ASSOCIATED ATTACHMENTS/ENCLOSURES:

Attachment 02.04.03-8D: Watts Bar Dam Local Watershed (Subbasins 25, 33, 34, 36, and 37) Unit Hydrograph Validation. CDQ000020080065

(69 Pages including Cover Sheet)

CALCULATION COVERSHEET/CCRIS UPDATE

REV 0 EDMS/RIMS NO.	EDMS TYPE:	EDMS ACCESSION NO (N/A for REV. 0)
L58090511002	calculations(nuclear)	L58 091230 041

Calc Title: Watts Bar Dam Local Watershed (Subbasins 25, 33, 34, 36, and 37) Unit Hydrograph Validation

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT	CN	NUC	GEN	CEB	CDQ000020080065	1	2	Entire calc ☒ Selected pages ☐

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 9	☐ 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. Spates	12/23/09

STATEMENT OF PROBLEM/ABSTRACT

Validate existing unit hydrographs for the subbasins of the Watts Bar Dam watershed (Subbasins 25, 33, 34, 36 and 37) using the 1973 and 2003 floods of record.

**EDCN-22404A (SQN), EDCN- 54018A (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 090511 002	calculations(nuclear)	N/A

Calc Title: Calculation of Initial Flood Flows from Subbasins 25, 33, 34, 36, and 37 for use in 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	CDQ000020080065	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
NDMARTIN	(415) 768-3941	Bechtel (CEB)	Design Review	☐ Yes ☒ No

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
Nicholas D. Martin *[signature]*	4/24/2009	Matthew C. Carney *[signature]*	4/24/09
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
Robert E. Swain *[signature]*	4/24/2009	*[signature]* K. R. Spates	4/27/09

STATEMENT OF PROBLEM/ABSTRACT

Prepare initial inflow hydrographs for Subbasins 25 (Watts Bar Local Above Clinch River), 33 (Clinch River Local Above Mile 16), 34 (Poplar Creek at Mouth), 36 (Clinch River Local Mouth to Mile 16), and 37 (Watts Bar Local Below Clinch River) for two floods that occurred in March 1973 and 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:

CALCULATION COVERSHEET/CCRIS UPDATE

REV 0 EDMS/RIMS NO.	EDMS TYPE:	EDMS ACCESSION NO (N/A for REV. 0)
L58090511002	calculations(nuclear)	L58 090709 003

Calc Title: Watts Bar Dam Local Watershed (Subbasins 25, 33, 34, 36, and 37) Unit Hydrograph Validation

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT	CN	NUC	GEN	CEB	CDQ000020080065	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	7/2/09	Bill Hamilton	7/2/09
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
Bill Hamilton	7/2/09	K.R. Spates	7/9/09

STATEMENT OF PROBLEM/ABSTRACT

Validate existing unit hydrographs for the subbasins of the Watts Bar Dam watershed (Subbasins 25, 33, 34, 36 and 37) 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	CDQ000020080065	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	

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

NPG CALCULATION RECORD OF REVISION

CALCULATION IDENTIFIER CDQ000020080065

Title	Watts Bar Dam Local Watershed (Subbasins 25, 33, 34, 36, and 37) Unit Hydrograph Validation

Revision No.	DESCRIPTION OF REVISION
0	Initial issue 54 pages
1	This calculation was revised to validate existing unit hydrographs for the subbasins of the Watts Bar Dam Local Watershed (Subbasins 25, 33, 34, 36, and 37) 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 have been marked with a right-hand margin revision bar. Content on pages 1 – 14, 54 of R0 was modified as indicated on pages 1 – 15, 59 of R1 with pages 1a and 9a added. New Pages 55-64 were added. Calculation header was revised (Watts Bar Dam Local Watershed (Subbasins 25, 33, 34, 36, and 37) Unit Hydrograph Validation, Revision 1) on all pages revised.Added new electronic Attachments 4-1, 4-2 and 4-3 Total hardcopy pages Revision 1: 66
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 7 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 Watts Bar SOCH Calibration calculation, CDQ000020080037, has been removed. Final calibration has been completed and the calculation has been approved. Changes and additions: Content on pages 1-8, 11, and 54 –58 R1 has been modified as indicated on pages 1-9, 11-13, and 54-58, R2. Pages 1b and 9b were added. Total hardcopy pages Revision 2: 68

NPG CALCULATION TABLE OF CONTENTS

Calculation Identifier: CDQ000020080065	Revision: 2	

TABLE OF CONTENTS

NPG CALCULATION TABLE OF CONTENTS

Calculation Identifier: CDQ000020080065	Revision: 2	

TABLE OF CONTENTS

SECTION	TITLE	PAGE

NOTE: N/A indicates electronic attachment

List of Figures

NPG CALCULATION TABLE OF CONTENTS

Calculation Identifier: CDQ000020080065	Revision: 2	

TABLE OF CONTENTS

SECTION	TITLE	PAGE

List of Tables

NPG COMPUTER INPUT FILE
STORAGE INFORMATION SHEET

Document CDQ000020080065	Rev. 2	Plant: GEN	

Subject: Watts Bar Dam Local Watershed (Subbasins 25, 33, 34, 36, and 37) 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 Input & Output files on the following page

☐ Microfiche/eFiche

ELECTRONIC FILE ATTACHMENTS			
Document: CDQ000020080065	Rev. 2	Plant: GEN	
Subject: Watts Bar Dam Local Watershed (Subbasins 25, 33, 34, 36, and 37) Unit Hydrograph Validation			

Electronic Attachment: Name of File or Folder	File Location
Supporting Spreadsheets	
Attachment 1-1: wattsbar_rev0.xls	Attached to PDF
Attachment 1-2: fortloudoun_rev0.xls	Attached to PDF
Attachment 1-3: meltonhill_rev0.xls	Attached to PDF
Attachment 1-4: tellico_rev0.xls	Attached to PDF
Attachment 1-5: EmoryAtOakdale_rev0.xls	Attached to PDF
Attachment 1-6: Emory_Oakdale_03540500_February-March1973.txt	Attached to PDF
Attachment 1-7: Adopted_Unit_Hydrographs.xls	Attached to PDF
Attachment 1-8: WaterBudget_1973_2003.xls	Attached to PDF
Attachment 1- 9: NWS_Rainfall_2003.xls	Attached to PDF
Attachment 1- 10: WattsBarReservoir.xls	Attached to PDF
Attachment 1-11: Rainfall_1973.xls	Attached to PDF
Attachment 1-12 2: Excess_Precip.xls	Attached to PDF
Attachment 1-13: HMS_Results.xls	Attached to PDF
Attachment 1-14: Initial_Flood_Hydrographs.xls	Attached to PDF
FLDHYDRO Files	
Attachment 2-1: WB_1973.dat	Attached to PDF
Attachment 2-2: Mar1973_Reservoir.dat	Attached to PDF
Attachment 2- 3: WB_2003.dat	Attached to PDF
Attachment 2- 4: WB_1973.out	Attached to PDF
Attachment 2- 5: Mar1973_Reservoir.out	Attached to PDF
Attachment 2- 6: WB_2003.out	Attached to PDF
HEC-HMS Files	
Attachment 3-1: Watts_Bar-1973_000020080065.zip	Filekeeper No. 311927
Attachment 3-2: Watts_Bar-2003_000020080065.zip	Filekeeper No. 311928
UH Validation Files	
Attachment 4-1: Watts Bar_Observed vs. SOCH Mar 1973 Hydrographs.xls	Attached to PDF
Attachment 4-2: Watts Bar_Observed vs. SOCH Mar 2003 Hydrographs.xls	Attached to PDF
Attachment 4-3: Validate_6HR_UH.xls	

NPG CALCULATION VERIFICATION FORM

Calculation Identifier CDQ000020080065 Revision 2

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

Comments:

This calculation entitled, "Watts Bar Dam Local Watershed (Subbasins 25, 33, 34, 36, and 37) 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.

(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 CDQ000020080065 Revision 0

Method of verification used:		
1. Design Review	☒	Verifier Bob Swain Date 4/23/2009
2. Alternate Calculation	☐	
3. Qualification Test	☐	

Comments:

The calculation entitled, "Calculation of Initial Flood Flows from Subbasins 25, 33, 34, 36, and 37 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. Subbasins 33, 34, and 36 use synthetic unit hydrographs to simulate the watershed response to one inch of excess precipitation. A brief explanation, summarizing information found in the File Book References, was added to the calculation to describe the derivation of these unit hydrographs.

2. Because GIS information was used to calculate drainage areas, the unit hydrograph for Subbasin 36 has been modified to account for the 9 percent decrease in drainage area size. A 32 mi^2 drainage area was used in the development of the TVA-derived unit hydrograph (Reference 7). Use of the unit hydrograph ordinates, with the 29.3 mi^2 drainage area measured in GIS resulted in a unit hydrograph volume of 1.1 inches; therefore, the unit hydrograph ordinates for Subbasin 36 were scaled to represent the smaller drainage area.

The calculation presents the development of initial simulated flows from Subbasins 25, 33, 34, 36, and 37 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 for validation of the unit hydrographs for Subbasins 25, 33, 34, 36, and 37.

NPG CALCULATION VERIFICATION FORM

Calculation Identifier CDQ000020080065 Revision 1

Method of verification used:		
1. Design Review	☒	Verifier Bill Hamilton Date 7/1/2009
2. Alternate Calculation	☐	
3. Qualification Test	☐	

Comments:

The calculation entitled, "Watts Bar Dam Local Watershed (Subbasins 25, 33, 34, 36, and 37) 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 Subbasins 25, 33, 34, 36, and 37 for floods that occurred in March 1973 and May 2003, which were used in the calibration of the SOCH Model and to validate unit hydrographs for Subbasins 25, 33, 34, 36, and 37. The observed and simulated flows and water surface elevation at several locations supports the conclusion that the unit hydrographs developed 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 developed specifically for each subbasin. These unit hydrographs were developed by the TVA in previous studies, mostly in the 1970s and early 1980s, utilizing the observed rainfall and streamflow and reservoir headwater and discharge data, and are being validated by checking their performance in reproducing recent floods.

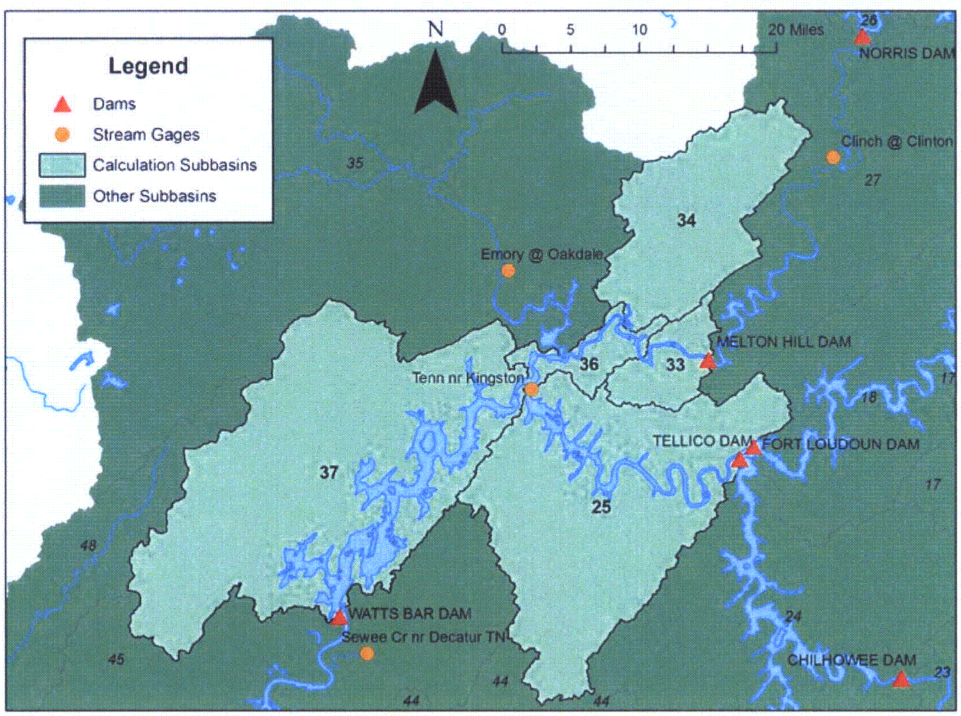

Figure 1: Location of Subbasins including Adjacent Dams and Stream Gages

As part of the dynamic hydrologic model of the Tennessee River system, the subbasin flood hydrographs are used as inputs to the Simulated Open Channel Hydraulic (SOCH) computer model. The SOCH model provides elevation and discharge hydrographs at selected locations within the modeled reach. This calculation presents the generation of initial simulated flows from Subbasins 25, 33, 34, 36, and 37 and from the Watts Bar Reservoir surface as well as the validation of the unit hydrographs for the five subbasins, for floods that occurred in March 1973 and May 2003. The March 1973 and May 2003 floods were selected by the TVA to be analyzed using the SOCH model. The simulated flows were used by the TVA in the calibration of the SOCH model and to validate the unit hydrographs for Subbasins 25, 33, 34, 36, and 37. These subbasins are located in the Tennessee River watershed as shown in Figure 1.

2 References

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

Reference 2: Viessman, W., J.W. Knapp, G.L. Lewis, and T.E. Harbaugh, *Introduction to Hydrology*, Second Edition, Harper & Row, Publishers, 1977.

Reference 3: Chow, V.T., D.R. Maidment, and L.W. Mays, *Applied Hydrology*, McGraw-Hill Book Company, 1988.

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

Reference 5: Tennessee Valley Authority, [Map] Drainage Areas above Guntersville Dam, June 18, 2008 (6 GIE 301 E 200801 R0 D).

Reference 6: Tennessee Valley Authority. Unit Area 25, Watts Bar Local Above Clinch River, and Unit Area 37, Watts Bar Local Below Clinch River. File Book Reference (EDMS No. L58 081223 821).

Reference 7: Tennessee Valley Authority. Unit Area 33, Clinch River Local Above Mile 16, and Unit Area 36, Clinch River Local Mouth to Mile 16, File Book Reference (EDMS No. L58 081223 822).

Reference 8: Tennessee Valley Authority, Unit Area 34, Poplar Creek, File Book Reference. (EDMS No. L58 081223 823)

Reference 9: Tennessee Valley Authority, Daily Average Outflow and Storage Data for Watts Bar Dam (EDMS L58 090311 802, wattsbar_rev0.xls see Attachment 1-1)

Reference 10: Tennessee Valley Authority, Daily Average Outflow and Storage Data for Fort Loudoun Dam (EDMS L58 090311 802, fortloudoun_rev0.xls see Attachment 1-2)

Reference 11: Tennessee Valley Authority, Daily Average Outflow and Storage Data for Melton Hill Dam (EDMS L58 090311 802, meltonhill_rev0.xls see Attachment 1-3).

Reference 12: Tennessee Valley Authority, Daily Average Outflow and Storage Data for Tellico Dam (EDMS L58 090311 802, tellico_rev0.xls see Attachment 1-4).

Reference 13: Tennessee Valley Authority, Observed Stage and Streamflow Data for Emory River at Oakdale, TN (EDMS L58 090311 802, EmoryAtOakdale_rev0.xls see Attachment 1-5).

Reference 14: United States Geological Survey (USGS), Daily Discharge Data for February and March 1973 at Gage 03540500 Emory River at Oakdale, TN, obtained from the National Water Information (NWIS), online at http://waterdata.usgs.gov/nwis, accessed 04/13/2009 (Attachment 1-6).

Reference 15: Tennessee Valley Authority, Calculation No. CDQ000020080055, Processing and Validation of National Weather Service's NEXRAD Stage III Hourly Precipitation Data for Hydrologic Analysis of Watersheds, Revision 3

Reference 16: Bechtel, Request for Information RFI 25447-000-GRI-GEX-00041, September 25, 2008. (EDMS No. L58 081030 003)

Reference 17: Tennessee Valley Authority, Calculation No. CDQ000020080067, Subbasin 35 (Emory River at Mouth) Unit Hydrograph Validation, Revision 0, February 2009. (EDMS No. L58 090227 002)

Reference 18: Linsley, R.K., Kohler, M.A., and J.L. Paulhus, *Hydrology for Engineers*, McGraw-Hill Book Company 1982.

Reference 19: 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)

Reference 20: U.S. Army Corps of Engineers, *Hydrologic Modeling System HEC-HMS User's Manual*, Version 3.2, April 2008.

Reference 21: U.S. Army Corps of Engineers, *Hydrologic Modeling System HEC-HMS Technical Reference Manual*, March 2000.

Reference 22: Tennessee Valley Authority, Calculation No.CDQ00020080037, SOCH Model Calibration, Watts Bar, Revision 0, (EDMS No. L58 090814 002).

Reference 23: American Nuclear Society, *American National Standard for Determining Design Basis Flooding at Power Reactor Sites*, ANSI/ANS-2.8-1992, 1992.

Reference 24: 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

The unit hydrograph (UH) is used to predict the runoff response at the outlet of a watershed, or subbasin, to the input of one unit of excess rainfall applied uniformly over a given duration of time. Runoff from other depths of excess rainfall can be obtained by scaling (Reference 2 and Reference 3).

The unit hydrograph is used to obtain the streamflow hydrograph resulting from a series of excess rainfall inputs of any depth using the process of "convolution." The discrete convolution equation, states that direct runoff, Q, is obtained by summing the products of the excess rainfall depths (direct runoff depths), P, and the unit hydrograph ordinates, U (Reference 2 and Reference 3). The reverse process, called deconvolution, is used to derive the ordinates of the unit hydrograph by reconstituting floods from precipitation and streamflow data. The unit hydrograph is derived from the unit duration of uniform excess precipitation applied evenly across the watershed.

Unit hydrograph theory is applicable under the following conditions (Reference 3):

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 TVA will employ SOCH model results to validate the unit hydrograph. 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, as enumerated below, to obtain input flood hydrographs for each subbasin.

The methodology used for unit hydrograph validation follows that described in ANSI/ANS-2.8-1992 (Reference 23). This document is included as a reference in the NRDC's Standard Review Plan 2.4.3, Probable Maximum Flood on Streams and Rivers (Reference 24). 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 25, 33, 34, 36, and 37. 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 base flow from the total local flow to obtain the direct runoff volume for the budget area.
3. Obtain rainfall data for the March 1973 and May 2003 floods and calculate the basin-average rainfall for each subbasin and also for the reservoir area.
4. Convert the observed rainfall series to excess precipitation series using the TVA's Antecedent Precipitation Index (API)/Runoff Index (RI) method as implemented in FLDHYDRO (Reference 4). Observed direct runoff volumes are used by FLDHYDRO to ensure that the calculated excess precipitation volumes agree with the observed. FLDHYDRO allocates excess precipitation 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 over the reservoir area (Step 3) less the direct runoff calculated in Step 4 for the reservoir area. Check that the volume of total 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 precipitation series to generate the initial, simulated local direct runoff hydrograph for each subbasin. Use FLDHYDRO to partition the total base flow volume from Step 2 according to relative subbasin areas and add base flow to direct runoff to obtain the initial simulated flood 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 to simulate initial flood hydrographs for Subbasins 25, 33, 34, 36, and 37 and for Watts Bar Reservoir are summarized below.

