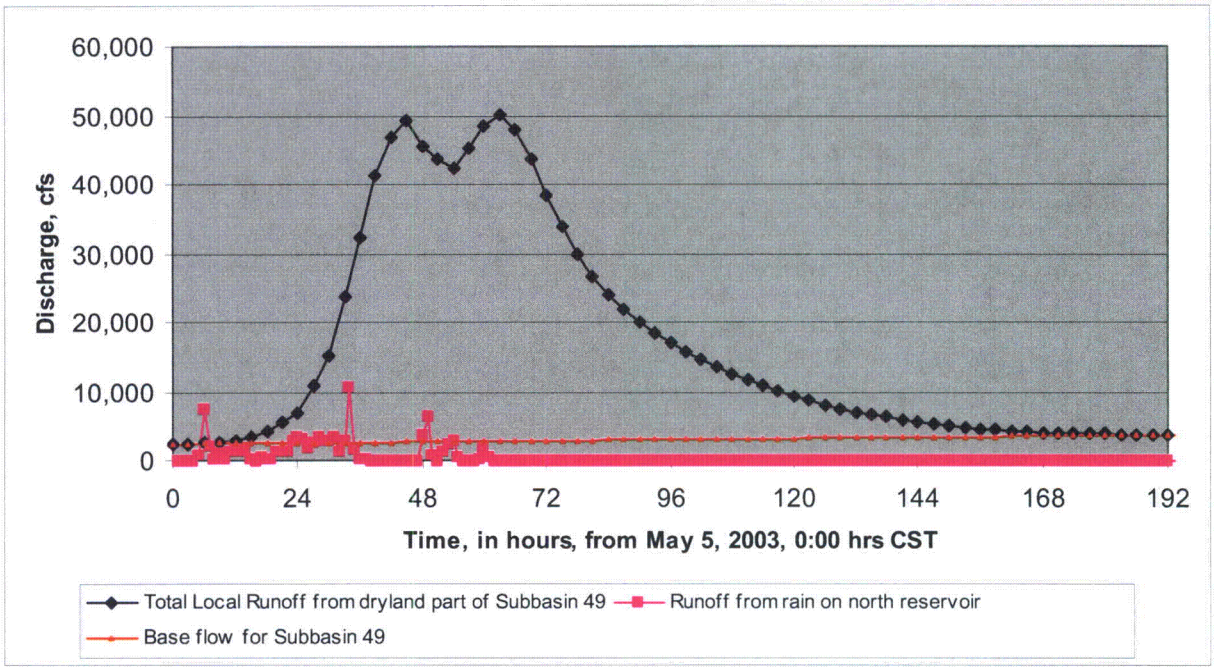

Figure 14: SOCH Model Inputs for Subbasin 49 for the May 2003 Simulation

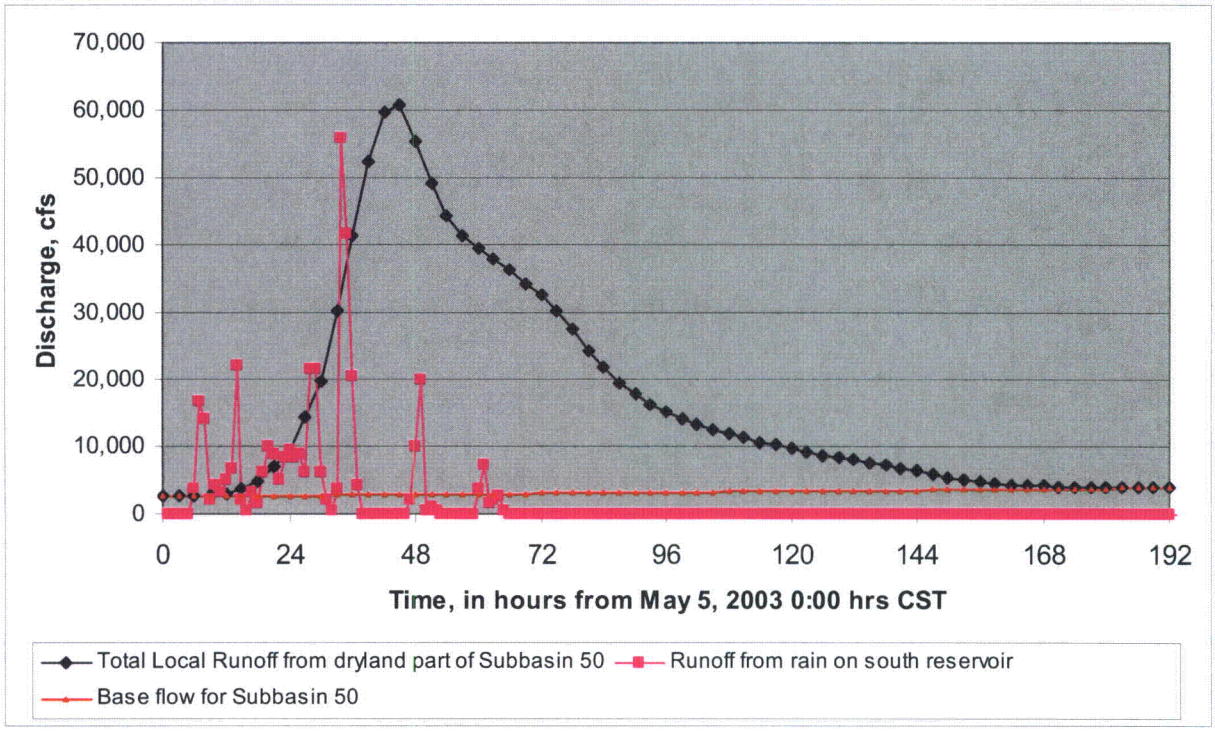

Figure 15: SOCH Model Inputs for Subbasin 50 for the May 2003 Simulation

7.4 SOCH Model Output & Unit Hydrograph Validation

The component time series presented in Section 7.3 of this calculation are provided for use as inputs to a SOCH model of the reach of the Tennessee River between the Nickajack and Guntersville Dams. Additional inputs to the model include observed discharge series for the Sequatchie River and outflow from Nickajack Dam as upstream boundary conditions (see Figure 2).

As described in Calculation CDQ000020080041 Rev 0 (Reference 10), simulated discharge and stage hydrographs output by the SOCH model compared well with observed values for the March 1973 and May 2003 floods, as shown in Figures 16 to 19. These figures were developed from data and simulation results provided by the TVA (Reference 14). Data and simulation results for all these figures and the rest of the figures in this section of the calculation are provided in the spreadsheets "SOCH Model Runs for March 1973.xls" and "SOCH Model Runs for May 2003.xls," provided as Attachments 1-18 and 1-19, respectively.

For the March 1973 event, simulated and observed water surface elevations were compared at the following locations:

- Nickajack Dam (TW) at River Mile 424.7
- South Pittsburg, TN at River Mile 418.1
- Widows Bar, AL at River Mile 407.6
- Scottsboro, AL at River Mile 385.8
- Guntersville Dam (HW) at River Mile 349.0

For the May 2003 event, simulated and observed water surface elevations were compared at the following locations:

- Nickajack Dam (TW) at River Mile 424.7
- South Pittsburg, TN at River Mile 418.1
- Scottsboro, AL at River Mile 385.8
- Guntersville Dam (HW) at River Mile 349.0

Observed and simulated discharges were compared at Guntersville for both floods. Figures 16 through 19 depict the comparisons. The close tracking of the observed water surface elevations provides an indirect validation of the local inflow unit hydrographs for Subbasins 49 and 50.

