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

ASSOCIATED ATTACHMENTS/ENCLOSURES:

Attachment 02.04.03-8AB: Subbasins 38 (Chatuge Dam), 39 (Nottely Dam), 40 (Hiwassee Dam), 41 (Apalachia Dam), and 43 (Ocoee No. 1 Dam) Unit Hydrograph Validations

(125 Pages including Cover Sheet)

NPG CALCULATION COVERSHEET/CCRIS UPDATE

REV 0 EDMS/RIMS NO.	EDMS TYPE:	EDMS ACCESSION NO (N/A for REV. 0)
L58 090414 001	calculations(nuclear)	L58 091230 037

Calc Title: Subbasins 38 (Chatuge Dam), 39 (Nottely Dam), 40 (Hiwassee Dam), 41 (Apalachia Dam), and 43 (Ocoee No. 1 Dam) Unit Hydrograph Validations

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT	CN	NUC	GEN	CEB	CDQ000020080061	0	1	Entire calc ☒ Selected pages ☐
NEW								

ACTION					
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 12	☐ 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 unit hydrographs for Chatuge Dam (Subbasin 38), Nottely Dam (Subbasin 39), Hiwassee Dam (Subbasin 40), Apalachia Dam (Subbasin 41), and Ocoee No.1 Dam (Subbasin 43) local areas using recent floods.

*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)

☐ LOAD INTO EDMS AND DESTROY
☒ LOAD INTO EDMS AND RETURN CALCULATION TO CALCULATION LIBRARY. ADDRESS: LP4D-C
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NPG CALCULATION COVERSHEET/CCRIS UPDATE

REV 0 EDMS/RIMS NO.	EDMS TYPE:	EDMS ACCESSION NO (N/A for REV. 0)
L58 090414 001	calculations(nuclear)	

Calc Title: Subbasins 38 (Chatuge Dam), 39 (Nottely Dam), 40 (Hiwassee Dam), 41 (Apalachia Dam), and 43 (Ocoee No. 1 Dam) Unit Hydrograph Validations

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	CDQ000020080061	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

DCN,EDC,N/A	APPLICABLE DESIGN DOCUMENT(S)	CLASSIFICATION
		"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 *Nicholas D. Martin*	4/14/2009	Matthew C. Carney *[signature]*	4/14/2009
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
Robert E. Swain *Robert E. Swain*	4/14/2009	*[signature] for K. Spates*	4-14-09

STATEMENT OF PROBLEM/ABSTRACT

4/14/09

Validate unit hydrographs for Chatuge Dam (Subbasin 38), Nottely Dam (Subbasin 39), Hiwassee Dam (Subbasin 40), Apalachia Dam (Subbasin 41), and Ocoee No. 1 Dam (Subbasin 43) local areas using recent floods.

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
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NPG CALCULATION COVERSHEET/CCRIS UPDATE

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	REV
	CN	NUC	GEN	CEB	CDQ000020080061	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	UNITGRPH Version 1.0	
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: CDQ000020080061	
Title	Subbasins 38 (Chatuge Dam), 39 (Nottely Dam), 40 (Hiwassee Dam), 41 (Apalachia Dam), and 43 (Ocoee No.1 Dam) Unit Hydrograph Validations
Revision No.	DESCRIPTION OF REVISION
0	Initial issue 123 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 2 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, 12a Pages Replaced: 1-8 & 12, 14-15 Total pages of calculation hard copy for Revision 1= 124

NPG CALCULATION TABLE OF CONTENTS

Calculation Identifier: CDQ000020080059	Revision: 1	

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Calculation Identifier: CDQ000020080059	Revision: 1	

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SECTION	TITLE	PAGE

LIST OF TABLES

NPG COMPUTER INPUT FILE
STORAGE INFORMATION SHEET

Document CDQ000020080061	Rev. 1	Plant: GEN	

Subject: Subbasins 38 (Chatuge Dam), 39 (Nottely Dam), 40 (Hiwassee Dam), 41 (Apalachia Dam), and 43 (Ocoee No. 1 Dam) Unit Hydrograph Validations

☐ 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 three pages.