- Subbasin drainage areas and the surface area of Watts Bar Reservoir
- Unit hydrograph ordinates and durations
- Emory River stream flow observed at the gage located near Oakdale, TN
- Observed storage and discharges at Watts Bar Dam
- Observed daily discharges at Melton Hill Dam, Tellico Dam, and Fort Loudoun Dam.
- Rainfall data associated with the March 1973 and May 2003 floods

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

6.1 Subbasin Characteristics

Subbasins 25, 33, 34, 36, and 37 are shown in Figure 1. Watts Bar Dam provides the outlet to Subbasin 37 and to the water budget area. Watts Bar Reservoir extends from the dam across Subbasin 37 (Watts Bar Local Below Clinch River) and into Subbasins 25 (Watts Bar Local Above Clinch River), 33 (Clinch River Local Above Mile 16), and 36 (Clinch River Local, Mouth to Mile 16). Discharges from Fort Loudoun and Tellico Dams provide inflows to Subbasin 25 from upstream. The outlet for Subbasin 36 corresponds to the mouth of the Clinch River at its confluence with the Tennessee River. The Emory River joins the Clinch River at the northern boundary of this subbasin; Poplar Creek enters Subbasin 36 in the northeast. The confluence of Poplar Creek with the Clinch River provides the outlet for Subbasin 34 (Poplar Creek at Mouth). Subbasin 34 is a headwater subbasin. The Clinch River at Mile 16 represents the outlet for Subbasin 33. Discharges from Melton Hill Dam enter Subbasin 33 at the upstream end of the subbasin.

The total area of Subbasins 25, 33, 34, 36, and 37 was measured as 905.5 mi^2 in GIS (Reference 5). The Watts Bar Reservoir area is included with Subbasins 25, 33, 36, and 37. Watershed areas for the subbasins in this calculation and for Watts Bar Reservoir are provided in Table 1. The subbasin areas measured in GIS are employed in this calculation. The original areas used for each subbasin (Reference 6, Reference 7, and Reference 8) are provided in Table 1 for comparison along with the percentage difference between the areas obtained from GIS and the File Book Reference.

Table 1: Subbasin Drainage Areas

Basin ID	Subbasin Name	Area mi^2 (from File Book Reference)	Area mi^2 (measured in GIS)	Difference %
25	Watts Bar Local Above Clinch River	293	295.3	0.8
33	Clinch River Local Above Mile 16	37	37.2	0.6
34	Poplar Creek at Mouth	136	135.2	-0.6
36	Clinch River Local, Mouth to Mile 16	32	29.3	-9.1
37	Watts Bar Local Below Clinch River	427	408.4	-4.6
Watts Bar Reservoir	Reservoir Area in Subbasins 25, 33, 36, and 37	N/A	59.5	N/A
Total Area		925	905.5	-2.2

6.2 Unit Hydrograph Ordinates

The unit hydrograph provides the response of a watershed to one inch of excess precipitation, as described in Section 4. A brief description of the unit hydrograph and of unit hydrograph development for each of the five subbasins is provided in the following sub-sections. Table 2 provides a summary of the important parameters for each unit hydrograph in this calculation. The unit hydrograph for each subbasin is enclosed in Attachment 1- 7.

Table 2: TVA Unit Hydrograph Parameters by Subbasin

Subbasin	Effective Duration (hours)	Ordinate Interval (hours)	Number of Ordinates	Peak Discharge (cfs)	Time to Peak (hours)	Area (mi^2)	Volume (inches)
25	6	6	16	11,063	6	295.3	0.99
33	2	2	25	4,490	6	37.2	0.997
34	2	2	46	2,800	20	135.2	1.008
36	2	2	25	3,703	6	29.3	1.02
37	6	6	16	16,125	6	408.4	1.04

6.2.1 Subbasins 25 and 37 Unit Hydrographs

Unit hydrographs for Subbasins 25 and 37 were developed in 1973 using a drainage area relationship from an existing unit hydrograph for a 1,026 mi^2 area upstream of Watts Bar Dam (Reference 6). According to the information provided in Reference 6, the UNITGRPH program (Reference 4) was not used in the development of these unit hydrographs. The unit hydrographs for Subbasins 25 and 37 are presented in Figure 2 and Figure 3 and are listed in Table 3 and Table 4, respectively.

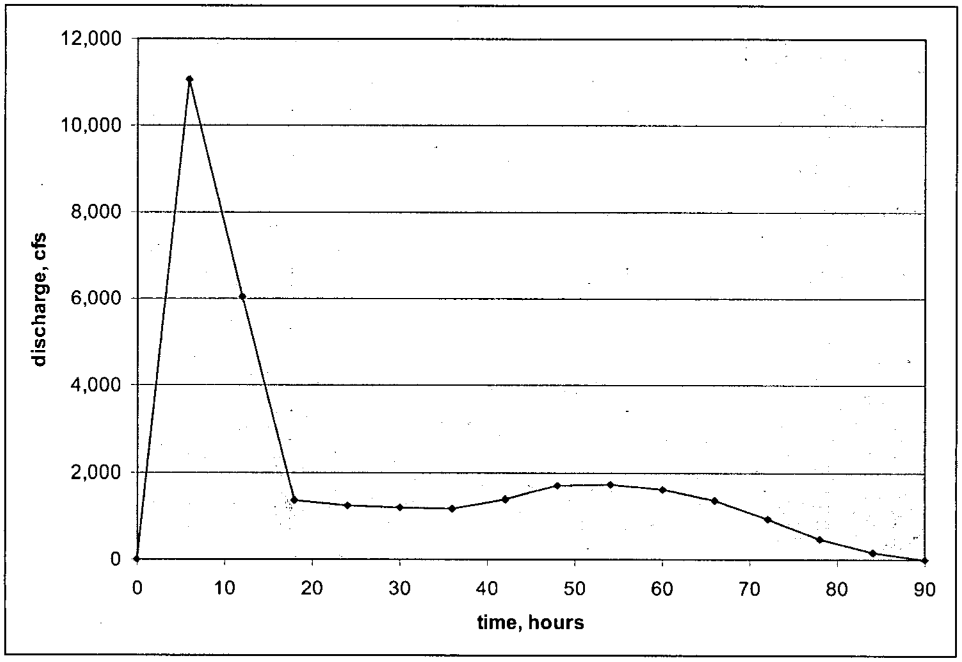

Figure 2: Subbasin 25 Six-Hour Unit Hydrograph

Table 3: Subbasin 25 Six-Hour Unit Hydrograph Time Base and Ordinates

Ordinate	Time (hrs)	Discharge (cfs)
1	0	0
2	6	11,063
3	12	6,050
4	18	1,361
5	24	1,248
6	30	1,191
7	36	1,172
8	42	1,399
9	48	1,702
10	54	1,739
11	60	1,607
12	66	1,361
13	72	945
14	78	492
15	84	170
16	90	0
Volume (cf)		680,400,000
Area (mi^2)		295.3
Depth (in)		0.99

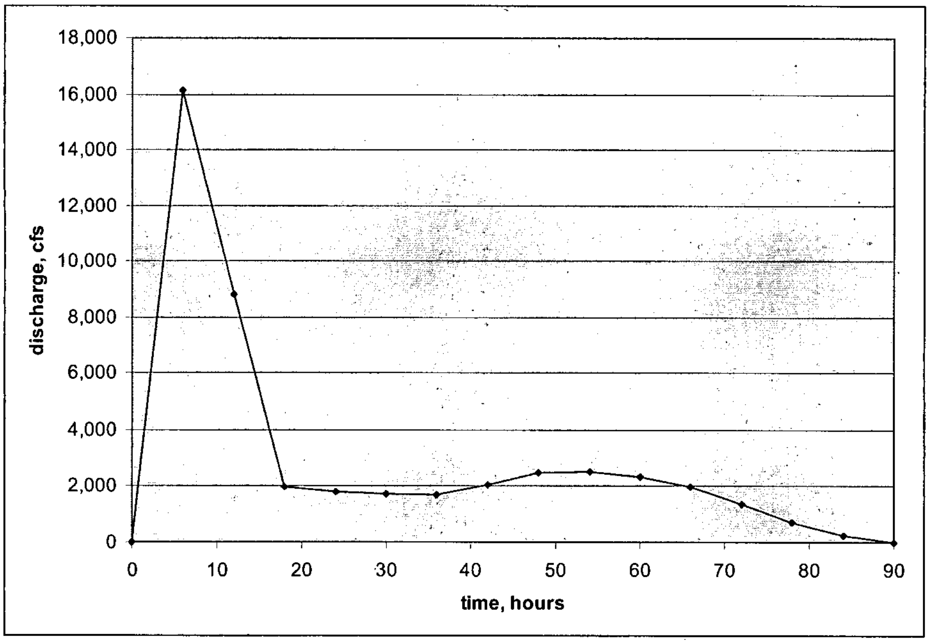

Figure 3: Subbasin 37 Six-Hour Unit Hydrograph

Table 4: Subbasin 37 Six-Hour Unit Hydrograph Time Base and Ordinates

Ordinate	Time (hrs)	Discharge (cfs)
1	0	0
2	6	16,125
3	12	8,814
4	18	1,983
5	24	1,818
6	30	1,735
7	36	1,708
8	42	2,038
9	48	2,479
10	54	2,534
11	60	2,341
12	66	1,983
13	72	1,378
14	78	716
15	84	248
16	90	0
Volume (cf)		991,440,000
Area (mi^2)		408.4
Depth (in)		1.04

6.2.2 Subbasins 33 and 36 Unit Hydrographs

Synthetic unit hydrographs were developed for Subbasins 33 and 36 in 1973 (Reference 7). These synthetic unit hydrographs were calculated using "relationships for similar watersheds, relating the unit hydrograph peak flow to the drainage area size, time to peak to the length and slope of the watershed, and the shape to the unit hydrograph peak discharge in cfs per square mile (Reference 7)." The adopted unit hydrographs are shown in Figure 4 and Figure 5 and are listed in Table 5 and Table 6.

As shown in Table 1, the original area of Subbasin 36 listed in the File Book Reference (Reference 7) is approximately ten percent larger than that measured with GIS. The larger area (32 mi^2) was used in the development of the unit hydrograph for Subbasin 36. Use of the unit hydrograph ordinates, developed for the drainage area of 32 mi^2, with the 29.3 mi^2 drainage area measured in GIS results in a unit hydrograph volume of direct runoff of approximately 1.1 inches. Consequently, the unit hydrograph ordinates for Subbasin 36 were scaled to represent the 29.3 mi^2 drainage area. To scale the ordinates, the peak of the unit hydrograph was multiplied by the ratio of the square roots of the drainage areas (i.e., $\sqrt{29.3}/\sqrt{32}$), and the rest of the ordinates were multiplied by the ratio of the drainage areas. The scaled unit hydrograph is employed in the calculations presented here and is summarized in Table 2, listed in Table 6, and shown on Figure 5. Scaling calculations are enclosed as Attachment 1- 7.

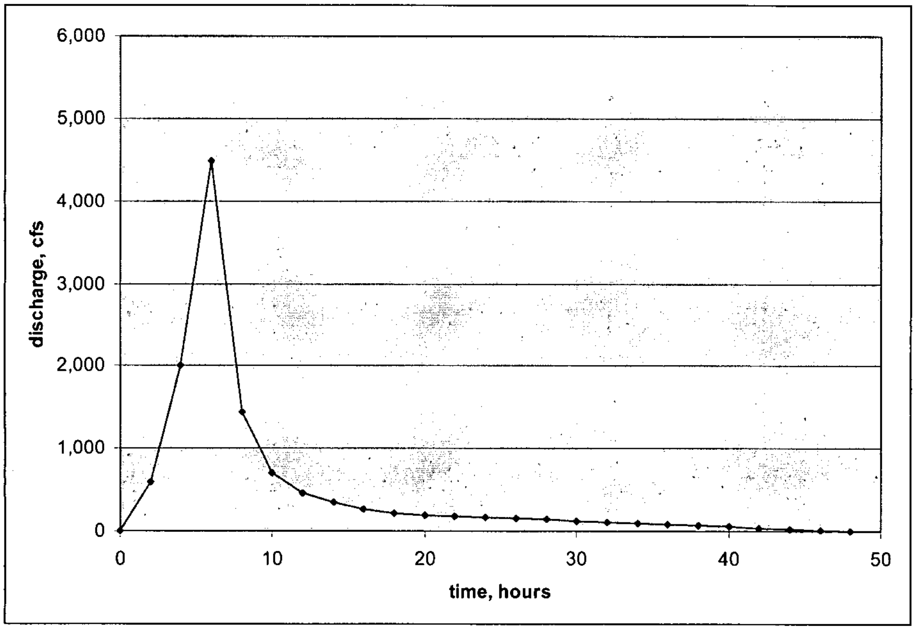

Figure 4: Subbasin 33 Two-Hour Unit Hydrograph

Table 5: Subbasin 33 Two-Hour Unit Hydrograph Time Base and Ordinates

Ordinate	Time (hrs)	Discharge (cfs)
1	0	0
2	2	590
3	4	2,000
4	6	4,490
5	8	1,440
6	10	700
7	12	460
8	14	350
9	16	265
10	18	220
11	20	195
12	22	180
13	24	166
14	26	152
15	28	139
16	30	125
17	32	111
18	34	97
19	36	83
20	38	69
21	40	55
22	42	42
23	44	28
24	46	14
25	48	0
Volume (cf)		86,191,200
Area (mi^2)		37.2
Depth (in)		0.997

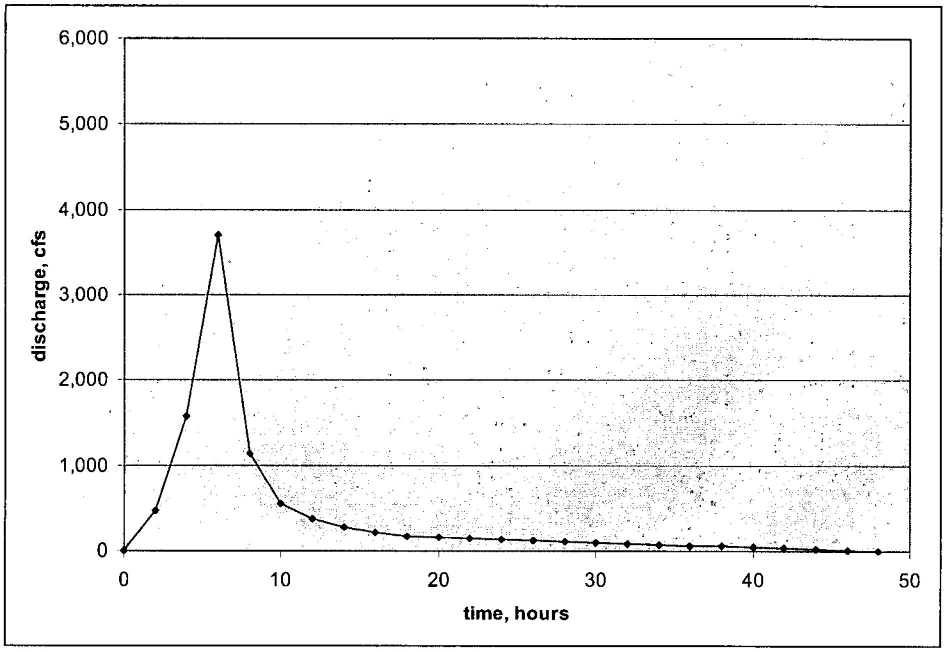

Figure 5: Subbasin 36 Two-Hour Unit Hydrograph

Table 6: Subbasin 36 Two-Hour Unit Hydrograph Time Base and Ordinates

Ordinate	Time (hrs)	Discharge (cfs)
1	0	0
2	2	467
3	4	1,575
4	6	3,703
5	8	1,145
6	10	549
7	12	366
8	14	275
9	16	211
10	18	174
11	20	156
12	22	142
13	24	132
14	26	121

Ordinate	Time (hrs)	Discharge (cfs)
15	28	110
16	30	99
17	32	88
18	34	77
19	36	66
20	38	55
21	40	44
22	42	33
23	44	22
24	46	11
25	48	0
Volume (cf)		69,256,729
Area (mi^2)		29.3
Depth (in)		1.02

6.2.3 Subbasin 34 Unit Hydrograph

A synthetic unit hydrograph was developed for Subbasin 34 in 1973. As with Subbasins 33 and 36, the calculation procedure employed "relationships for similar watersheds, relating the unit hydrograph peak flow to the drainage area size, time to peak to the length and slope of the watershed, and the shape to the unit hydrograph peak discharge in cfs per square mile (Reference 8)." This unit hydrograph is shown in Figure 6 and is listed in Table 7.

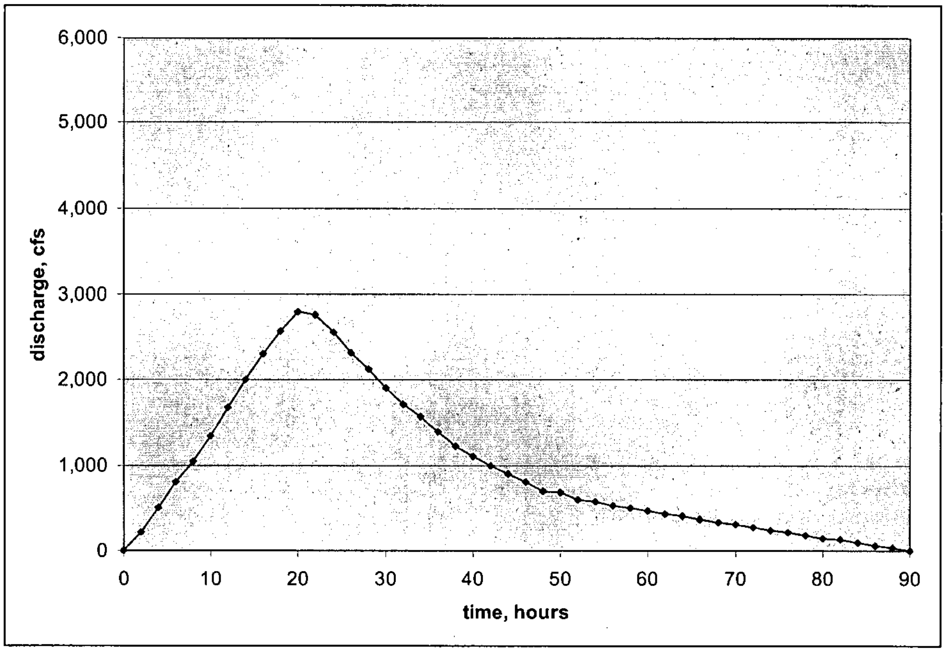

Figure 6: Subbasin 34 Two-Hour Unit Hydrograph

Table 7: Subbasin 34 Two-Hour Unit Hydrograph Time Base and Ordinates

Ordinate	Time (hrs)	Discharge (cfs)
1	0	0
2	2	220
3	4	500
4	6	800
5	8	1,040
6	10	1,350
7	12	1,680
8	14	2,000
9	16	2,300
10	18	2,570
11	20	2,800
12	22	2,760
13	24	2,560
14	26	2,320
15	28	2,120
16	30	1,910
17	32	1,720
18	34	1,570
19	36	1,390
20	38	1,230
21	40	1,100
22	42	1,000
23	44	900
24	46	800
25	48	700

Ordinate	Time (hrs)	Discharge (cfs)
26	50	680
27	52	600
28	54	575
29	56	534
30	58	502
31	60	470
32	62	438
33	64	406
34	66	374
35	68	342
36	70	310
37	72	278
38	74	246
39	76	214
40	78	182
41	80	150
42	82	128
43	84	96
44	86	64
45	88	32
46	90	0
Volume (cf)		316,519,200
Area (mi^2)		135.2
Depth (in)		1.008

6.3 Observed Discharge and Storage

Observed daily discharges and reservoir storage at Watts Bar, Fort Loudoun, and Melton Hill Dams from 1962 to 2007 were obtained from the TVA and are enclosed as Attachment 1- 1 (Reference 9), Attachment 1- 2 (Reference 10), and Attachment 1- 3 (Reference 11). The TVA provided observed daily discharges at Tellico Dam Attachment 1- 4 (Reference 12) for 1981 through 2007. Bi-hourly stream flow values recorded at the Emory River gage in Oakdale TN, also obtained from TVA, are included as Attachment 1- 5 (Reference 13). Daily stream flow values recorded at the same Emory River gage were obtained from the USGS for February and March of 1973 and are included as Attachment 1- 6 (Reference 14).