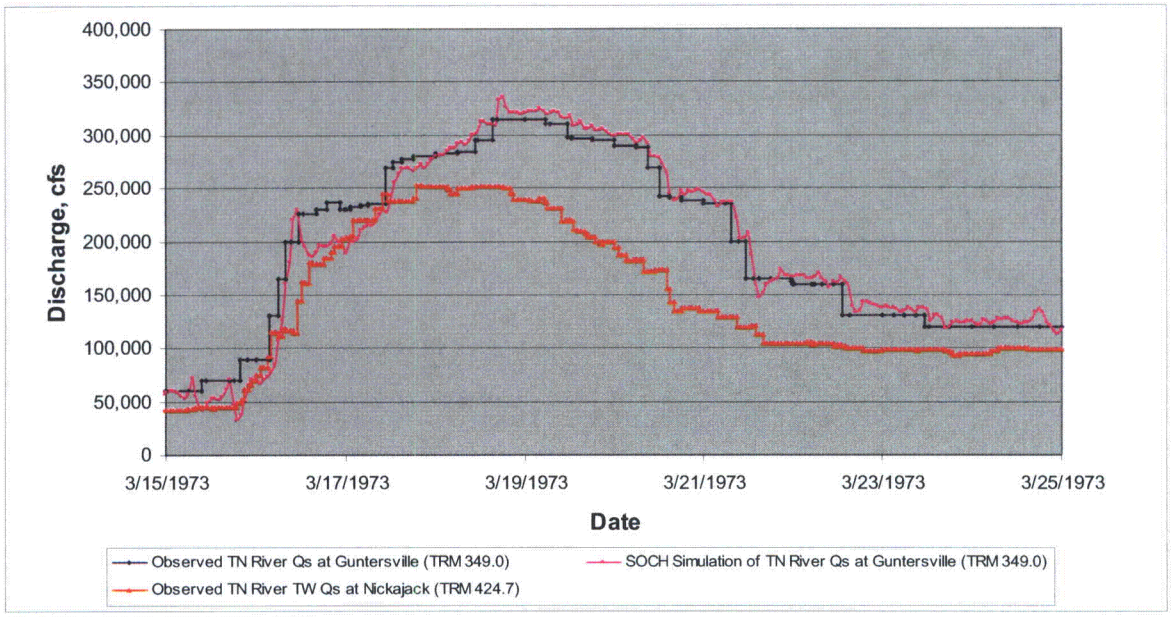

Figure 16: Observed and Simulated Discharge Hydrographs for the Tennessee River between Nickajack and Guntersville Dams, March 1973

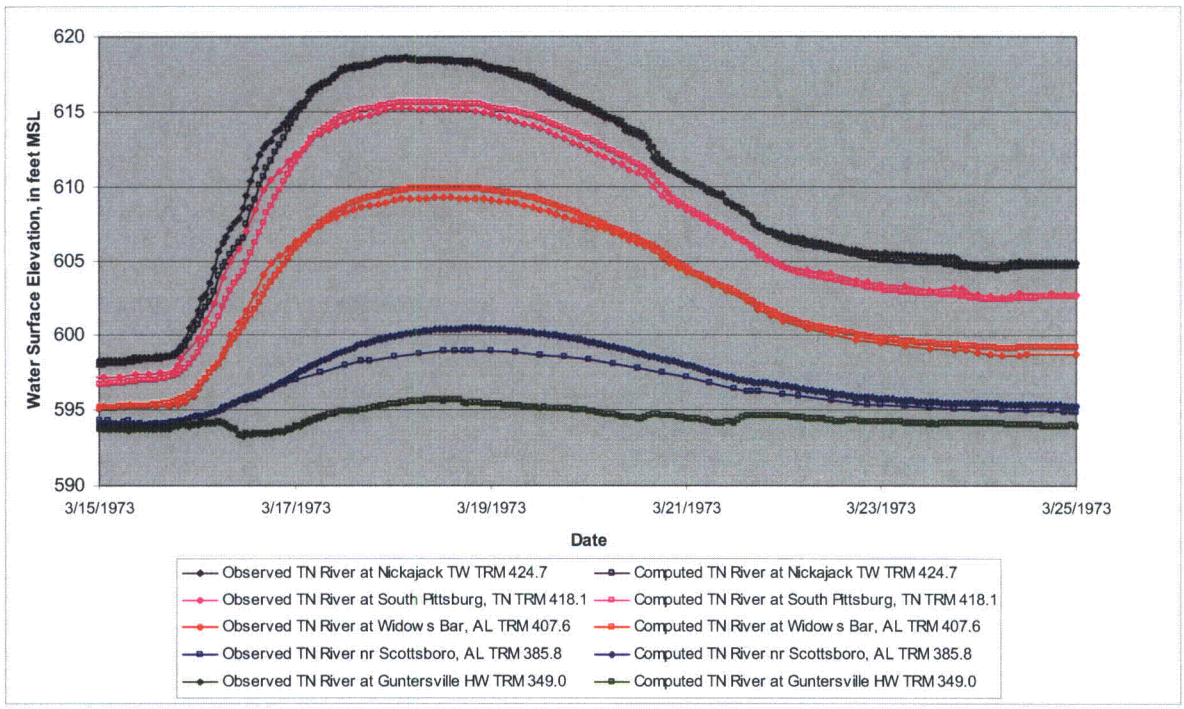

Figure 17: Observed and Simulated Stage Hydrographs for the Tennessee River between Nickajack and Guntersville Dams, March 1973