☐ Microfiche/eFiche

ELECTRONIC FILE ATTACHMENTS			
Document: CDQ000020080061	Rev. 0	Plant: GEN	
Subject: Subbasins 38 (Chatuge Dam), 39 (Nottely Dam), 40 (Hiwassee Dam), 41 (Apalachia Dam), and 43 (Ocoee No. 1 Dam) Unit Hydrograph Validations			

The files listed below, which contain both input and output data, are electronically attached to the parent Adobe .pdf calculation file. All files are therefore stored in an unalterable medium and are retrievable through the EDMS number for this calculation. Click on the "Attachments" Tab within Adobe to view the attachment listing, to access and view the files as needed.

Electronic Attachment: File Name	Comments
Supporting Spreadsheets	
Attachment 1- 1: chatuge_rev0.xls	Attached to PDF
Attachment 1- 2: nottely_rev0.xls	Attached to PDF
Attachment 1- 3: hiwassee_rev0.xls	Attached to PDF
Attachment 1- 4: apalachia_rev0.xls	Attached to PDF
Attachment 1- 5: ocoeeno1_rev0.xls	Attached to PDF
Attachment 1- 6: Hiwassee_rev0.xls	Attached to PDF
Attachment 1- 7: Ocoee_rev0.xls	Attached to PDF
Attachment 1- 8: blueridge_rev0.xls	Attached to PDF
Attachment 1- 9: Chatuge_Reverse_Reservoir_Routing_2003.xls	Attached to PDF
Attachment 1- 10: Chatuge_Reverse_Reservoir_Routing_2004.xls	Attached to PDF
Attachment 1- 11: Nottely_Reverse_Reservoir_Routing_2004.xls	Attached to PDF
Attachment 1- 12: Nottely_Reverse_Reservoir_Routing_2005.xls	Attached to PDF
Attachment 1- 13: Hiwassee_Reverse_Reservoir_Routing_2003.xls	Attached to PDF
Attachment 1- 14: Hiwassee_Reverse_Reservoir_Routing_2004.xls	Attached to PDF
Attachment 1- 15: OcoeeNo1_Reverse_Reservoir_Routing_1998.xls	Attached to PDF
Attachment 1- 16: OcoeeNo1_Reverse_Reservoir_Routing_2003.xls	Attached to PDF
Attachment 1- 17: OcoeeNo1_Reverse_Reservoir_Routing_2004.xls	Attached to PDF
Attachment 1- 18: Chatuge_Flood_Analysis_CT.xls	Attached to PDF
Attachment 1- 19: Nottely_Flood_Analysis_CT.xls	Attached to PDF
Attachment 1- 20: Hiwassee_Flood_Analysis_CT.xls	Attached to PDF
Attachment 1- 21: OcoeeNo1_Flood_Analysis_Ct.xls	Attached to PDF
Attachment 1- 22: Apalachia_Reverse_Reservoir_Routing_1998.xls	Attached to PDF
Attachment 1- 23: Apalachia_Reverse_Reservoir_Routing_2003.xls	Attached to PDF
Attachment 1- 24: Apalachia_Flood_Analysis_CT.xls	Attached to PDF
Attachment 1- 25: Chatuge_Dam-Base_Flow_Separation.xls	Attached to PDF
Attachment 1- 26: Nottely_Dam-Base_Flow_Separation.xls	Attached to PDF
Attachment 1- 27: Hiwassee_Dam-Base_Flow_Separation.xls	Attached to PDF
Attachment 1- 28: Apalachia_Dam-Base_Flow_Separation.xls	Attached to PDF
Attachment 1- 29: Ocoee_Dam-Base_Flow_Separation.xls	Attached to PDF
Attachment 1- 30: NWS_Precip_Basins-38-44a.xls	Attached to PDF
Attachment 1- 31: B40-Unitgraph_Analysis.xls	Attached to PDF
Attachment 1- 32: UH_S-graph_Translation.xls	Attached to PDF
Attachment 1- 33: B43-Unitgraph_Analysis.xls	Attached to PDF
Attachment 1- 34: B38_FloodComp.xls	Attached to PDF
Attachment 1- 35: Basin38_Flood2004.xls	Attached to PDF
Attachment 1- 36: Basin38_Flood1966.xls	Attached to PDF
Attachment 1- 37: B38-UNITGRPH_Analysis.xls	Attached to PDF
Attachment 1- 38: B39-May_1973.xls	Attached to PDF
Attachment 1- 39: B39-August_1967.xls	Attached to PDF