6.4 Observed Rainfall

Two sources of rainfall data were used in this calculation. TVA rain gage data with Thiessen weights were employed to simulate the March 1973 flood. Gridded precipitation data from the U.S. National Weather Services (NWS) were used to simulate the May 2003 flood. The NWS gridded precipitation data (Reference 15) are discussed in this section. The TVA rainfall data are presented in Reference 16.

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/ back to 2005. Hourly precipitation data are not generally available without special arrangements with the NWS.

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 15). 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 15 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.

7 Computations and Analyses

7.1 Flood Events for Unit Hydrograph Validation

The May 2003 and March 1973 floods were selected by the TVA for analysis because these two floods were significant across the Tennessee River watershed. In Subbasins 25, 33, 34, 36, and 37 the storms generating these floods spanned the following times:

- May 5, 2003, 01:00 hrs to May 7, 2003, 17:00 hrs, the "May 2003" storm
- March 15,1973, 04:00 hrs to March 17, 1973 09:00 hrs, the "March 1973" storm

7.2 Water Budget Computation

The water budget analysis consists of solving the continuity equation for the water budget area:

$$\overline{L} = \frac{dS}{dt} + \overline{O} - \overline{I} \qquad (1)$$

where L is the local inflow rate to the budget area, O is the outflow rate from the budget area outlet, I is inflow rate from upstream subbasins, and S is storage within the budget area. An interval of one day was selected for the analysis (i.e. dt = 1 day), and the bars above L, O, and I represent daily-average flow rates.

The water budget area in this calculation is comprised of Subbasins 25, 33, 34, 36, and 37. The change in storage within the budget area is represented by the change in Watts Bar Reservoir storage under the requirement that channel storage within the budget area outside of the reservoir boundaries is constant during the calculation. The analysis interval of one day is sufficiently long such that the travel time within the boundaries of the budget area is neglected when daily-averaged values are used. Given these conditions, the water budget computation simplifies to calculating the inflow to Watts Bar Reservoir using reverse reservoir routing and then subtracting inflows to the water budget area from upstream subbasins.

Reverse reservoir routing involves solving the continuity equation for a reservoir (Reference 3):

$$\overline{R_i} = \frac{dS}{dt} + \overline{O} \qquad (2)$$

where R_i is the reservoir inflow rate. An interval of one day was selected for the analysis so the over bars represent daily-averages; S, t, and O are defined above. Equation (2) requires a level water surface in the reservoir (i.e. level-pool routing). The change in storage over a day is calculated as the observed storage volume for one day less the observed storage volume for the preceding day. Equations (1) and (2) can be combined to provide the simplified water budget computation in Equation (3).

$$\bar{L} = \bar{R}_i - \bar{I} \tag{3}$$

The local inflow rate to the budget area, *L*, is composed of direct runoff and base flow originating within Subbasins 25, 33, 34, 36, and 37 and of direct runoff produced by rain falling on the surface of the Watts Bar Reservoir. Upstream inflows, *I*, to the budget area come from Tellico Dam, Fort Loudoun Dam, and Melton Hill Dam releases and from flow in the Emory River. Data required to calculate inflow (*L*) to the budget are listed below.

- Watts Bar Reservoir storage (*S*) and outflow (*O*) measured at Watts Bar Dam are used in reverse reservoir routing calculations, Equation (2). These data are enclosed in Attachment 1- 1 (Reference 9).
- Daily averaged outflows measured at Fort Loudoun Dam Attachment 1- 2 (Reference 10), Melton Hill Dam Attachment 1- 3 (Reference 11), and Tellico Dam Attachment 1- 4 (Reference 12) provide inflows (*I*) to the budget area.
- Observed stream flow in the Emory River provides another inflow (*I*) to the budget area. These data are enclosed as Attachment 1- 5 (Reference 13) and Attachment 1- 6 (Reference 14).

Emory River stream flows are measured at a gage near Oakdale, TN which is approximately 16 miles upstream from the budget area boundary. These gage values are scaled to compensate for the difference in drainage area (868.8 mi^2 for Subbasin 35 Emory River at Mouth versus 764 mi^2 for the gage near Oakdale) to represent discharge at the budget area boundary using the scaling factor of 1.1 developed in Reference 17. Total upstream inflow (*I*) is obtained from the sum of Fort Loudoun, Melton Hill, and Tellico Dam releases and the scaled inflow from the Emory River.

The calculated inflow to the Watts Bar Reservoir for each day during the March 1973 and May 2003 floods provides the total flood volume for the budget area. These hydrographs represent the aggregated flood discharge from Subbasins 25, 33, 34, 36, and 37 and from rainfall on Watts Bar Reservoir. Table 8 and Table 9 present the calculated total local inflows (*L*) to the budget area for the March 1973 and May 2003 floods. The calculated inflows to and the measured outflows from Watts Bar Reservoir for the March 1973 and May 2003 floods are shown in Figure 7 and Figure 8. These calculations are enclosed in Attachment 1- 8.

Table 8: Water Budget Calculation for March 1973 Flood

	$\bar{O}$	S	$\overline{R}_i = \frac{dS}{dt} + \overline{O}$	$\bar{I}$					$\overline{L} = \overline{R}_i - \overline{I}$
Date	**Watts Bar Average Daily Discharges**	**Watts Bar Midnight Storage Volume**	**Watts Bar Inflows**	**Tellico Daily Average Outflows**	**Fort Loudoun Daily Average Outflows**	**Melton Hill Daily Outflows**	**Scaled Emory River Daily Flows**	**Total Inflows from Upstream**	**Total Local Flows**
	Attachment 1- 1			Attachment 1- 4	Attachment 1- 2	Attachment 1- 3	Attachment 1- 6		
	cfs	1000 dsf*	cfs	cfs	cfs	cfs	cfs	cfs	cfs
3/10/1973	13,600	405	14,090	4,512	5,700	707	2,112	13,031	1,059
3/11/1973	15,700	413	23,250	6,614	7,300	1,978	2,464	18,356	4,894
3/12/1973	16,900	424	27,680	7,322	9,700	1,948	5,511	24,481	3,199
3/13/1973	17,700	427	21,340	6,425	8,300	0	3,795	18,520	2,820
3/14/1973	21,400	430	24,070	6,199	10,400	918	2,794	20,311	3,759
3/15/1973	35,200	446	50,710	8,964	10,900	3,468	12,100	35,432	15,278
3/16/1973	114,700	576	244,980	57,783	50,300	26,884	58,190	193,157	51,823
3/17/1973	180,400	613	217,460	33,254	75,300	24,025	30,580	163,159	54,301
3/18/1973	134,000	562	83,270	11,294	32,500	9,455	9,988	63,237	20,033
3/19/1973	96,100	527	60,570	10,510	31,200	3,901	5,566	51,177	9,393
3/20/1973	90,000	501	64,760	10,665	31,400	9,814	4,191	56,070	8,690
3/21/1973	84,300	499	82,350	15,562	35,800	17,403	6,215	74,980	7,370
3/22/1973	79,400	494	73,480	13,082	31,200	18,450	4,884	67,616	5,864
3/23/1973	79,300	488	73,310	12,013	31,100	20,900	3,586	67,599	5,711
3/24/1973	79,100	480	71,910	11,634	31,200	22,291	2,794	67,919	3,991
3/25/1973	76,000	476	72,040	12,026	31,200	21,354	2,453	67,033	5,007

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

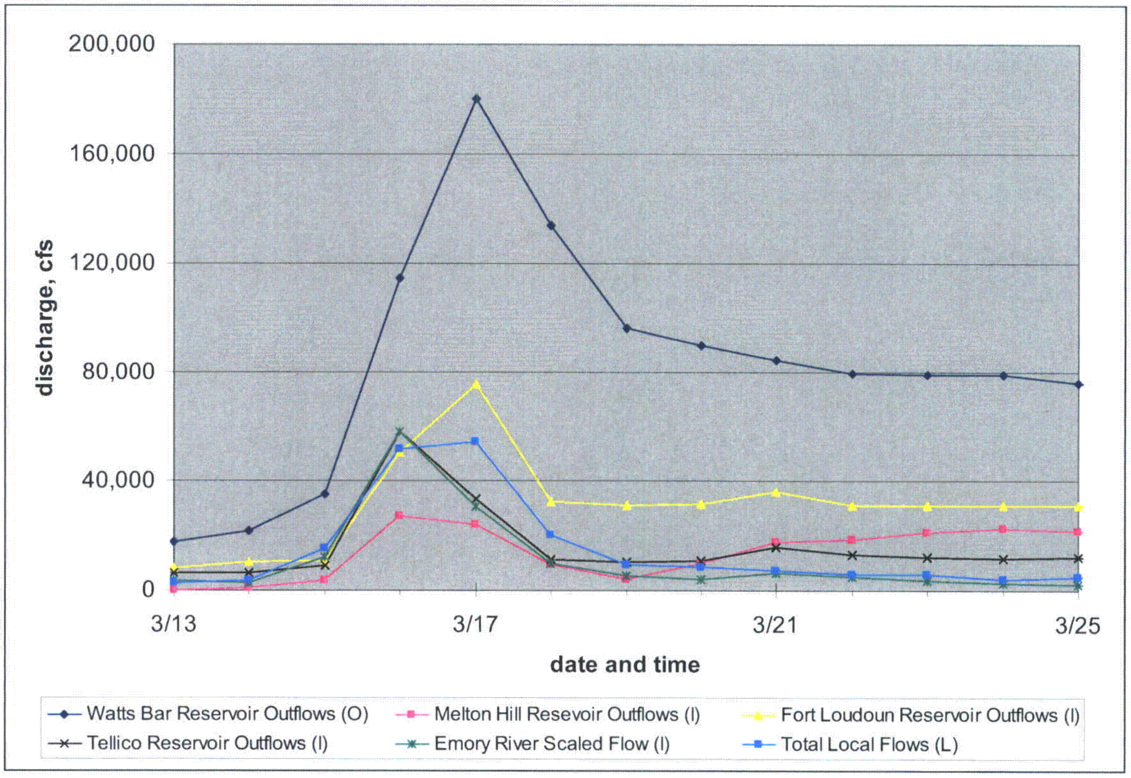

Figure 7: Calculated Total Local Flows (*L*), Measured Upstream Inflows (*I*), and Measured Watts Bar Reservoir Outflows (*O*) for March 1973 Flood

Table 9: Water Budget Calculation for May 2003 Flood

Date	$\bar{O}$	S	$\overline{R_i} = \frac{dS}{dt} + \bar{O}$	$\bar{I}$					$\bar{L} = \overline{R_i} - \bar{I}$
	Watts Bar Average Daily Discharges	Watts Bar Midnight Storage Volume	Watts Bar Inflows	Tellico Daily Average Outflows	Fort Loudoun Daily Average Outflows	Melton Hill Daily Outflows	Scaled Emory River Daily Flows	Total Inflows from Upstream	Total Local Flows[2]
	Attachment 1-1			Attachment 1-4	Attachment 1-2	Attachment 1-3	Attachment 1-5		
	cfs	1000 dsf[3]	cfs	cfs	cfs	cfs	cfs	cfs	cfs
4/25/2003	29,704	510	38,527	0	21,389	9,891	1,458	32,738	5,789
4/26/2003	23,548	506	19,024	0	8,663	7,098	1,421	17,182	1,842
4/27/2003	23,531	504	21,377	0	9,209	8,303	1,356	18,868	2,509
4/28/2003	24,834	502	23,617	0	13,891	7,624	1,112	22,627	990
4/29/2003	26,364	502	25,590	0	13,986	8,000	960	22,946	2,644
4/30/2003	26,352	498	22,980	0	13,936	6,715	2,539	23,190	-210
5/1/2003	26,297	490	17,577	0	13,722	5,666	3,112	22,500	-4,923
5/2/2003	26,599	486	23,094	0	13,687	4,628	2,365	20,680	2,414
5/3/2003	17,958	492	23,660	0	12,157	5,905	2,111	20,173	3,487
5/4/2003	8,700	498	15,141	0	9,735	3,664	1,565	14,964	177
5/5/2003	25,354	518	45,232	0	14,175	7,295	13,884	35,354	9,878
5/6/2003	87,227	609	178,019	19,265	59,296	7,849	45,310	131,720	46,299
5/7/2003	134,632	649	175,018	39,030	59,991	8,973	29,004	136,998	38,020
5/8/2003	139,700	631	121,710	19,177	62,736	549	17,030	99,492	22,218
5/9/2003	139,724	603	111,757	19,005	66,578	3,628	6,949	96,160	15,597
5/10/2003	120,930	567	85,022	8,584	60,084	2,819	3,906	75,393	9,629
5/11/2003	92,178	547	72,222	0	54,668	2,136	3,717	60,521	11,701
5/12/2003	81,524	536	70,188	0	60,655	6,979	3,689	71,323	-1,135
5/13/2003	96,294	522	82,336	0	60,933	10,985	2,483	74,401	7,935
5/14/2003	76,487	510	64,575	0	48,215	8,842	1,840	58,897	5,678
5/15/2003	56,668	509	55,529	0	44,659	7,340	1,449	53,448	2,081
5/16/2003	56,579	502	49,889	0	38,275	8,100	1,418	47,793	2,096
5/17/2003	56,368	497	51,191	0	38,618	5,754	2,462	46,834	4,357
5/18/2003	51,306	506	59,524	0	38,503	7,914	5,613	52,030	7,494
5/19/2003	50,279	507	51,401	0	34,347	8,082	4,085	46,514	4,887
5/20/2003	45,517	507	45,720	0	29,557	9,284	2,708	41,549	4,171
5/21/2003	34,653	523	50,761	0	29,522	9,811	3,029	42,362	8,399

[2] Several of the calculated Total Local Flows (L) are negative. These negative values are artifacts of the calculation method that occur because the water budget computation does not account for routing of flows across the water budget area and reservoir to Watts Bar Dam. These negative values are outside of the range of the May 2003 flood which extends from 5/5/2003 through 5/11/2003.

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

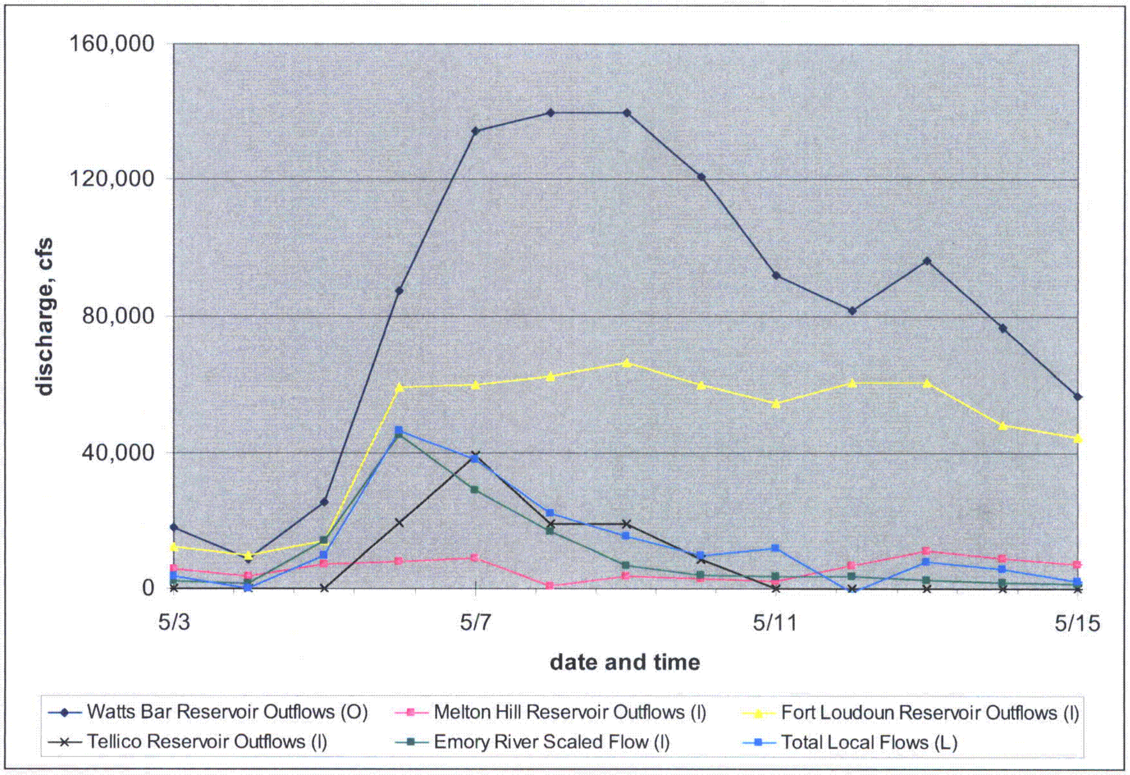

Figure 8: Calculated Total Local Flows (*L*), Measured Upstream Inflows (*I*), and Measured Watts Bar Reservoir Outflows (*O*) for May 2003 Flood

7.3 Base Flow Separation

The Watts Bar inflow hydrographs ($\overline{L}$) shown in Figure 7 and Figure 8 represent the total flow originating within the water budget area. A portion of the total flow comes from groundwater contributions to the river system. Base flow separation involves the estimation of the groundwater contribution to total flow and the removal of the groundwater-contributed portion of the flow from the flood hydrograph. Base flow separation is required to determine an estimate of direct runoff associated with the flood.