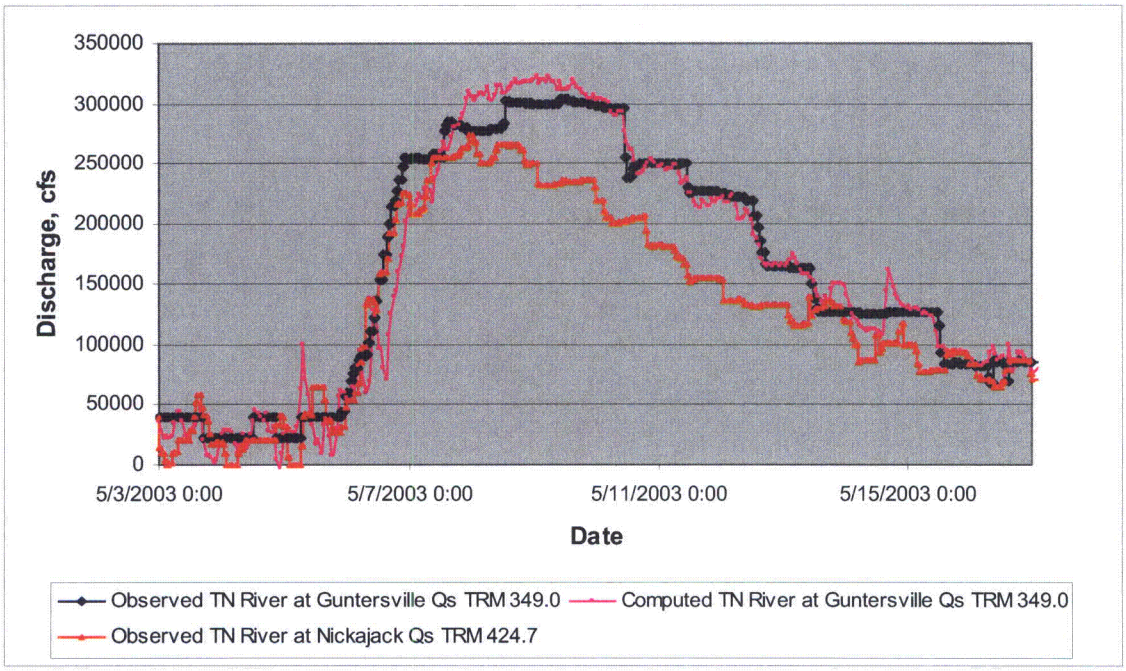

Figure 18: Observed and Simulated Discharge Hydrographs for the Tennessee River between Nickajack and Guntersville Dams, May 2003