ELECTRONIC FILE ATTACHMENTS			
Document: CDQ000020080061	Rev. 0	Plant: GEN	
Subject: Subbasins 38 (Chatuge Dam), 39 (Nottely Dam), 40 (Hiwassee Dam), 41 (Apalachia Dam), and 43 (Ocoee No. 1 Dam) Unit Hydrograph Validations			

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Electronic Attachment: File Name	Comments
Attachment 1- 40: B39-October_1964.xls	Attached to PDF
Attachment 1- 41: B39_FloodComp.xls	Attached to PDF
Attachment 1- 42: B39-UNITGRPH_Analysis.xls	Attached to PDF
Attachment 1- 43: B41_FloodComp.xls	Attached to PDF
Attachment 1- 44: B41-UNITGRPH_Analysis.xls	Attached to PDF
Attachment 1- 45: Apalachia_Local_Flows-1994.xls	Attached to PDF
Attachment 1- 46: Apalachia-Time_Series_for_HMS.xls	Attached to PDF
Attachment 1- 47: Adopted_UH_Ordinates_&_Routing_Parameters.xls	Attached to PDF
FLDHYDRO and UNITGRPH Files	
Attachment 2- 1: Bas38_03.dat	Attached to PDF
Attachment 2- 2: Bas38_04.dat	Attached to PDF
Attachment 2- 3: Bas38_03.out	Attached to PDF
Attachment 2- 4: Bas38_04.out	Attached to PDF
Attachment 2- 5: Bas39_04.dat	Attached to PDF
Attachment 2- 6: Bas39_05.dat	Attached to PDF
Attachment 2- 7: Bas39_04.out	Attached to PDF
Attachment 2- 8: Bas39_05.out	Attached to PDF
Attachment 2- 9: Bas40_04M.dat	Attached to PDF
Attachment 2- 10: Bas40_04M.out	Attached to PDF
Attachment 2- 11: B4198nlem.dat	Attached to PDF
Attachment 2- 12: B4198nlem.out	Attached to PDF
Attachment 2- 13: Bas43_98-E.dat	Attached to PDF
Attachment 2- 14: B43P1_03-M2.dat	Attached to PDF
Attachment 2- 15: B43P2_03-M2.dat	Attached to PDF
Attachment 2- 16: Bas43_04-E.dat	Attached to PDF
Attachment 2- 17: Bas43_98-E.out	Attached to PDF
Attachment 2- 18: B43P1_03-M2.out	Attached to PDF
Attachment 2- 19: B43P2_03-M2.out	Attached to PDF
Attachment 2- 20: Bas43_04-E.out	Attached to PDF
Attachment 2- 21: UGin_40.dat	Attached to PDF
Attachment 2- 22: B40_L1.prn	Attached to PDF
Attachment 2- 23: B40_L1.plt	Attached to PDF
Attachment 2- 24: UGin_43.dat	Attached to PDF
Attachment 2- 25: B43_L2.prn	Attached to PDF
Attachment 2- 26: B43_L2.plt	Attached to PDF
Attachment 2- 27: UGin_38.dat	Attached to PDF
Attachment 2- 28: B38_L4.plt	Attached to PDF
Attachment 2- 29: B38_L4.prn	Attached to PDF
Attachment 2- 30: UGin_39.dat	Attached to PDF
Attachment 2- 31: B39_L6-1IT.plt	Attached to PDF
Attachment 2- 32: B39_L6-1IT.prn	Attached to PDF

ELECTRONIC FILE ATTACHMENTS			
Document: CDQ000020080061	Rev. 0	Plant: GEN	
Subject: Subbasins 38 (Chatuge Dam), 39 (Nottely Dam), 40 (Hiwassee Dam), 41 (Apalachia Dam), and 43 (Ocoee No. 1 Dam) Unit Hydrograph Validations			

The files listed below, which contain both input and output data, are electronically attached to the parent Adobe .pdf calculation file. All files are therefore stored in an unalterable medium and are retrievable through the EDMS number for this calculation. Click on the "Attachments" Tab within Adobe to view the attachment listing, to access and view the files as needed.