For this calculation, the straight line method was used for baseflow separation with the separation line drawn from the starting point of runoff to a point on the receding limb of the hydrograph where baseflow resumes (Reference 3 and Reference 18). Visual inspection of the flood hydrographs was employed to select starting and ending points for the separation line. Daily average total inflow ($\overline{L}$) values provide an approximation of the total flood volume from Subbasins 25, 33, 34, 36, and 37 and from direct rainfall on Watts Bar Reservoir. Given the inaccuracies inherent in this approximation method, a simple visual determination of estimated baseflow is appropriate for the May 2003 and March 1973 floods. The total streamflow and resulting baseflow hydrographs for the March 1973 and May 2003 floods are plotted on Figure 9 and Figure 10, respectively.

Reference 16 provides estimates of baseflow that were used for each subbasin during the 1973 flood in a previous study. The previously estimated base flow was 2,590 cfs at the start of direct runoff and 3,470 cfs at the end of direct runoff for the water budget area. The separation line shown in Figure 9 is approximately 3,760 cfs at the start of direct runoff and 5,860 cfs at the end of direct runoff. The base flow separation line shown in Figure 9 is slightly different from that provided in Reference 16. However, the separation line in Figure 9 provides a better visual fit to the calculated total inflow because the base flow values from Reference 16 would not intersect the "Budget Area Inflow" line.

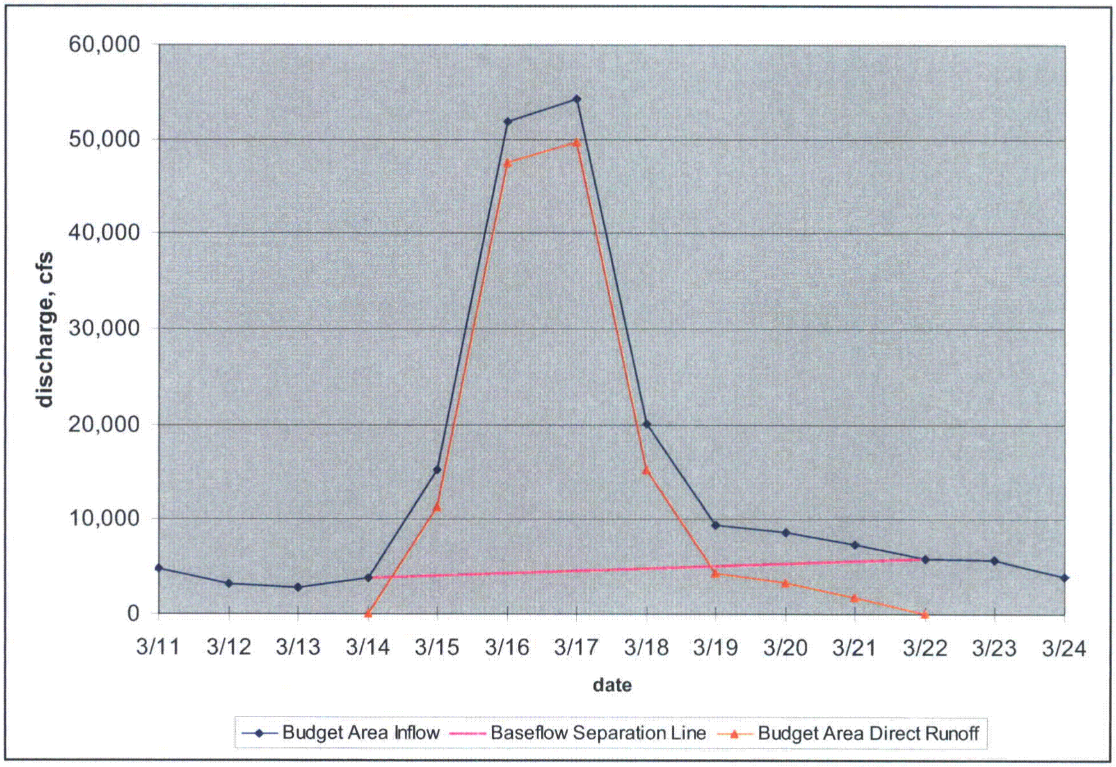

Figure 9: Base Flow Separation for the March 1973 Flood

The estimated inflow hydrograph ($\overline{L}$) for the May 2003 flood shown on Figure 8 and listed in Table 9 contains several negative values. These values are artifacts of the calculation method and occur because the water budget computation does not account for routing of flows across the water budget area and reservoir to Watts Bar Dam. The SOCH model simulations will account for routing. The calculated negative values occur both before and after the May 2003 flood. Because of the calculated negative values before and after the flood, a constant base flow value of 3,000 cfs was chosen for the May 2003 flood from the average of estimated inflow hydrograph ($\overline{L}$) values for the ten days before the flood (i.e. April 25, 2003 through May 4,

2003) and for the ten days after the flood (i.e. May 12, 2003 through May 21, 2003). The constant base flow separation for the May 2003 flood is shown on Figure 10.

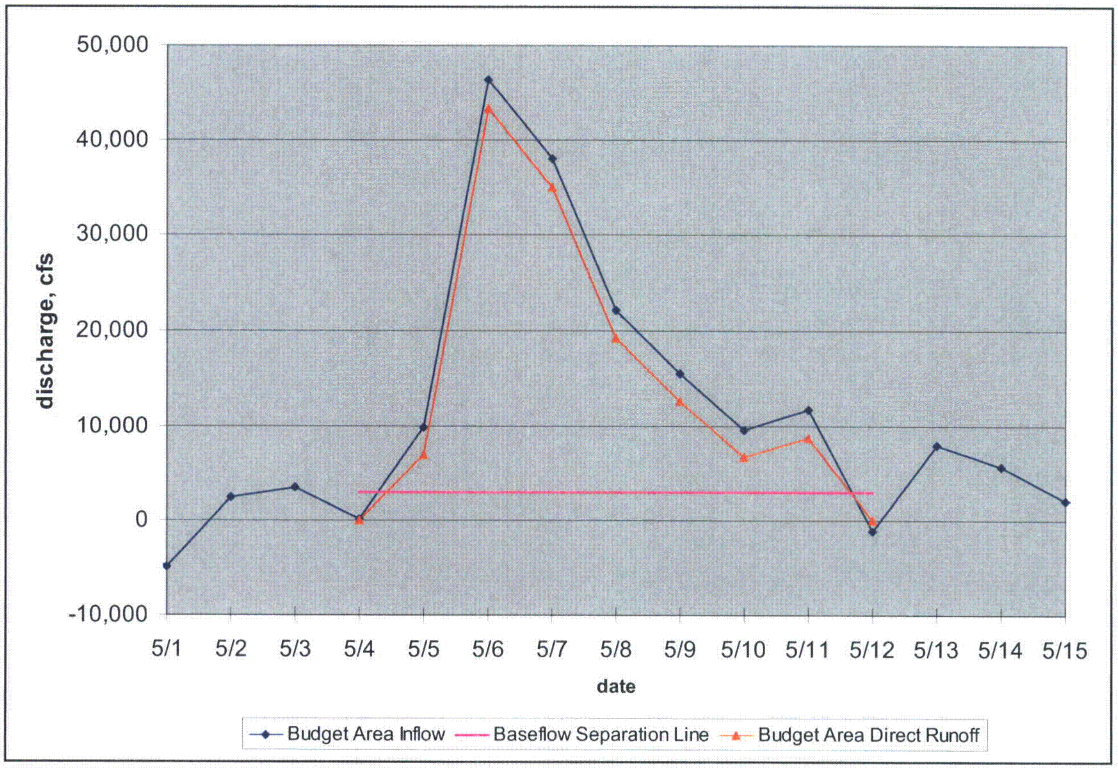

Figure 10: Base Flow Separation for the May 2003 Flood

Direct runoff hydrographs for the May 2003 flood and March 1973 flood were calculated by removing the estimated base flow from the total flow hydrographs for the water budget area. Direct runoff volumes are summarized in Table 10. The values in Table 10 represent the aggregated runoff volume from Subbasins 25, 33, 34, 36, and 37 and from direct rainfall on Watts Bar Reservoir. Base flow separation and runoff volume calculations for the March 1973 and May 2003 floods are enclosed in Attachment 1- 8.

Table 10: Total Direct Runoff Volumes for the March 1973 and May 2003 Floods

Flood	Total Runoff Volume (ac-ft)	Drainage Area (mi^2)	Runoff Depth (in)
March 1973	264,213	905.5	5.47
May 2003	262,498	905.5	5.44

7.4 Observed Subbasin Average Rainfall

Observed basin-average rainfall for the May 2003 storm was obtained from Reference 15. The hourly precipitation series developed from NWS gridded data for Subbasins 25, 33, 34, 36, and 37 along with adjustments to Central Time and unit conversion are provided in Attachment 1- 9. Observed basin average rainfall for the March 1973 storm was obtained from Reference 16.

7.5 Direct Runoff from Rainfall on Watts Bar Reservoir

Watts Bar Reservoir has a surface area of approximately 59.5 mi^2 (Reference 16). As shown in Figure 1, portions of the reservoir are in Subbasins 25, 33, 36, and 37. Reservoir surface area is included in the areas of these subbasins provided in Table 1. Rain that falls on the reservoir surface contributes directly to the inflow to the reservoir (I) calculated with Equation (2) and to the estimated direct runoff volumes for the March 1973 and May 2003 floods listed in Table 10. The contribution of rainfall on the reservoir surface to the direct runoff volume for each flood can be calculated as the depth of rainfall falling on the reservoir during the storm multiplied by the reservoir surface area. The equivalent direct runoff time series, for rainfall on the reservoir surface, can be estimated as depth of rainfall each hour during the storm multiplied by the surface area of the reservoir with appropriate unit conversions incorporated into the calculation.

The observed rain falling on the reservoir surface during the March 1973 storm was provided by the TVA in Reference 16. For the May 2003 storm, the NWS basin average rainfall for Subbasins 25, 33, 36, and 37 was used to represent rainfall on the reservoir surface. Rainfall from the different subbasins was allocated to the reservoir surface using the proportional area of the reservoir within each subbasin.

Reference 16 provides a reservoir surface area of 59.47 mi^2 for the 1973 flood. A constant total reservoir surface area of 59.5 mi^2 was used in calculations for both floods. The area of the reservoir within each subbasin was also held constant in the analysis of the May 2003 flood. The reservoir surface areas for each subbasin are provided in Table 11. The total surface area of 59.5 mi^2 (and the surface areas within each subbasin) approximately corresponds to a headwater elevation in the reservoir of 741 feet (see worksheet "Lake Surface Areas" in Attachment 1- 10). For the range of dates listed in Table 9 (i.e. the 2003 flood), the average daily headwater elevation in is 741.5 feet and the median is 740.9 feet (Reference 9).

Table 11: Reservoir Surface Area by Subbasin

Sub-basins	Reservoir Areas				
	37	36	33	25	Total
Acres	26,043	3,988	416	7,611	38,059
Square Miles	40.69	6.23	0.65	11.89	59.5
Proportion	0.684	0.105	0.011	0.200	1.00

Because the watershed areas for the unit hydrographs for Subbasins 25, 33, 36, and 37 each include a portion of the surface area of Watts Bar Reservoir, the additional direct runoff generated by rain falling on the reservoir surface over and above the direct runoff convoluted with the unit hydrographs is calculated for these subbasins. This additional direct runoff contribution is the difference between the measured rainfall depth on the reservoir area and estimated excess precipitation depth (excess precipitation is calculated using FLDHYDRO as discussed in Section 7.6). These additional contributions were converted to an equivalent volume of additional direct runoff as outlined above.

Figure 11 and Figure 12 display the additional direct runoff calculated for the March 1973 and May 2003 floods, respectively. These additional contributions were converted to an equivalent volume of additional direct runoff as mentioned above. The additional direct runoff volume is presented in Table 12 for the March 1973 and May 2003 floods. Additional direct runoff time series calculations are enclosed in Attachment 1- 10.

Table 12: Additional Direct Runoff Volume Corresponding to the Difference between Rainfall on Watts Bar Reservoir and Excess Precipitation Calculated for Subbasins 25, 33, 34, 36, and 37

Flood	Watts Bar Reservoir (inches per 59.5 mi^2)			Water Budget Area (inches per 905.5 mi^2)*		
	Observed Rainfall	Excess Precipitation (Runoff from FLDHYDRO)	Additional Direct Runoff Volume from Watts Bar Reservoir	Water Budget Area Runoff Volume from Table 10	Additional Direct Runoff Volume from Watts Bar Reservoir	Direct Runoff Volume from Subbasins 25, 33, 34, 36, and 37
March 1973	6.52	5.48	1.04	5.47	0.07	5.40
May 2003	7.78	5.78	2.00	5.44	0.14	5.30

*The entire water budget area, rather than only the areas of Subbasins 25, 33, 36, and 37, is used as an approximation to adjust the direct runoff volume to account for rain falling on Watts Bar Reservoir as discussed in Section 7.5.

To compensate for the volume of additional direct runoff, it is subtracted from the water budget area volume to adjust the volume of direct runoff originally estimated. The proportion of Watts Bar Reservoir surface area to subbasin area varies among Subbasins 25, 33, 36, and 37. The Watts Bar Reservoir is completely outside of Subbasin 34. The combined runoff volume from Subbasins 25, 33, 34, 36, and 37 shown in Table 12 was adjusted to simplify calculations. The combined runoff volume is input to FLDHYDRO as the CHKVOL parameter and FLDHYDRO partitions the runoff among the subbasins. The adjustments to the combined runoff volumes for the March 1973 and May 2003 floods are less than 0.15 inch as shown in Table 12. The combined adjustment is reasonable given the small magnitude of the adjustment.

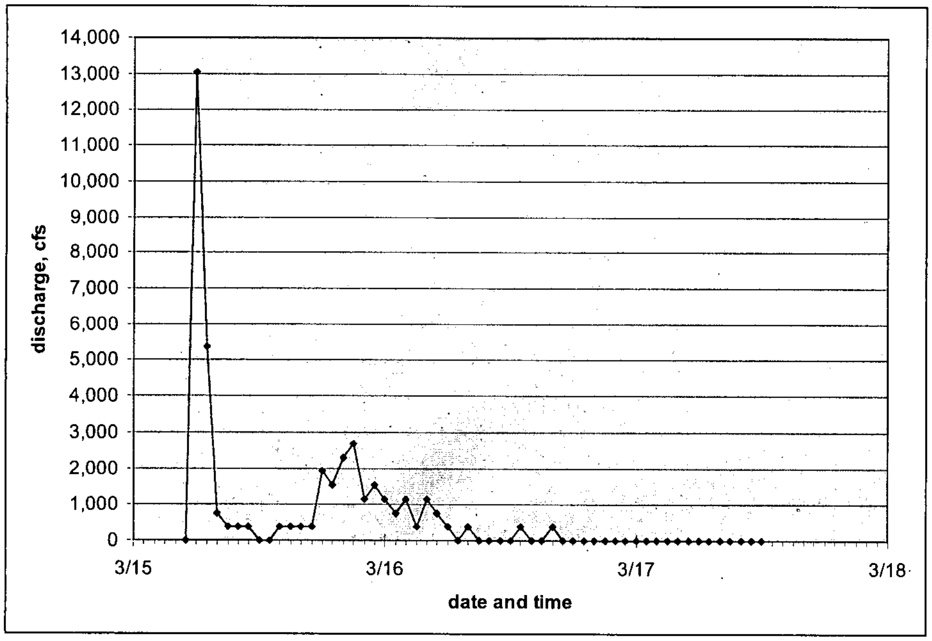

Figure 11: Additional Direct Runoff from Rainfall on Watts Bar Reservoir during the March 1973 Storm

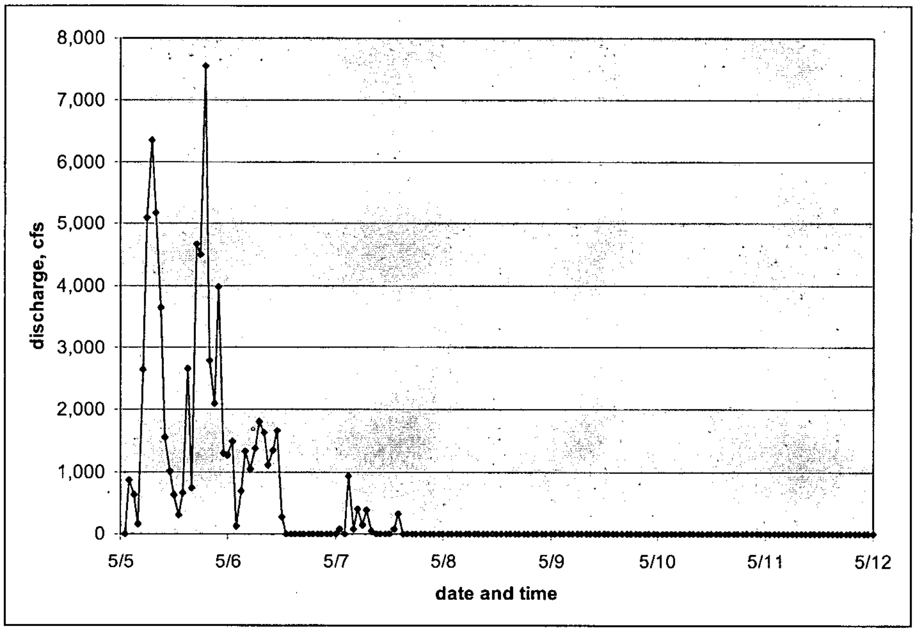

Figure 12: Additional Direct Runoff from Rainfall on Watts Bar Reservoir during the May 2003 Storm

7.6 Allocation of Basin Average Excess Precipitation among Subbasins 25, 33, 34, 36, and 37

Effective rainfall, or excess precipitation, is the input to the linear basin model that is converted into direct runoff at the basin outlet via convolution with the unit hydrograph. The amount of excess can be developed from observed rainfall by application of a loss function which incorporates the hydrologic abstractions of evaporation and transpiration, interception, depression storage, and infiltration (Reference 3). The amount of excess precipitation, or direct runoff, produced by a given storm is dependent on the soil and land use characteristics, state of the basin at the beginning of the storm, and the characteristics of the storm (Reference 18 and Reference 19). Storm characteristics related to excess rainfall generation include precipitation intensity, total rainfall amount, and spatial and temporal distribution of rainfall across the watershed (although use of the unit hydrograph method precludes incorporating the spatial distribution of rainfall into the analysis of storm runoff). The state of the basin encompasses antecedent soil moisture conditions, the amount of depression storage remaining in the watershed after recent rains, and vegetation-related concerns like evapotranspiration and interception.

The TVA utilizes 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 18 and Reference 19. 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.

7.6.1 FLDHYDRO Operation

Direct runoff is equivalent to excess precipitation. The direct runoff volumes produced by Subbasins 25, 33, 34, 36, and 37 during the May 2003 and March 1973 floods are provided in Table 12. For each flood, the direct runoff volume needs to be partitioned into contributions from each subbasin and distributed across the duration of the flood.