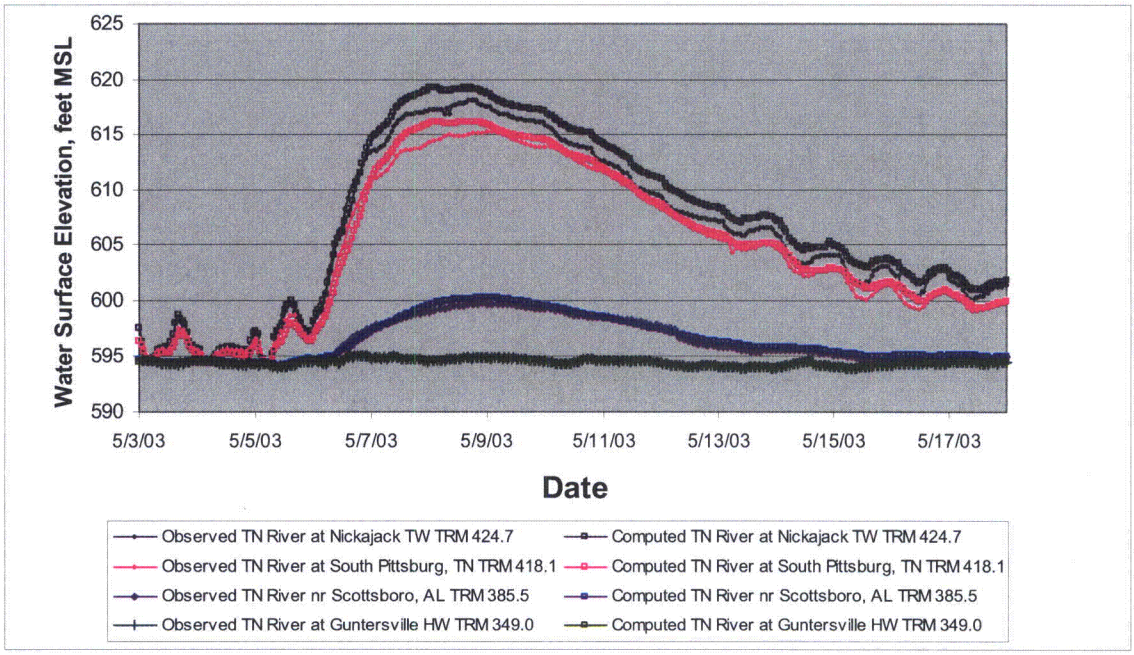

Figure 19: Observed and Simulated Stage Hydrographs for the Tennessee River between Nickajack and Guntersville Dams, May 2003

8 SUMMARY & CONCLUSIONS

Unit hydrographs for Subbasins 49 and 50 for the simulation of local inflow to the Tennessee River between Nickajack and Guntersville Dams were developed by the TVA in the 1960s and updated in 1973. 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 Guntersville Reservoir. Therefore, it was necessary to validate the unit hydrographs indirectly. Local runoff hydrographs were developed from observed rainfall series for use as inputs to the SOCH model simulation of the reach of the Tennessee River between Nickajack and Guntersville Dams for the two validation runs.

Since the stage and discharge hydrographs simulated in the SOCH model runs utilizing local inputs developed with the unit hydrographs match observed high water marks and measured discharges along the reach, it can be concluded that the TVA unit hydrographs accurately describe the response of the local catchment area between the reservoirs and they are still valid for use in hydrologic studies to determine the Probable Maximum Flood (PMF) at the TVA Nuclear Plant sites (see Section 1).

8.1 Validated Unit Hydrographs

The original TVA unit hydrographs for Subbasins 49 and 50 were validated for the March 1973 and May 2003 floods in this calculation and are produced in Table 17 and as Attachment 1-20 to facilitate subsequent work on the TVA design basis PMF evaluations.

Table 17: Validated Unit Hydrograph Ordinates for Subbasins 49 and 50

Subbasin 49 6-hr Unit Hydrograph	
Time, hrs	Discharge, cfs/in
0	0
3	2,564
6	5,917
9	12,031
12	18,243
15	22,089
18	21,202
21	18,342
24	14,595
27	12,129
30	10,354
33	8,875
36	7,790
39	6,804
42	6,114
45	5,424
48	4,931
51	4,438
54	4,043
57	3,747
60	3,451
63	3,156
66	2,958
69	2,663
72	2,465
75	2,219
78	1,972
81	1,775
84	1,578
87	1,381
90	1,183
93	1,035
96	888
99	740
102	592
105	542
108	493
111	444
114	394
117	345
120	296
123	247
126	197
129	148
132	99
135	49
138	0

Subbasin 50 6-hr Unit Hydrograph	
Time, hrs	Discharge, cfs/in
0	0
3	3,266
6	8,164
9	14,492
12	20,411
15	22,963
18	20,921
21	17,145
24	13,676
27	11,226
30	9,593
33	8,471
36	7,756
39	7,042
42	6,532
45	5,817
48	5,358
51	4,797
54	4,337
57	3,776
60	3,368
63	2,858
66	2,551
69	2,347
72	2,194
75	2,041
78	1,939
81	1,837
84	1,735
87	1,633
90	1,531
93	1,429
96	1,327
99	1,225
102	1,123
105	1,021
108	919
111	816
114	714
117	561
120	408
123	306
126	204
129	102
132	0