Electronic Attachment: File Name	Comments
Attachment 2- 33: B4198UG.dat	Attached to PDF
Attachment 2- 34: B4198UG.out	Attached to PDF
Attachment 2- 35: UGin_41-98.dat	Attached to PDF
Attachment 2- 36: B41_L5.prn	Attached to PDF
Attachment 2- 37: B41_L5.plt	Attached to PDF
Attachment 2- 38: B4194nle.dat	Attached to PDF
Attachment 2- 39: B4194nle.out	Attached to PDF
HEC-HMS Files	
Attachment 3- 1: Basin_38_000020080061.zip	Filekeeper No. 311726
Attachment 3- 2: Basin_39_000020080061.zip	Filekeeper No. 311727
Attachment 3- 3: Basin_40_000020080061.zip	Filekeeper No. 311728
Attachment 3- 4: Basin_41_000020080061.zip	Filekeeper No. 311729
Attachment 3- 5: Basin_43_000020080061.zip	Filekeeper No. 311730

NPG CALCULATION VERIFICATION FORM

Calculation Identifier CDQ000020080061 Revision 1

Method of verification used:			
1.	Design Review	☒	
2.	Alternate Calculation	☐	Verifier Mark Crisp Date 12/11/09
3.	Qualification Test	☐	Mark W Crisp

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 61: There are five dams for which the inflow hydrographs where obtained by Reverse Reservoir Routing. When compared to the original reservoir release and storage data, the inflow hydrographs are slightly different in volume.

Subbasin 38, Chatuge Dam: For the May 2003 storm, the inflow hydrograph was averaged and smoothed, resulting in a hydrograph that is higher in volume by 2.35%. For the September 2004 storm, the inflow hydrograph was averaged, but not smoothed, resulting in a hydrograph that is lower in volume by 0.38%.

Subbasin 39, Nottely Dam: For the September 2004 storm, the inflow hydrograph was averaged, resulting in a hydrograph that is lower in volume by 0.51%. For the July 2005 storm, the inflow hydrograph was averaged, resulting in a hydrograph that is higher in volume by 1.75%.

Subbasin 40, Hiwassee Dam: For the May 2003 storm, the inflow hydrograph was averaged, resulting in a hydrograph that is higher in volume by 0.07%. For the December 2004 storm, the inflow hydrograph was averaged, resulting in a hydrograph that is lower in volume by 0.64%.

Subbasin 41, Apalachia Dam: For the April 1998 storm, the inflow hydrograph was averaged, resulting in a hydrograph that is higher in volume by 0.74%.

Subbasin 43, Ocoee Dam: For the May 2003 storm, the inflow hydrograph was averaged and smoothed, resulting in a hydrograph that is higher in volume by 0.01%. For the September 2004 storm, the inflow hydrograph was averaged and smoothed, resulting in a hydrograph that is higher in volume by 0.08%.

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.

TVAN CALCULATION VERIFICATION FORM

Calculation Identifier CDQ000020080061		Revision 0

Method of verification used:

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

Verifier Bob Swain Date 2/27/2009

Comments:

The calculation entitled "Subbasins 38 (Chatuge Dam), 39 (Nottely Dam), 40 (Hiwassee Dam), 41 (Apalachia Dam), and 43 (Ocoee No. 1 Dam) Unit Hydrograph Validations" 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 calculations for Subbasin 41 were modified to focus only on reproducing the local subbasin flood hydrographs, rather than flood hydrographs at the subbasin outlet. The 2003 flood was originally simulated by developing a model that encompassed all of the subbasins upstream, which did not allow for validation of the unit hydrograph for Subbasin 41. Upon further review, the 2003 flood was found to be too small for analysis, so it was dropped from the calculation.

2. To improve the validation results, new unit hydrographs were developed for Subbasins 38, 39, and 41. The revised unit hydrographs were calculated using a flood occurring between 1997 and 2007. If historical data were available, then a flood used in the original derivation of the unit hydrograph was employed to create a composite, revised unit hydrograph. Revised unit hydrographs were validated using both floods occurring between 1997 and 2007 and floods that occurred before 1980, if the appropriate historical data were available.

3. New material was added to Section 5 "Methodology" to incorporate material and NRC references found in the Methodology Section of the Basin 42 Blue Ridge Dam calculation.

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 1980's, utilizing observed rainfall and streamflow and reservoir headwater elevation and discharge data, and are being validated by checking their performance in reproducing recent floods.