The FLDHYDRO program can be used to partition a known total excess precipitation (or direct runoff) volume across several sub-watersheds (Reference 4). In this method of operation, the total volume of excess precipitation, or direct runoff, for the subbasins is given to FLDHYDRO as the CHKVOL value in the input file. Rainfall during the flood and antecedent rainfall are also provided to FLDHYDRO for each subbasin in the input file. FLDHYDRO then calculates a distribution of excess precipitation for each subbasin so that the CHKVOL value, representing the sum of excess precipitation in all subbasins, is satisfied. As part of this operation, FLDHYDRO preserves unique antecedent conditions (API) for each subbasin by maintaining the relative relationships between the initial API values calculated for each subbasin and the API employed for each subbasin to generate the output excess precipitation.

The FLDHYDRO program can also be used to distribute estimated base flow for the budget area to the individual subbasins when FLDHYDRO is used to simulate direct runoff via convolution of the unit hydrographs with runoff values (parameter NARFE = 2 in the input file). Beginning and ending base flow values in cfs/mi^2 are given to the program in the input file. If the values calculated for the budget area in cfs/mi^2 are given to each subbasin, the FLDHYDRO program will allocate base flow among the subbasins accounting for the duration of simulated direct runoff and for the areas of the subbasins.

7.6.2 FLDHYDRO Input and Output

A FLDHYDRO input file was developed for each flood (i.e. one for the March 1973 flood and one for the May 2003 flood). The input file for each flood contains basin average rainfall during the flood for each subbasin, antecedent rainfall for each subbasin, the total volume of direct runoff (i.e. the CHKVOL value) for the five subbasins, the unit hydrographs for the five subbasins, and the estimated base flow. NWS basin average rainfall data were used for the 2003 flood. Reference 16 provides basin average rainfall values for each subbasin for the 1973 flood; Attachment 1- 11 provides the manipulations required to prepare the 1973 flood rainfall values for the FLDHYDRO input file. The CHKVOL values for each flood are listed in the "Direct Runoff Volume from Subbasins" column of Table 12.

Estimated base flows are shown by the separation lines on Figure 9 and Figure 10; these calculations are enclosed in Attachment 1- 8. The beginning base flow discharge and the ending base flow discharge for each flood are divided by the water budget area and provided to FLDHYDRO in the input file. FLDHYDRO allocates the base flow among the subbasins according to area and distributes the base flow across the calculated period of direct runoff. The calculated beginning and ending base flow values used in FLDHYDRO are provided in Table 13.

Table 13: Base Flow Input Parameters for FLDHYDRO

Flood	Beginning Base Flow Value (cfs/mi^2)	Ending Base Flow Value (cfs/mi^2)
March 1973	4.15	6.48
May 2003	3.31	3.31

Table 14 provides a summary of excess precipitation volumes obtained from FLDHYDRO for each subbasin. Cumulative rainfall and runoff and the time series of rainfall and runoff obtained from FLDHYDRO for the five subbasins for the March 1973 storm are displayed on Figure 13 through Figure 22. Figure 23 through Figure 32 provide equivalent plots for the May 2003 storm.

Because the CHKVOL values were obtained by subtracting the difference between rainfall and excess precipitation across the reservoir surface and because FLDHYDRO operation was required to obtain the estimate of excess precipitation, an iterative process was used to determine the final CHKVOL value. In this process, FLDHYDRO was run with water budget area direct runoff volume (see Table 10) to obtain an initial estimate of excess precipitation. Then, the additional direct runoff volume for the reservoir (i.e. the difference between rainfall and excess precipitation over the reservoir surface area) was calculated. An initial estimate of the direct runoff from the subbasins was calculated and FLDHYDRO rerun with this estimate as the CHKVOL value as the third step. Steps two and three were repeated until the same total depth of excess precipitation (i.e. the same CHKVOL value) was obtained for the reservoir surface and for the subbasins. FLDHYDRO input and output files are enclosed as Attachment 2- 1 through Attachment 2- 6.

Table 14: Selected FLDHYDRO Inputs and Resulting Excess Precipitation Volumes

Flood	FLDHYDRO Input File	CHKVOL Value from Table 12 (inches per 905.5 mi^2)	Subbasin	Subbasin Area (mi^2)	Basin-Average Rainfall (inches per subbasin area)	Excess Precipitation from FLDHYDRO (inches per subbasin area)	Total Excess Precipitation from FLDHYDRO (inches per 905.5 mi^2)	Difference Between CHKVOL and Total Excess Precipitation from FLDHYDRO (%)
March 1973	WB_1973.dat	5.40	25	295.3	6.89	4.94	5.33	-1.3
			33	37.2	6.39	4.31		
			34	135.2	6.55	5.14		
			36	29.3	6.25	5.04		
			37	408.4	7.01	5.79		
May 2003	WB_2003.dat	5.30	25	295.3	8.19	5.52	5.27	-0.6
			33	37.2	6.34	3.52		
			34	135.2	5.04	3.08		
			36	29.3	7.26	5.30		
			37	408.4	7.76	5.97		

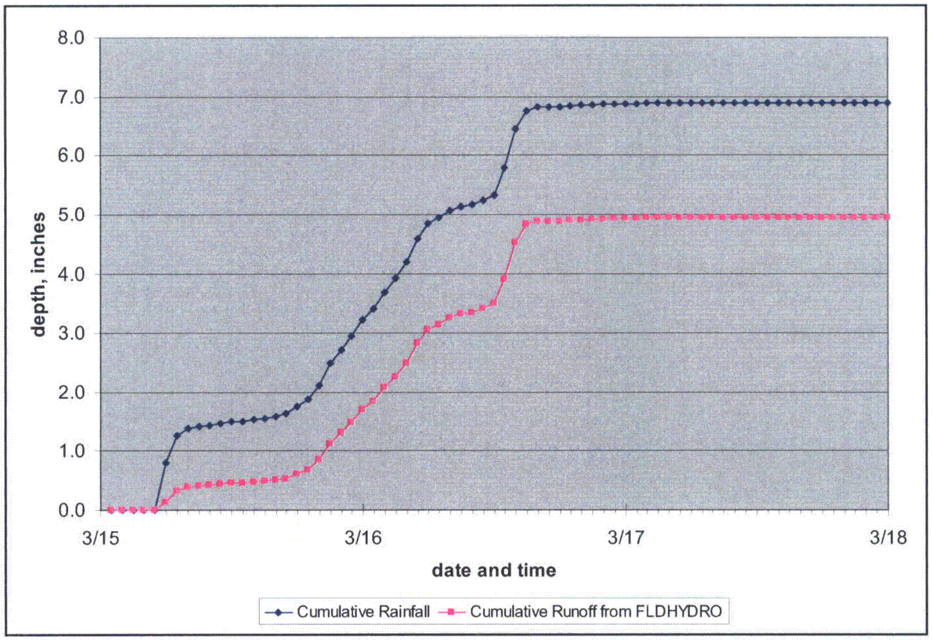

Figure 13: Subbasin 25 Cumulative Rainfall and Runoff for the March 1973 Storm

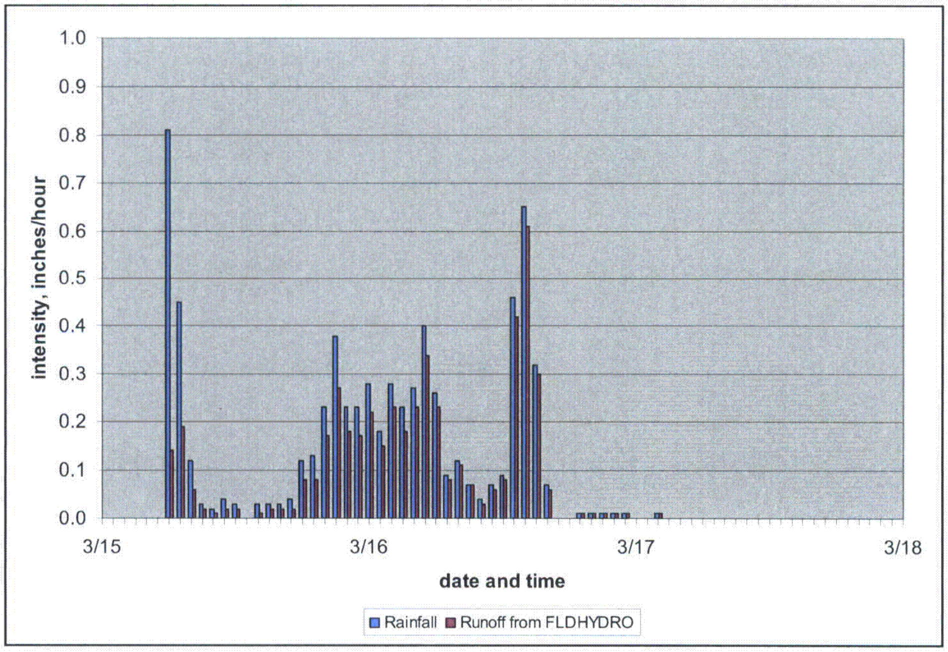

Figure 14: Subbasin 25 Rainfall and Runoff Time Series for the March 1973 Storm

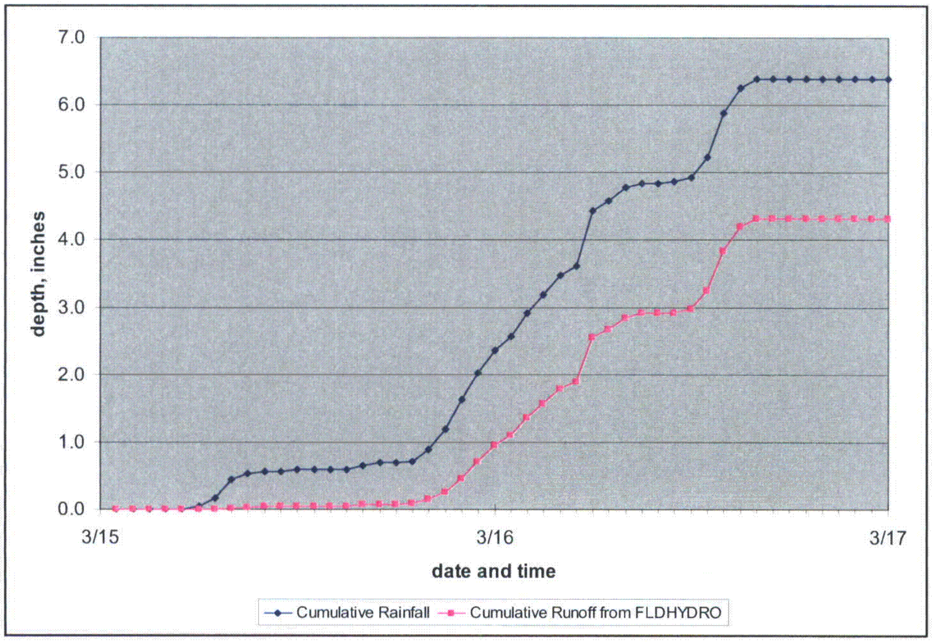

Figure 15: Subbasin 33 Cumulative Rainfall and Runoff for the March 1973 Storm

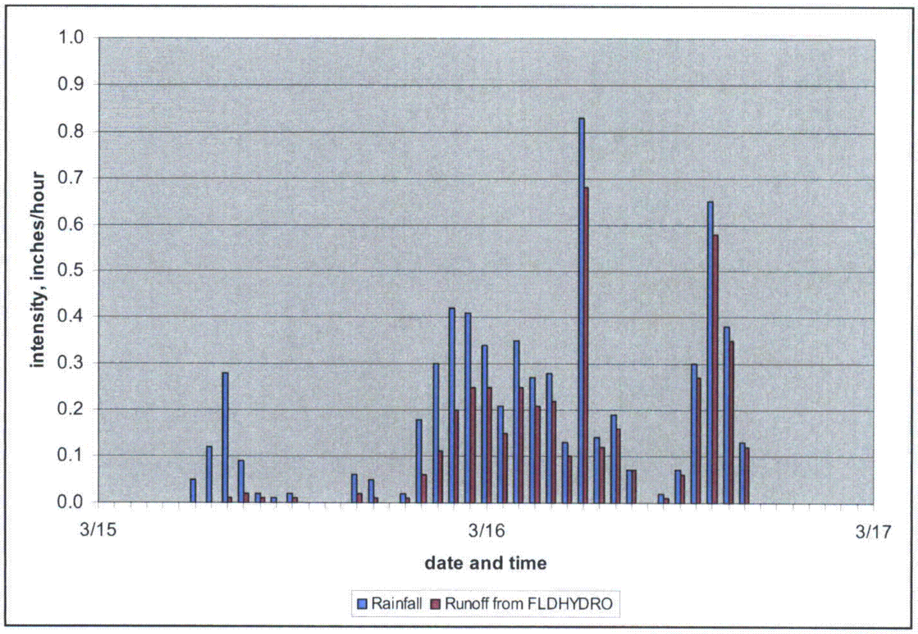

Figure 16: Subbasin 33 Rainfall and Runoff Time Series for the March 1973 Storm

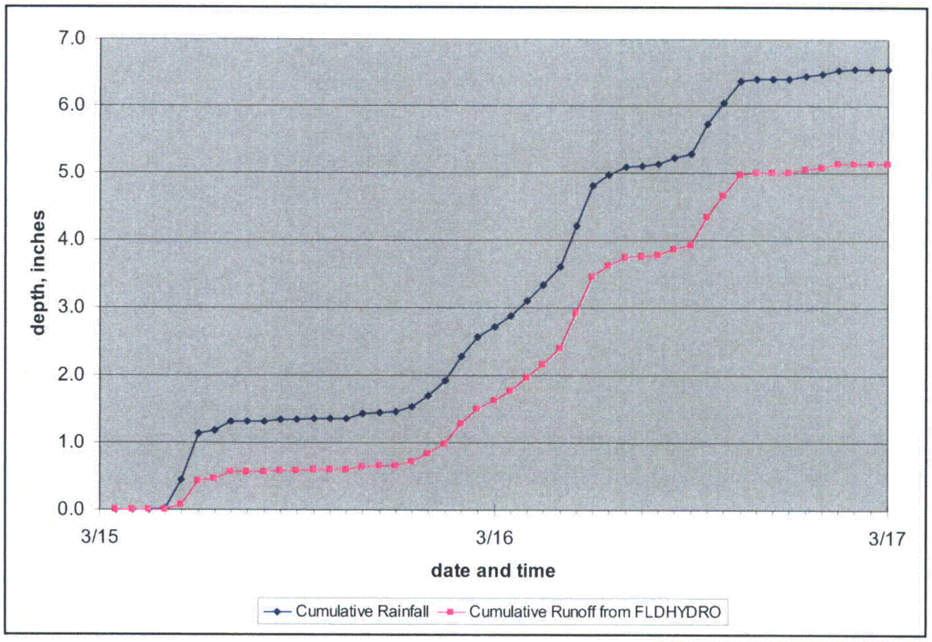

Figure 17: Subbasin 34 Cumulative Rainfall and Runoff for the March 1973 Storm

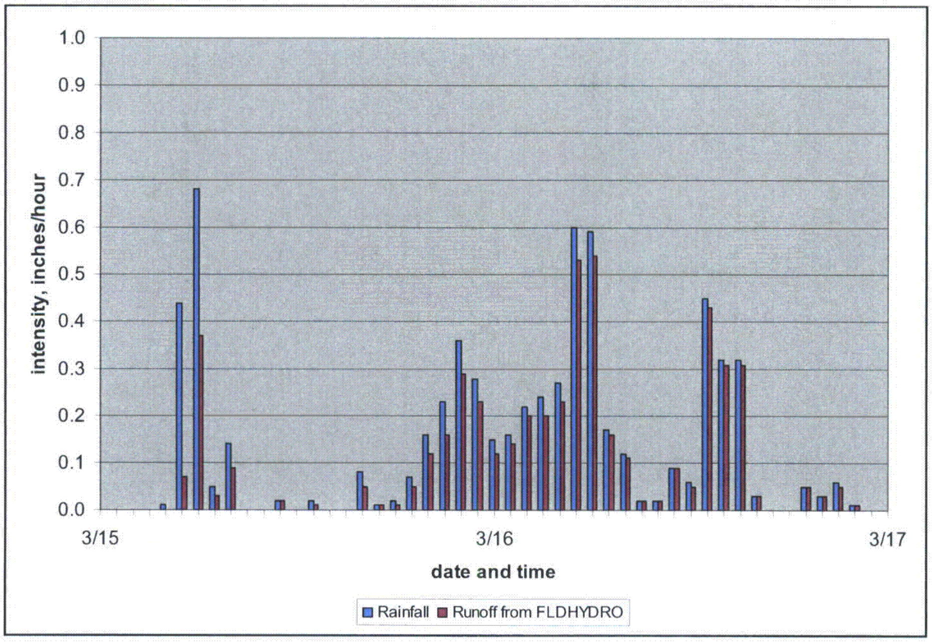

Figure 18: Subbasin 34 Rainfall and Runoff Time Series for the March 1973 Storm

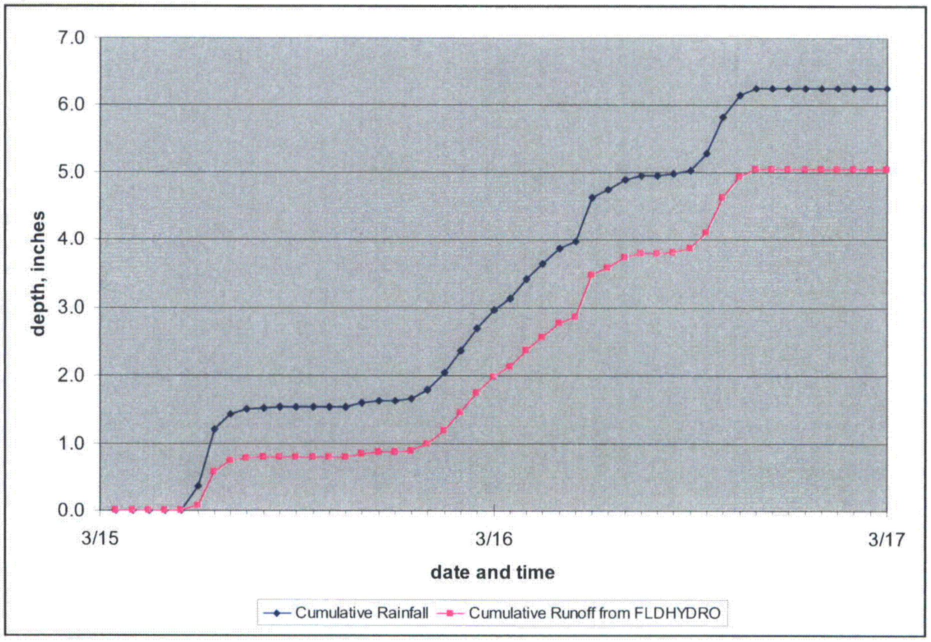

Figure 19: Subbasin 36 Cumulative Rainfall and Runoff for the March 1973 Storm

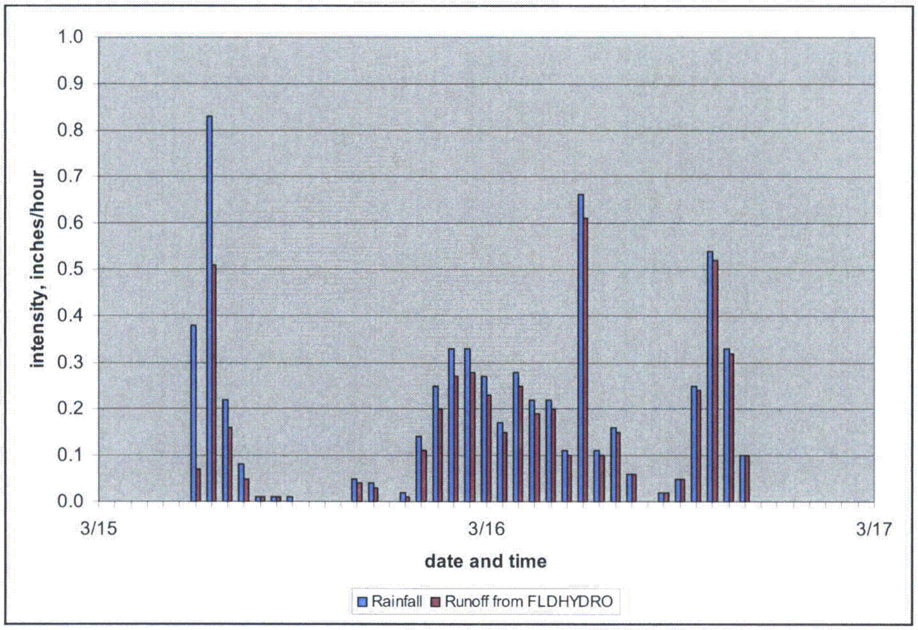

Figure 20: Subbasin 36 Rainfall and Runoff Time Series for the March 1973 Storm

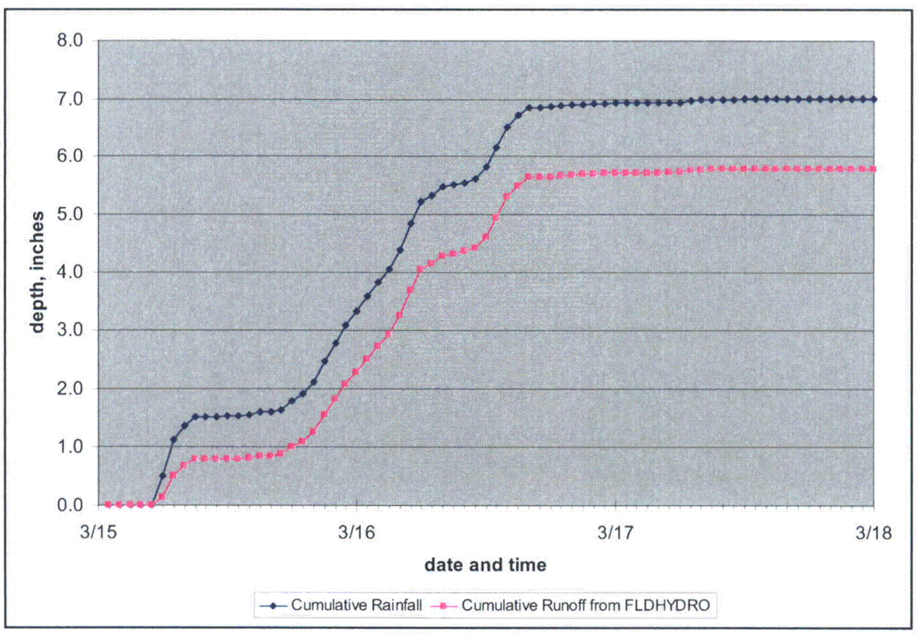

Figure 21: Subbasin 37 Cumulative Rainfall and Runoff for the March 1973 Storm

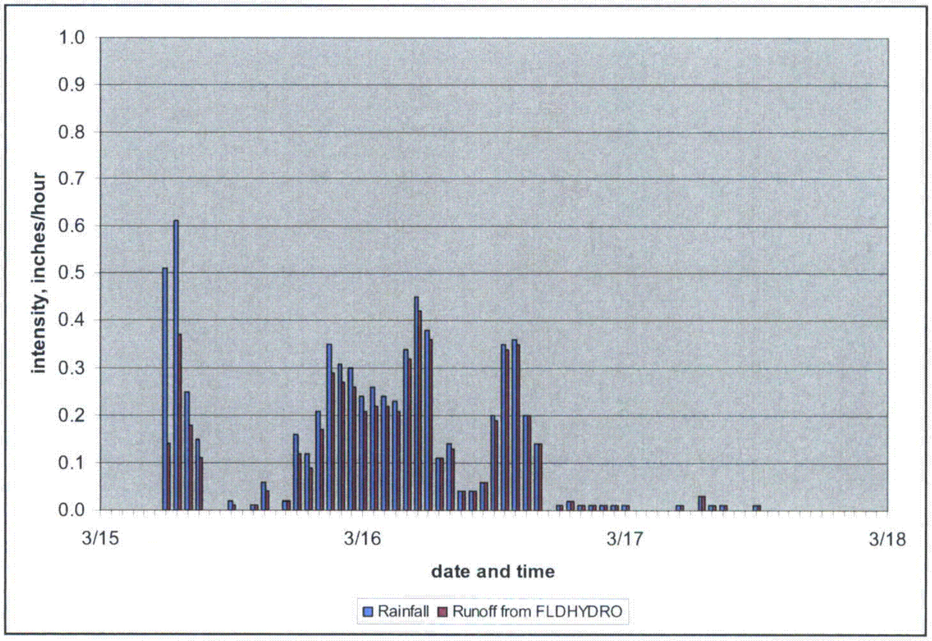

Figure 22: Subbasin 37 Rainfall and Runoff Time Series for the March 1973 Storm

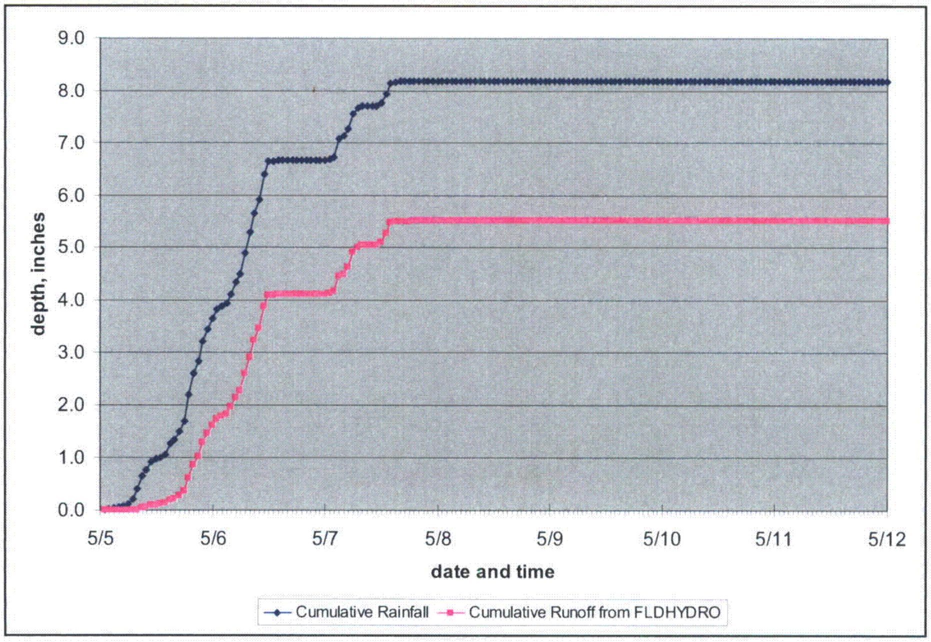

Figure 23: Subbasin 25 Cumulative Rainfall and Runoff for the May 2003 Storm

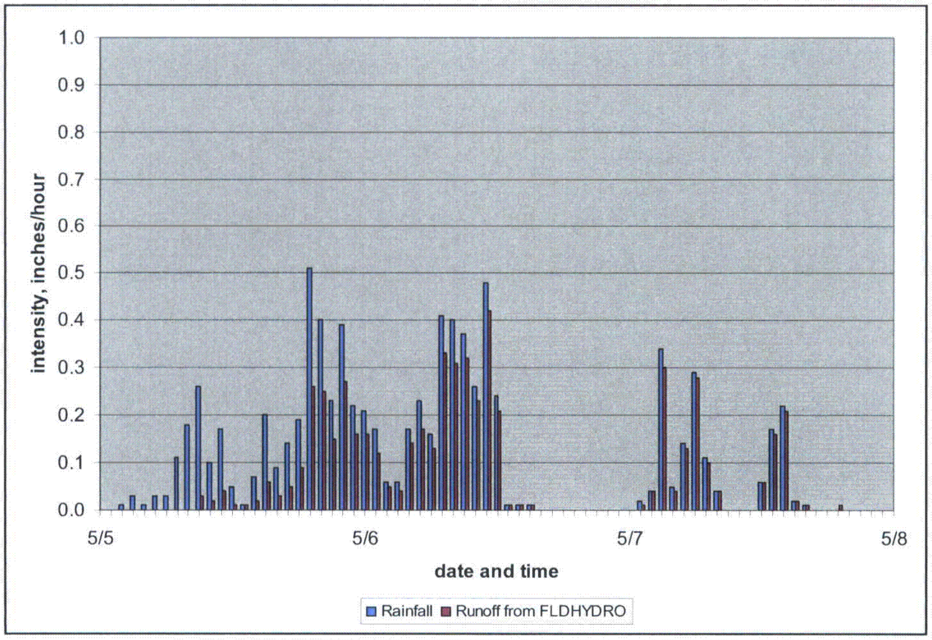

Figure 24: Subbasin 25 Rainfall and Runoff Time Series for the May 2003 Storm

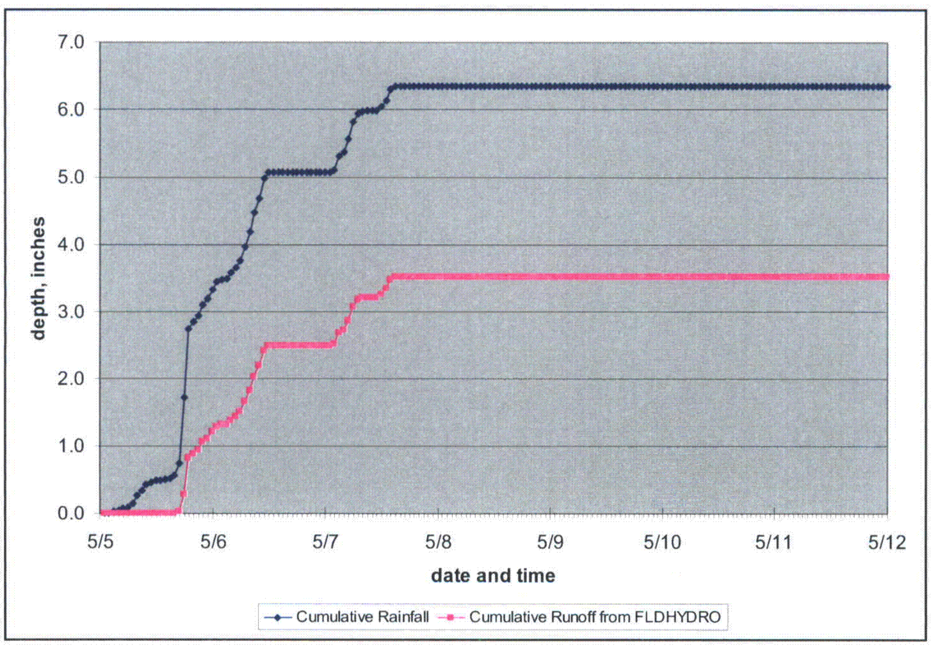

Figure 25: Subbasin 33 Cumulative Rainfall and Runoff for the May 2003 Storm

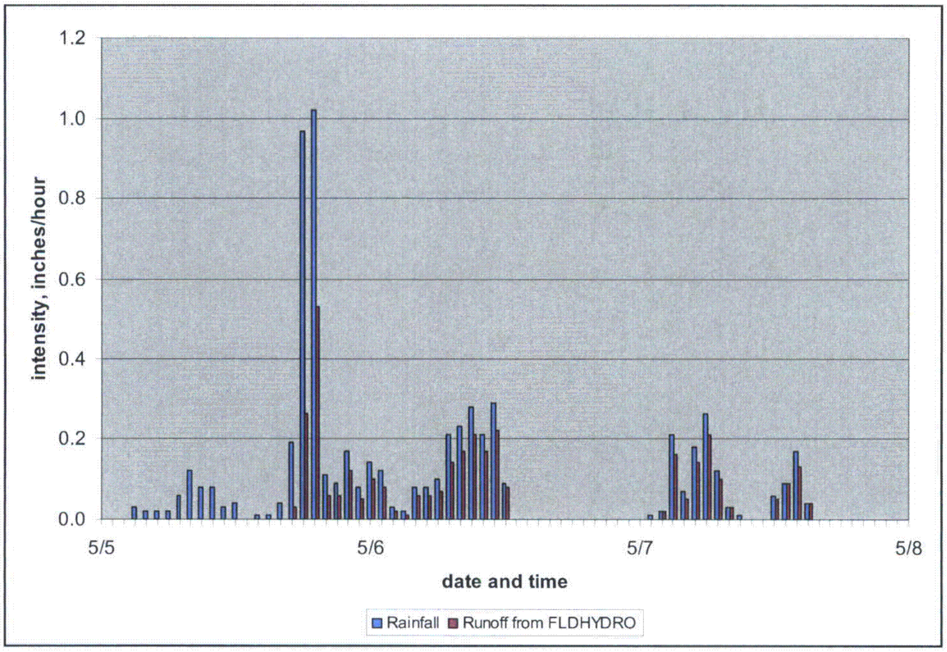

Figure 26: Subbasin 33 Rainfall and Runoff Time Series for the May 2003 Storm

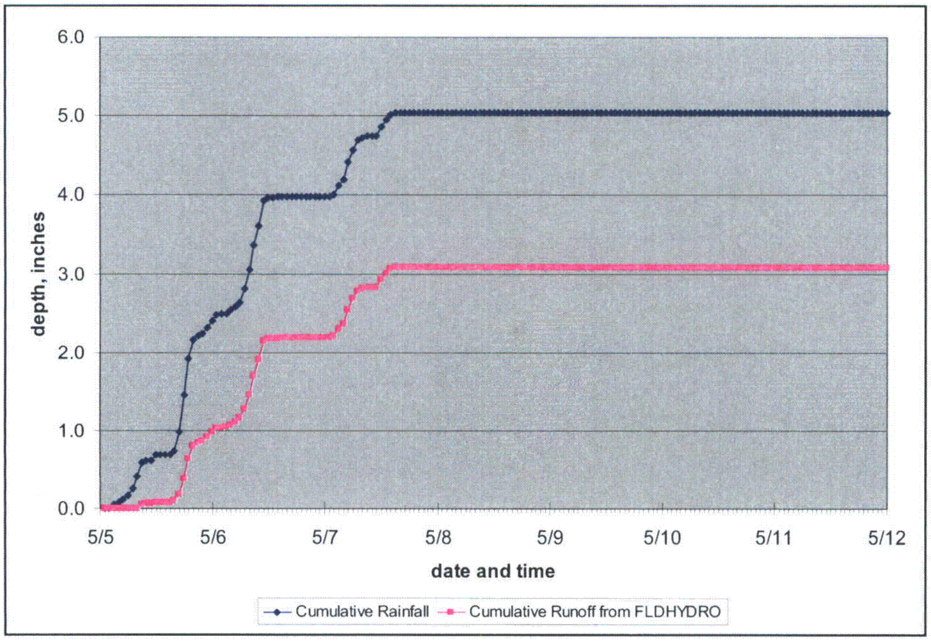

Figure 27: Subbasin 34 Cumulative Rainfall and Runoff for the May 2003 Storm

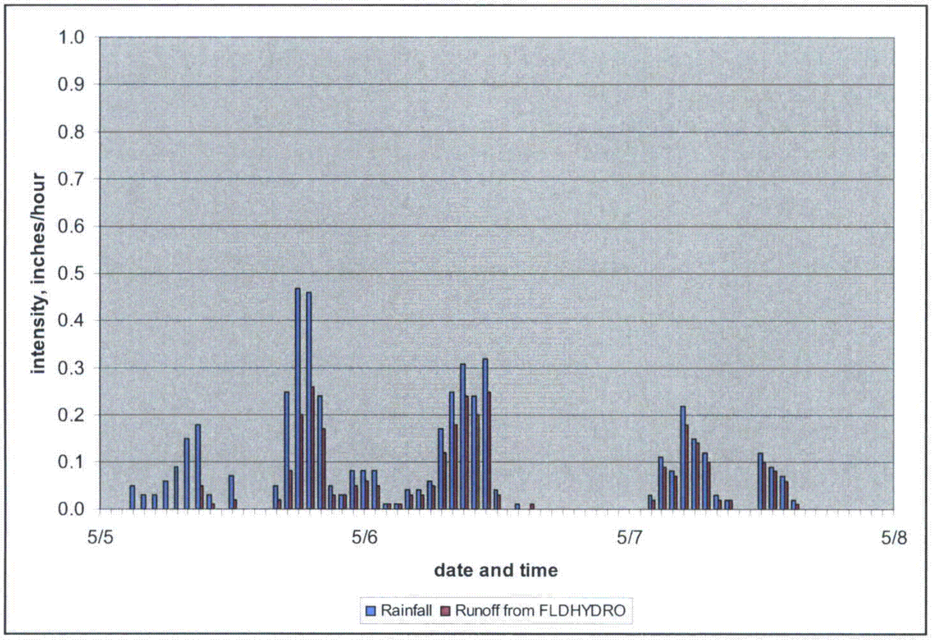

Figure 28: Subbasin 34 Rainfall and Runoff Time Series for the May 2003 Storm

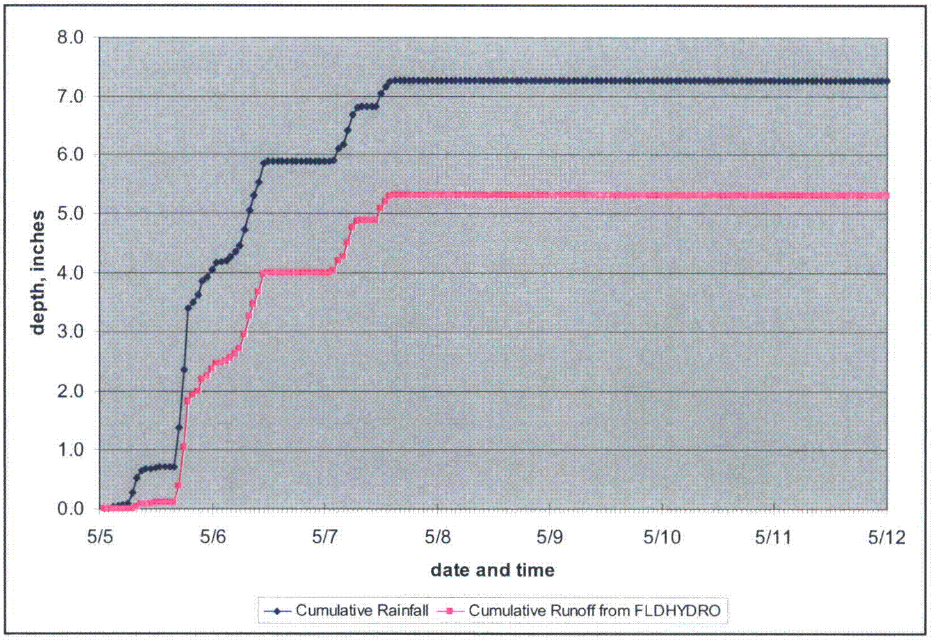

Figure 29: Subbasin 36 Cumulative Rainfall and Runoff for the May 2003 Storm

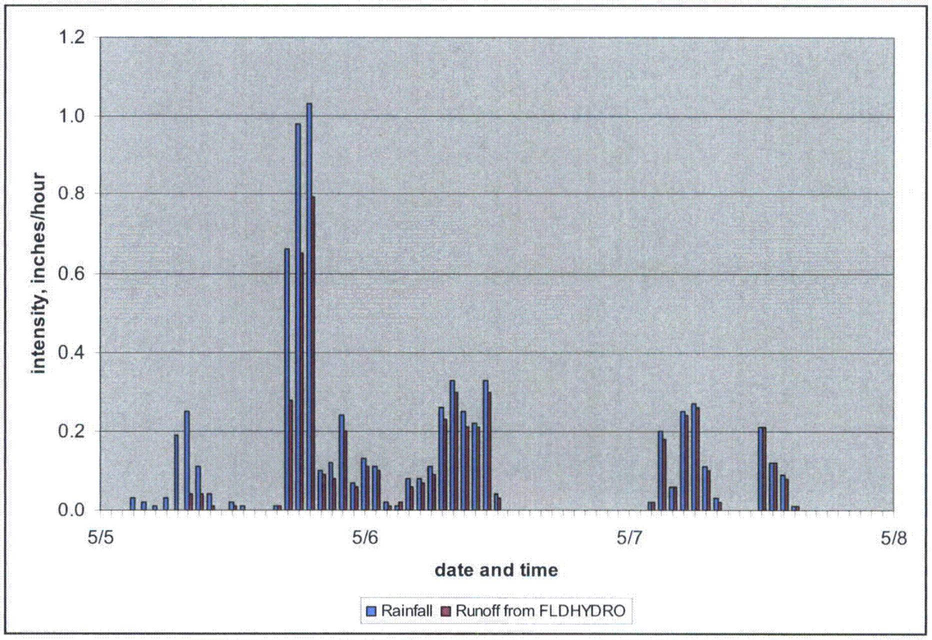

Figure 30: Subbasin 36 Rainfall and Runoff Time Series for the May 2003 Storm

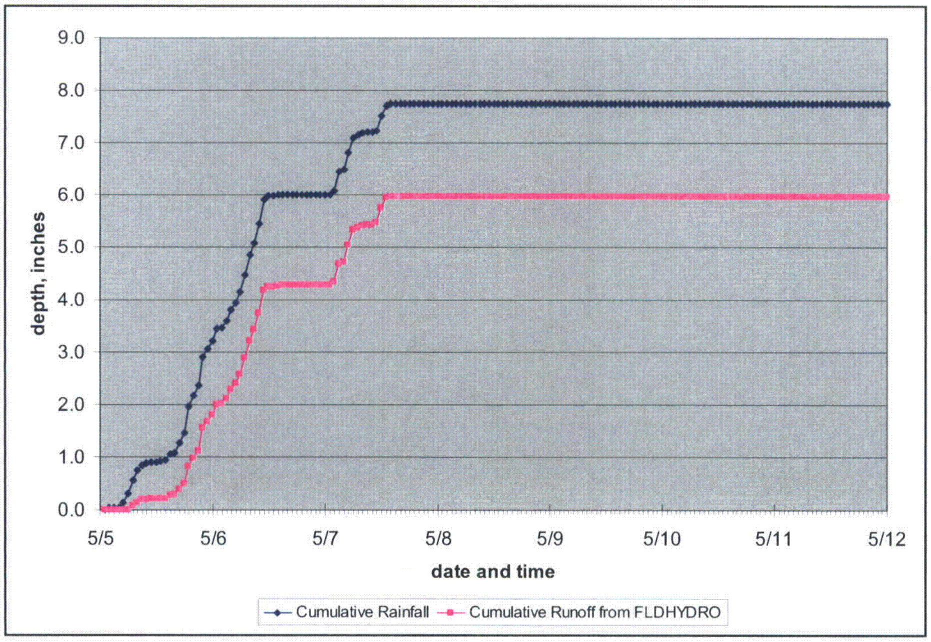

Figure 31: Subbasin 37 Cumulative Rainfall and Runoff for the May 2003 Storm

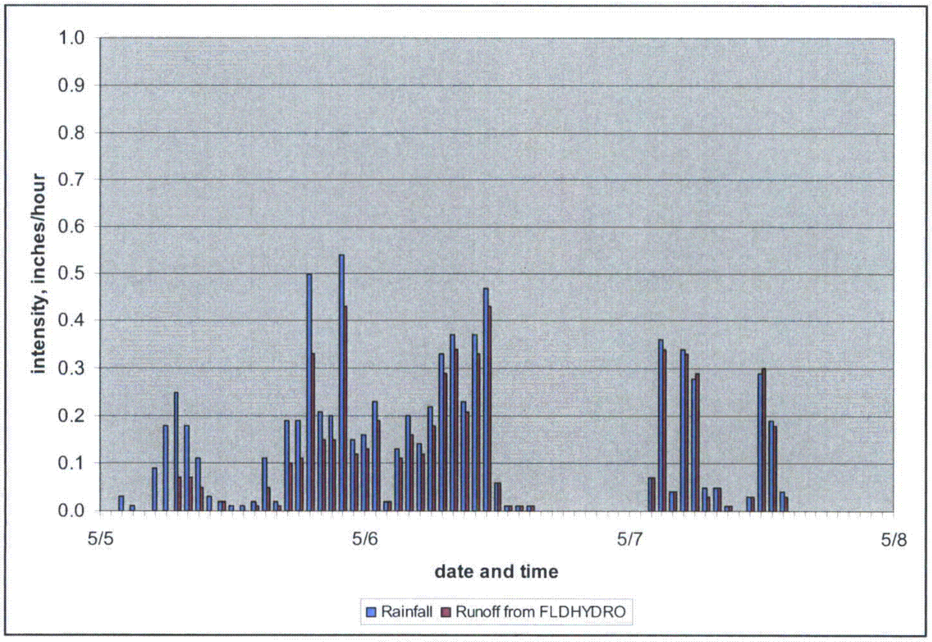

Figure 32: Subbasin 37 Rainfall and Runoff Time Series for the May 2003 Storm

7.7 Calculation of Subbasin Initial Inflow Hydrographs

Local direct runoff hydrographs were calculated for the March 1973 and May 2003 floods for Subbasins 25, 33, 34, 36, and 37 via convolution of the excess precipitation obtained from FLDHYDRO and the unit hydrographs presented in 6.2. HEC-HMS (Reference 20 and Reference 21) was used for the convolution calculations. In the HEC-HMS convolutions, or simulations, excess basin average rainfall (or runoff) output from FLDHYDRO was utilized as "precipitation data." Excess precipitation values were aggregated to time intervals that matched the duration of the corresponding unit hydrograph (Attachment 1- 12).

Flood hydrographs were calculated for the March 1973 and May 2003 floods by adding base flow to the direct runoff values obtained by convoluting excess precipitation and the subbasin unit hydrograph. Base flow estimates for each subbasin were obtained from FLDHYDRO output (Attachment 2- 4 and Attachment 2- 6). The time base of estimated direct runoff from FLDHYDRO did not exactly match that provided by HEC-HMS in all cases. When the time bases did not match, linear extrapolation was used to extend the estimated base flow to correspond to the time base of direct runoff provided by convolutions completed in HEC-HMS. The convolution and base flow calculations are enclosed in Attachment 1- 13. Table 15 identifies the worksheet, within the spreadsheets provided as Attachment 1- 12 and Attachment 1- 13, that contains the calculations for each flood and subbasin. The flood hydrographs for Subbasins 25, 33, 34, 36, and 37 for the March 1973 and May 2003 floods will be used by the TVA as initial SOCH model inputs.

Table 15: Matrix Identifying Pertinent Calculation Worksheets within Attachment 1- 12 and Attachment 1- 13

Flood	Subbasin	Excess Precipitation Aggregation Attachment 1- 12	Convolution and Base Flow Attachment 1- 13
March 1973	25	25_1973	Subbasin_25-1973
	33	33_1973	Subbasin_33-1973
	34	34_1973	Subbasin_34-1973
	36	36_1973	Subbasin_36-1973
	37	37_1973	Subbasin_37-1973
May 2003	25	25_2003	Subbasin_25-2003
	33	33_2003	Subbasin_33-2003
	34	34_2003	Subbasin_34-2003
	36	36_2003	Subbasin_36-2003
	37	37_2003	Subbasin_37-2003

7.7.1 March 1973 Flood

A HEC-HMS project file was developed to calculate direct runoff hydrographs for each of the subbasins for the March 1973 flood. The following basin models were developed:

- Subbasin_25
- Subbasin_33
- Subbasin_34