This calculation presents the validation of the unit hydrographs for Chatuge Dam (Subbasin 38), Nottely Dam (Subbasin 39), Hiwassee Dam (Subbasin 40), Apalachia Dam (Subbasin 41), and Ocoee No.1 Dam (Subbasin 43) local areas. These subbasins are located within the Tennessee River watershed as shown in Figure 1.

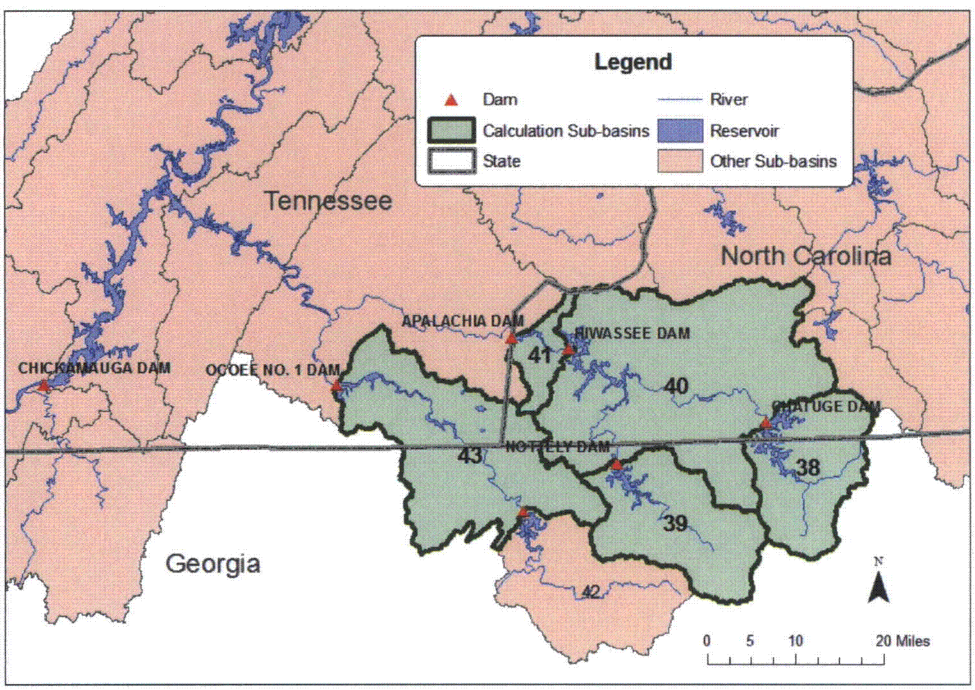

Figure 1: Location of subbasins, identified by number, in this calculation

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, 1988.

Reference 4: American Nuclear Society, American National Standard for Determining Design Basis Flooding at Power Reactor Sites, ANSI/ANS-2.8-1992, 1992.

Reference 5: 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.

Reference 6: Tennessee Valley Authority, UNITGRPH-FLDHYDRO-TRBROUTE-CHANROUT User's Manual, Version 1.0, March 2009, (EDMS No. L58 090325 001).

Reference 7: U.S. Army Corps of Engineers, Hydrologic Modeling System HEC-HMS User's Manual, Version 3.2, April 2008.

Reference 8: U.S. Army Corps of Engineers, Hydrologic Modeling System HEC-HMS Technical Reference Manual, March 2000.

Reference 9: Tennessee Valley Authority, Calculation No. CDQ000020080091. Subbasin 42 (Blue Ridge Dam) Unit Hydrograph Validation, Revision 2

Reference 10: Tennessee Valley Authority, Unit Area 38, Chatuge Dam, File Book Reference (EDMS No. L58 081223 824).

Reference 11: Tennessee Valley Authority, Unit Area 39, Nottely Dam, File Book Reference (EDMS No. L58 081223 825).

Reference 12: Tennessee Valley Authority, Unit Area 40, Hiwassee Dam, File Book Reference (EDMS No L58 081223 826).

Reference 13: Tennessee Valley Authority, Unit Area 41, Apalachia Dam, File Book Reference (EDMS No. L58 081223 827).

Reference 14: Tennessee Valley Authority, Unit Area 43, Ocoee No.1 Local, File Book Reference (EDMS No. L58 081223 829).