- Subbasin_36
- Subbasin_37

The following input files were developed for the project and input to HEC-HMS via the Time Series Data Manager (all time series are adjusted to Central Time for this calculation):

- Precipitation Gage "B25_1973" with six-hour incremental depths of excess rainfall
- Precipitation Gage "B33_1973" with two-hour incremental depths of excess rainfall
- Precipitation Gage "B34_1973" with two-hour incremental depths of excess rainfall
- Precipitation Gage "B36_1973" with two-hour incremental depths of excess rainfall
- Precipitation Gage "B37_1973" with six-hour incremental depths of excess rainfall

Unit hydrographs for each subbasin were input to HEC-HMS with the Paired Data Manager. A six-hour time step was used in the convolution of Subbasins 25 and 37; A two-hour time step was used for Subbasins 33, 34, and 36. Estimated base flow from FLDHYDRO output was added to the direct runoff hydrographs to obtain initial flood hydrographs for each subbasin. The initial flood hydrographs are shown in Figure 33. HEC-HMS direct runoff output and associated flood hydrograph calculations are enclosed in Attachment 1- 13.

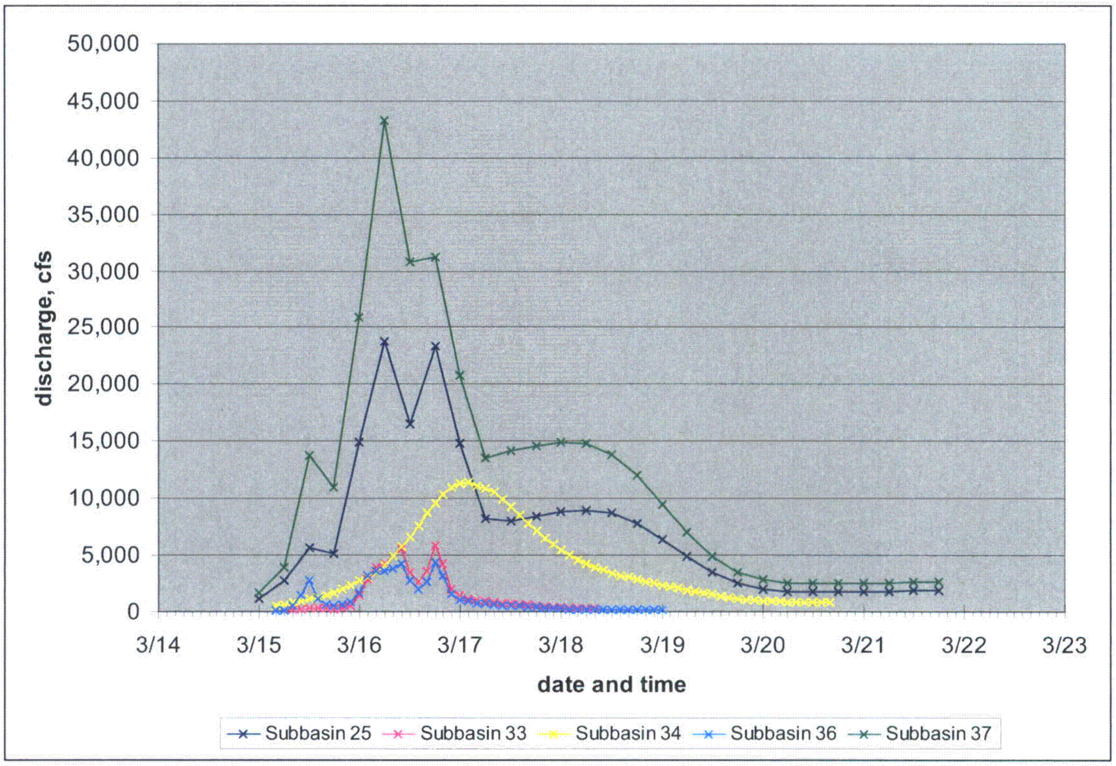

Figure 33: Initial Flood Hydrographs for the March 1973 Flood

7.7.2 May 2003 Flood

A second HEC-HMS project file was developed for the May 2003 flood. The same project file format was employed for the May 2003 flood as for the March 1973 flood as enumerated below. The 2003 simulation used the same unit hydrographs and convolution time steps as the 1973 simulation. The following basin models were developed:

- Subbasin_25
- Subbasin_33
- Subbasin_34
- Subbasin_36
- Subbasin_37

The following input files were developed for the project and input to HEC-HMS via the Time Series Data Manager (all time series are adjusted to Central Time for this calculation):

- Precipitation Gage "B25_2003" with six-hour incremental depths of excess rainfall
- Precipitation Gage "B33_2003" with two-hour incremental depths of excess rainfall
- Precipitation Gage "B34_2003" with two-hour incremental depths of excess rainfall

- Precipitation Gage "B36_2003" with two-hour incremental depths of excess rainfall
- Precipitation Gage "B37_2003" with six-hour incremental depths of excess rainfall

Estimated base flow was added to the direct runoff hydrograph calculated in HEC-HMS for each subbasin. The resulting initial flood hydrographs for each subbasin are shown in Figure 34. HEC-HMS direct runoff output and the corresponding flood hydrograph calculations are enclosed in Attachment 1- 13.

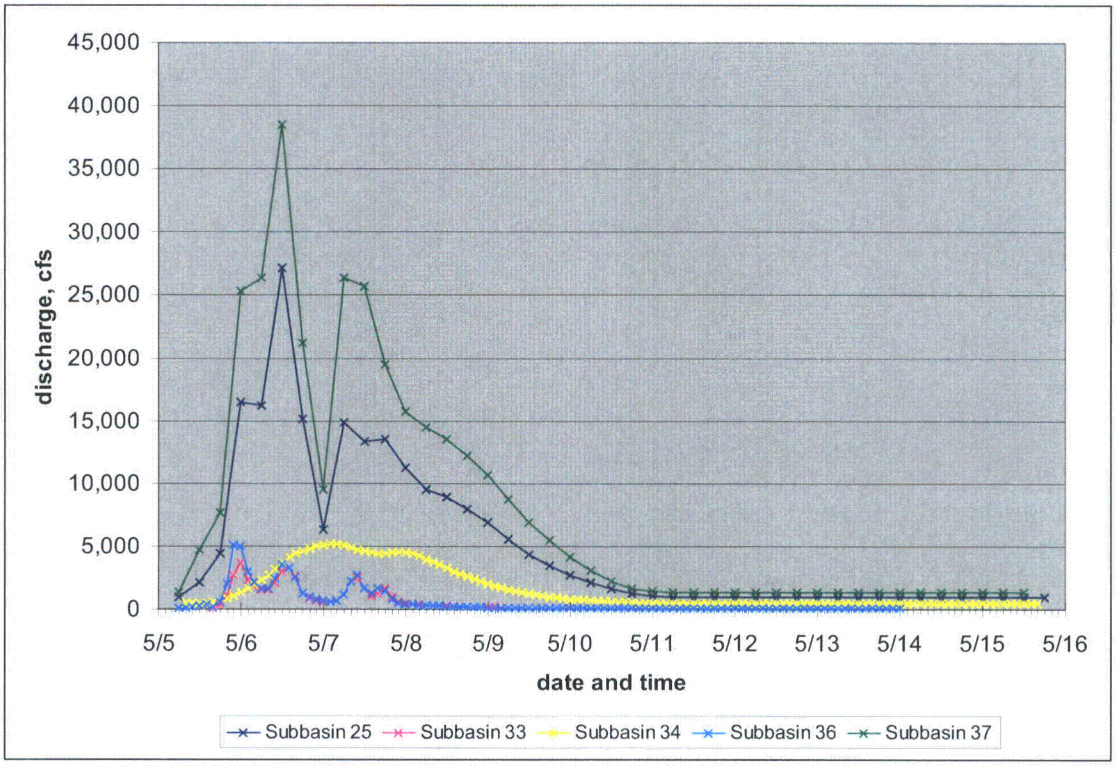

Figure 34: Initial Flood Hydrographs for the May 2003 Flood

7.8 Water Balance Confirmation

Table 16 provides a comparison of the direct runoff volume calculated for the water budget area (see Sections 7.2 and 7.3) and sum of the direct runoff volumes from the initial direct runoff hydrographs for Subbasins 25, 33, 34, 36, and 37 and Watts Bar Reservoir. Direct runoff hydrographs were obtained from HEC-HMS (Section 7.7). The total direct runoff volumes calculated for the water budget area and obtained from the direct runoff hydrographs match within two percent. The small discrepancy in calculated volumes is due to the slight change to direct runoff volume introduced by FLDHYDRO operation as shown in Table 14 and due to the fact that the unit hydrograph volumes do not exactly match one inch as shown in Table 2. Enclosed Attachment 1- 13 provides these calculations.

Table 16: Water Balance Confirmation

Volume Balance		
Flood	March 1973 (acre-ft)	May 2003 (acre-ft)
Water Budget Direct Runoff Volume ($905.5\ mi^2$)	264,213	262,498
Sum of Volumes from Direct Runoff Hydrographs for Subbasins 25, 33, 34, 36, and 37 and from Watts Bar Reservoir ($905.5\ mi^2$)	266,196	266,252
Volume Balance	0.73 %	1.41 %
Subbasin and Reservoir Totals		
Subbasin 25 Direct Runoff Volume ($295.3\ mi^2$)	77,162	86,221
Subbasin 33 Direct Runoff Volume ($37.2\ mi^2$)	8,528	6,965
Subbasin 34 Direct Runoff Volume ($135.2\ mi^2$)	37,349	22,380
Subbasin 36 Direct Runoff Volume ($29.3\ mi^2$)	8,013	8,427
Subbasin 37 Direct Runoff Volume ($408.4\ mi^2$)	131,782	135,879
Additional Direct Runoff Volume from Watts Bar Reservoir (59.5 mi2)	3,299	6,327

7.9 SOCH Model Input

Ten 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 25,
- Total direct runoff for Subbasin 33,
- Total direct runoff for Subbasin 34,
- Total direct runoff for Subbasin 36,
- Total direct runoff for Subbasin 37,
- Losses and runoff for Subbasin 25,
- Losses and runoff for Subbasin 33,
- Losses and runoff for Subbasin 34,
- Losses and runoff for Subbasin 36,
- Losses and runoff for Subbasin 37,

The time series were developed in spreadsheets in Attachment 1-1 through 1-5. Plots of the component time series are provided as Figures through 12 in Sections 7.2 through 7.5.