Reference 15: Tennessee Valley Authority, [Map] Drainage Areas above Guntersville Dam, June 18, 2008.

Reference 16: Newton, D.R., and J.W. Vinyard, Computer-Determined Unit Hydrograph from Floods, Journal of the Hydraulics Division, ASCE, Vol. 93, No. HY5, September 1967.

Reference 17: Bechtel, Request for Information RFI 25447-000-GRI-GEX-00002, September 8, 2008 (EDMS No. L58 080925 002).

Reference 18: Tennessee Valley Authority, Observed Outflow and Headwater Elevation Data for Chatuge Dam (EDMS L58 090311 802, chatuge_rev0.xls see Attachment 1- 1).

Reference 19: Tennessee Valley Authority, Observed Outflow and Headwater Elevation Data for Nottely Dam (EDMS L58 090311 802, nottely_rev0.xls see Attachment 1- 2).

Reference 20: Tennessee Valley Authority, Observed Outflow and Headwater Elevation Data for Hiwassee Dam (EDMS L58 090311 802, hiwassee_rev0.xls see Attachment 1- 3).

Reference 21: Tennessee Valley Authority, Observed Outflow and Headwater Elevation Data for Apalachia Dam (EDMS L58 090311 802, apalachia_rev0.xls see Attachment 1- 4).

Reference 22: Tennessee Valley Authority, Observed Outflow and Headwater Elevation Data for Ocoee No. 1 Dam (EDMS L58 090311 802, ocoeeno1_rev0.xls see Attachment 1- 5).

Reference 23: Tennessee Valley Authority, Storage Volume Data for Chatuge Dam, Nottely Dam, Hiwassee Dam, and Apalachia Dam (EDMS L58 090311 802, Hiwassee_rev0.xls see Attachment 1- 6).

Reference 24: Tennessee Valley Authority, Storage Volume Data for Blue Ridge Dam, Ocoee No. 3 Dam, and Ocoee No. 1 Dam (EDMS L58 090311 802, Ocoee_rev0.xls see Attachment 1- 7).

Reference 25: Tennessee Valley Authority, Calculation No. CDQ000020080055, Processing and Validation of National Weather Service's NEXRAD Stage III Hourly Precipitation Data for Hydrologic and Hydraulic Analysis of Watersheds, Revision 3

Reference 26: Linsley, R.K., J.B. Franzini, D.L. Freyberg, and G. Tchobanogolous, Water Resources Engineering, Fourth Edition, Irwin McGraw-Hill, 1992.

Reference 27: Fread, D.L., "Chapter 10: Flow Routing", in Handbook of Hydrology, D.R. Maidment ed., McGraw-Hill, 1993.

Reference 28: Zoppou, C., "Reverse Routing of Flood Hydrographs Using Level Pool Routing", Journal of Hydrologic Engineering, vol. 4, no. 2, April 1999.

Reference 29: Tennessee Valley Authority, Observed Outflow and Headwater Elevation Data for Blue Ridge Dam (electronic data transmitted by the TVA to Bechtel, May 2008 in blueridge_rev0.xls see Attachment 1- 8).

Reference 30: 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 31: Linsley, R.K., Kohler, M.A., and Paulhus, J.H., Hydrology for Engineers, McGraw-Hill Book Company, 1982.

Reference 32: Singh, K.P. and D.R. Dawdy, Computer-Determined Unit Hydrograph From Floods, Journal of Hydraulics Division, ASCE, Vol. 93, No. HY6, November 1968.

Reference 33: Singh, V. P., Elementary Hydrology, Prentice-Hall, 1992.

Reference 34: Bechtel Request for Information RFI 25447-000-GRI-GEX-00063, January 28, 2009 (EDMS No. L58 090128 800).

Reference 35: Bechtel, Request for Information RFI 25447-000-GRI-GEX-00061, December 16, 2008 (EDMS No. L58 081217 801).

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 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 the direct runoff, Q, is obtained by summing the products of the excess rainfall depths (direct runoff depths), P, and the unit hydrograph ordinates, U (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 (UH) 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

The methodology used for unit hydrograph validation follows that described in ANSI/ANS-2.8-1992 (Reference 4). 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 5). With regard to verifying runoff models, ANSI/ANS-2.8-1992 indicates the following:

> "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."