7.10 SOCH Model Output and Unit Hydrograph Validation

The component time series presented in Sections 7.2 through 7.5 of this calculation were used as inputs to a SOCH model of the reach of the Tennessee River between Melton Hill, Fort Loudoun, Tellico and Watts Bar Dams. Additional inputs to the model include observed discharge series for the Emory River and outflow from Melton Hill, Fort Loudoun, and Tellico Dams as upstream boundary conditions. (See Figure 1)

For the March 1973 event, simulated and observed water surface elevations were compared at three gage locations: Tennessee River Miles 602.3 and 552.4 and Clinch River Mile 23.10. Discharge hydrographs were compared at TRM 529.9. For the May 2003 event, simulated and observed water surface elevations were compared at three gage locations: Tennessee River Miles 568.1 and 602.3 and Clinch River Mile 0.3. Discharge hydrographs were compared at TRM 529.9.

As described in Calculation CDQ000020080037 Rev 0 (Reference 22), local inflows to Watts Bar Reservoir from Subbasin 25, 33, 34, 36, and 37 were combined with the observed data (Melton Hill, Fort Loudoun, and Tellico discharge and tailwater elevation, Watts Bar discharge and head water elevation, and Emory River stream flow) for the March 1973 and May 2003 events and conservatively predict the observed elevations at gage locations along the reservoir for peak elevations of the historic floods. Additionally, the model replicated the discharges for the two historic floods within reasonable margin. These comparisons are shown in Figures 35 through 38. As a result, the unit hydrographs developed for basins 25, 33, 34, 36, and 37 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.

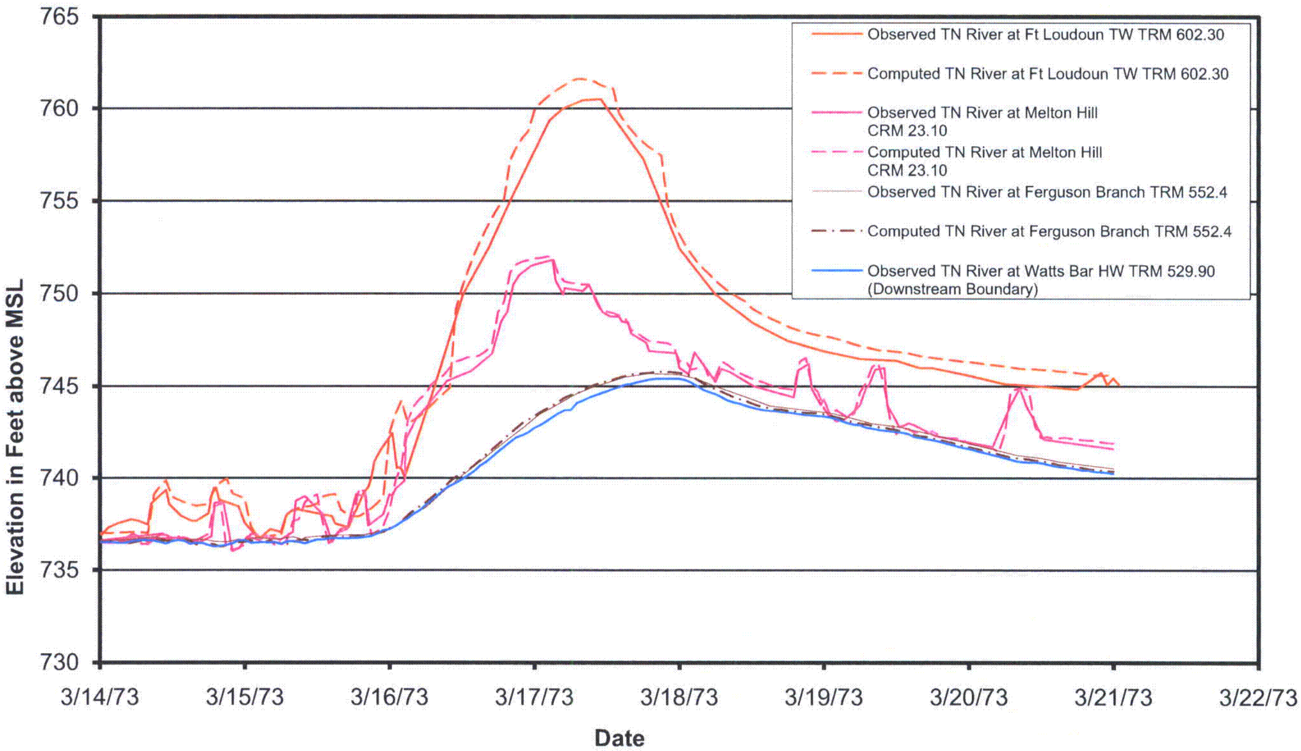

Figure 35: Observed and Simulated Stage Hydrographs for the Tennessee River between Melton Hill, Fort Loudoun, Tellico, and Watts Bar Dams, March 1973

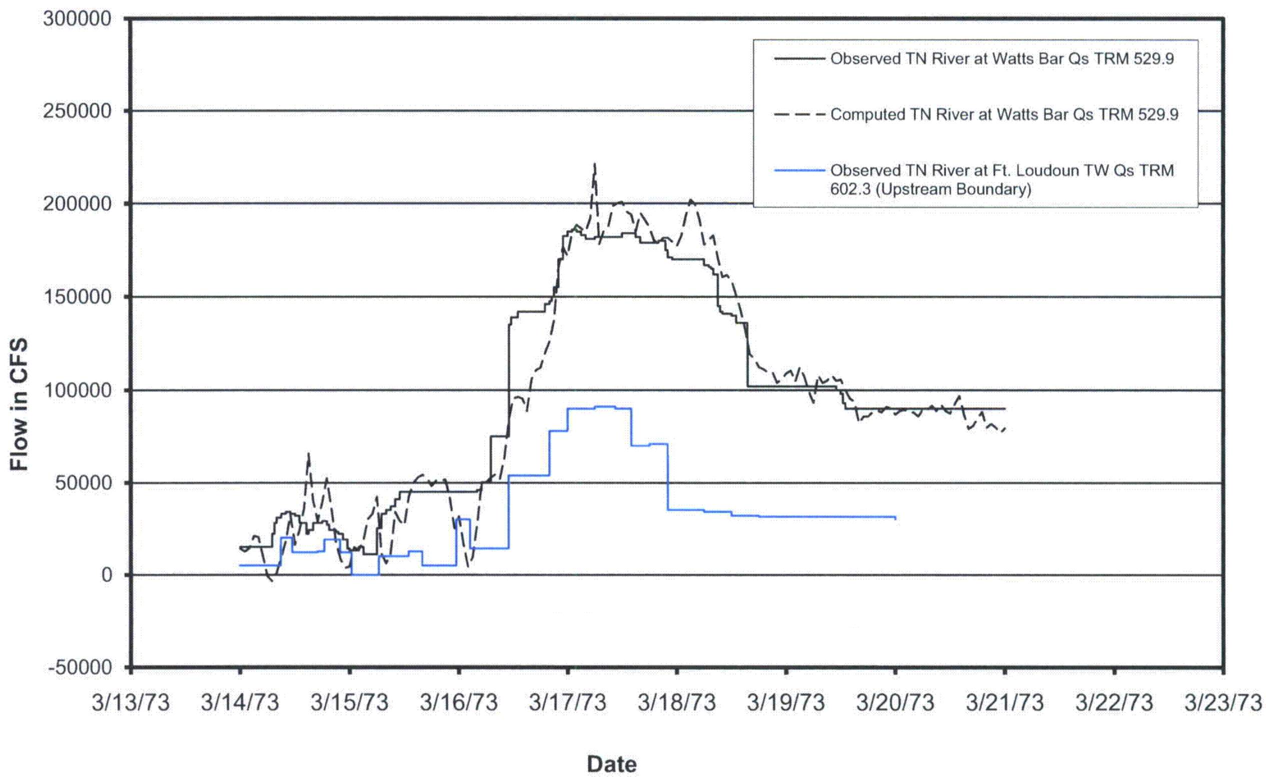

Figure 36: Observed and Simulated Discharge Hydrographs at Watts Bar Dam, March 1973

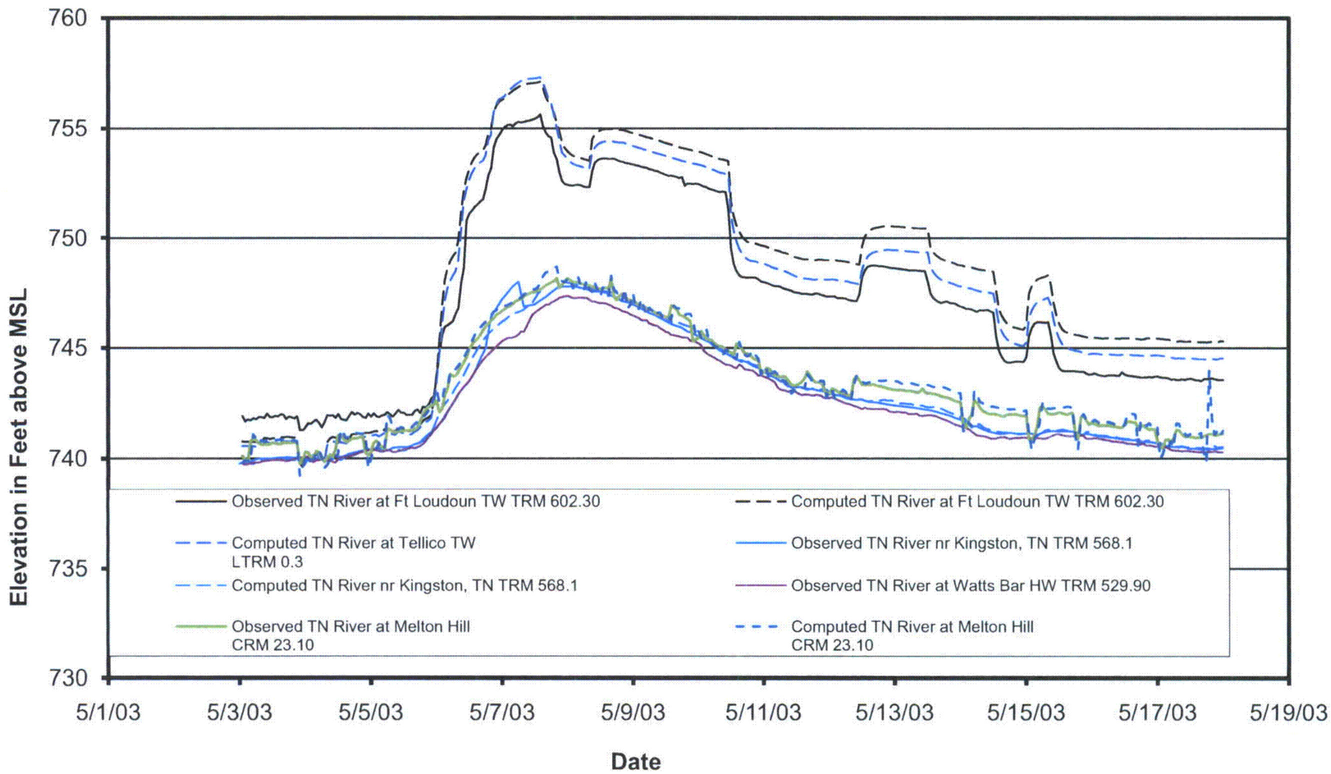

Figure 37: Observed and Simulated Stage Hydrographs for the Tennessee River between Melton Hill, Fort Loudoun, Tellico, and Watts Bar Dams, May 2003

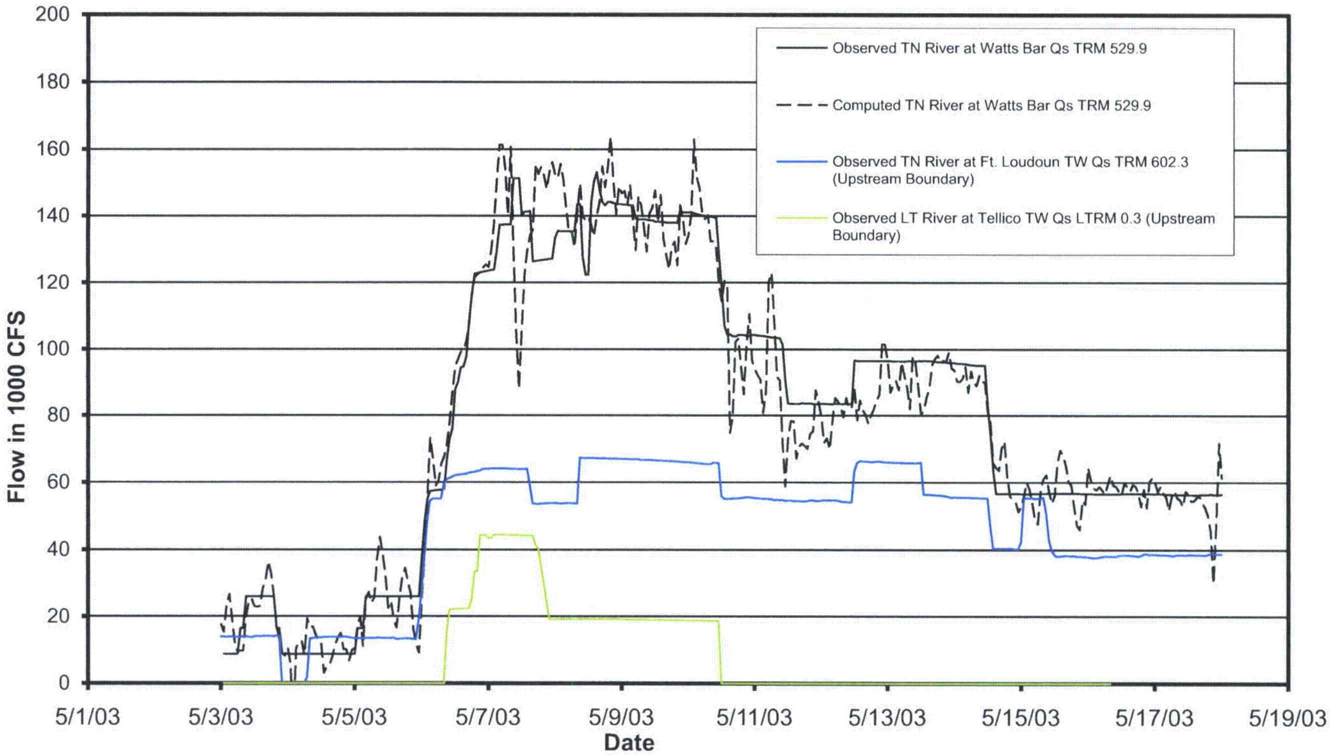

Figure 38: Observed and Simulated Discharge Hydrographs at Watts Bar Dam, May 2003

8 Conclusions

Unit hydrographs for subbasins 25, 33, 34, 36, and 37 for the simulation of local inflow to the Tennessee River between Melton Hill, Fort Loudoun, Tellico, and Watts Bar 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 use to develop inflow series for Watts Bar Reservoir. Therefore, it was necessary to validate the unit hydrographs indirectly. Local runoff hydrographs were developed from observed rainfall series for used as input to the SOCH model simulation of the reach of the Tennessee River between Melton Hill, Fort Loudoun, Tellico, and Watts Bar Dams for the two validation runs.

8.1 Unit Hydrograph Validation

The original unit hydrographs in Section 6.2 for Subbasins 25, 33, 34, 36, and 37 were indirectly validated for the March 1973 and May 2003 floods in this calculation and are provided in Tables 17 through 21(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 the PMF.

Table 17: Validated Subbasin 25 Six-Hour Unit Hydrograph Time Base and Ordinates

Ordinate	Time (hrs)	Discharge (cfs)
1	0	0
2	6	11,063
3	12	6,050
4	18	1,361
5	24	1,248
6	30	1,191
7	36	1,172
8	42	1,399
9	48	1,702
10	54	1,739
11	60	1,607
12	66	1,361
13	72	945
14	78	492
15	84	170
16	90	0

Table 18: Validated Subbasin 33 Two-Hour Unit Hydrograph Time Base and Ordinates

Ordinate	Time (hrs)	Discharge (cfs)
1	0	0
2	2	590
3	4	2,000
4	6	4,490
5	8	1,440
6	10	700
7	12	460
8	14	350
9	16	265
10	18	220
11	20	195
12	22	180
13	24	166
14	26	152
15	28	139
16	30	125
17	32	111
18	34	97
19	36	83
20	38	69
21	40	55
22	42	42
23	44	28
24	46	14
25	48	0

Table 19: Validated Subbasin 34 Two-Hour Unit Hydrograph Time Base and Ordinates

Ordinate	Time (hrs)	Discharge (cfs)
1	0	0
2	2	220
3	4	500
4	6	800
5	8	1,040
6	10	1,350
7	12	1,680
8	14	2,000
9	16	2,300
10	18	2,570
11	20	2,800
12	22	2,760
13	24	2,560
14	26	2,320
15	28	2,120
16	30	1,910
17	32	1,720
18	34	1,570
19	36	1,390
20	38	1,230
21	40	1,100
22	42	1,000
23	44	900
24	46	800
25	48	700
26	50	680
27	52	600
28	54	575
29	56	534
30	58	502
31	60	470
32	62	438
33	64	406
34	66	374
35	68	342
36	70	310
37	72	278
38	74	246
39	76	214
40	78	182
41	80	150
42	82	128
43	84	96
44	86	64
45	88	32
46	90	0

Table 20: Validated Subbasin 36 Two-Hour Unit Hydrograph Time Base and Ordinates

Ordinate	Time (hrs)	Discharge (cfs)
1	0	0
2	2	467
3	4	1,575
4	6	3,703
5	8	1,145
6	10	549
7	12	366
8	14	275
9	16	211
10	18	174
11	20	156
12	22	142
13	24	132
14	26	121
15	28	110
16	30	99
17	32	88
18	34	77
19	36	66
20	38	55
21	40	44
22	42	33
23	44	22
24	46	11
25	48	0

Table 20:Validated Subbasin 37 Six-Hour Unit Hydrograph Time Base and Ordinates

Ordinate	Time (hrs)	Discharge (cfs)
1	0	0
2	6	16,125
3	12	8,814
4	18	1,983
5	24	1,818
6	30	1,735
7	36	1,708
8	42	2,038
9	48	2,479
10	54	2,534
11	60	2,341
12	66	1,983
13	72	1,378
14	78	716
15	84	248
16	90	0