For the purpose of validating the unit hydrographs for these subbasins, the period of record from which the highest two or more floods are selected extends from 1997 through 2007. This period was targeted because high resolution, radar-based, hourly precipitation data are available as described in Section 6.5. Furthermore, since the original unit hydrographs for these subbasins were developed from floods that occurred between 1946 and 1973 (see Section 6.2), it was necessary to use recent rainfall and streamflow data to evaluate the possibility that 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.

In general, the methodology used for unit hydrograph validation includes the following steps:

1. Screen historical streamflow data to identify the two highest floods during 1997 to 2007 (Section 7.2) for which rainfall data are available. These selected floods are used for unit hydrograph validation.
2. Obtain the observed hydrograph data for the two floods and transfer the flow series to the subbasin outlet using established hydrologic procedures as necessary (e.g. reverse reservoir routing or stream flow routing and hydrograph separation) to develop the subbasin hydrograph (Section 7.1).
3. Separate base flow from the subbasin local hydrograph to obtain the "observed" direct runoff hydrograph for the local basin, and calculate the volume of the direct runoff based on the hydrograph ordinates (Section 7.3).
4. Obtain observed rainfall data for the selected floods and calculate the basin average precipitation for the adopted time step (Section 7.4).
5. Convert the observed rainfall series to an excess precipitation series using the TVA's API-RI method as implemented in FLDHYDRO (Reference 6; Section 7.5). This includes inputting the observed runoff volume obtained in Step 3 to ensure that the excess precipitation volume calculated by FLDHYDRO approximately equals the estimated runoff volume.
6. Regenerate or revise the original unit hydrograph for each subbasin using the corrected version of the UNITGRPH program (Section 7.6).

7. Run HEC-HMS (Reference 7 and Reference 8) utilizing the regenerated or revised subbasin unit hydrograph and the excess precipitation series as input and compare the resulting simulated hydrograph with the observed direct runoff hydrograph in terms of total volume and the timing and magnitude of peak discharge (Section 7.7 and Section 8).

6 Design Input Data

The input data used in the validation of the unit hydrographs covered in this calculation are summarized below. Each subbasin in this calculation is terminated by a dam at its downstream extent.

- Unit hydrograph ordinates and durations
- Observed outflows from the dam forming the downstream extents of the unit areas (i.e., Chatuge Dam, Nottely Dam, Ocoee No. 1 Dam, Apalachia Dam, and Hiwassee Dam) and corresponding headwater elevations
- Observed outflows from dams, if any, located upstream of the unit areas (i.e. subbasins that receive flow from upstream subbasins). In this calculation, Hiwassee Dam, Apalachia Dam, and Ocoee No.1 Dam receive flows from dams located upstream.
- The stage-volume relationship for each of the reservoirs
- Observed rainfall data for derivation of excess precipitation for the selected floods

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

6.1 Subbasin Areas

The subbasins in this calculation are part of the Hiwassee River watershed, which is part of the Tennessee Valley watershed. The referenced subbasins lie within two separate drainages that contribute to the larger Hiwassee River watershed, as illustrated in Figure 1 and Figure 2. Chatuge Dam (Subbasin 38), Nottely Dam (Subbasin 39), Hiwassee Dam (Subbasin 40), and Apalachia Dam (Subbasin 41) unit areas are in the upper Hiwassee River watershed. Subbasins 38 and 39 are headwater subbasins (i.e., they form the upper-most extent of the watershed). Hiwassee Dam and Apalachia Dam receive runoff from upstream subbasins. Subbasin 40 (Hiwassee Dam) receives runoff from Subbasins 38 and 39; the Hiwassee River conveys this runoff through Subbasin 40. The Hiwassee River carries runoff from Subbasins 38, 39, and 40 through Subbasin 41 to Apalachia Dam.

Ocoee No.1 Dam (Subbasin 43) is in the Ocoee River watershed, which is situated to the south of Subbasins 38 to 41 and is tributary to the Hiwassee River below Apalachia Dam. Ocoee No. 1 Dam receives runoff from the upstream Subbasin 42 (Blue Ridge Dam), which is conveyed by the Ocoee River through Subbasin 43 to Ocoee No. 1 Dam. Unit hydrograph validation for Blue Ridge Dam (Subbasin 42) is provided in a separate calculation (Reference 9).

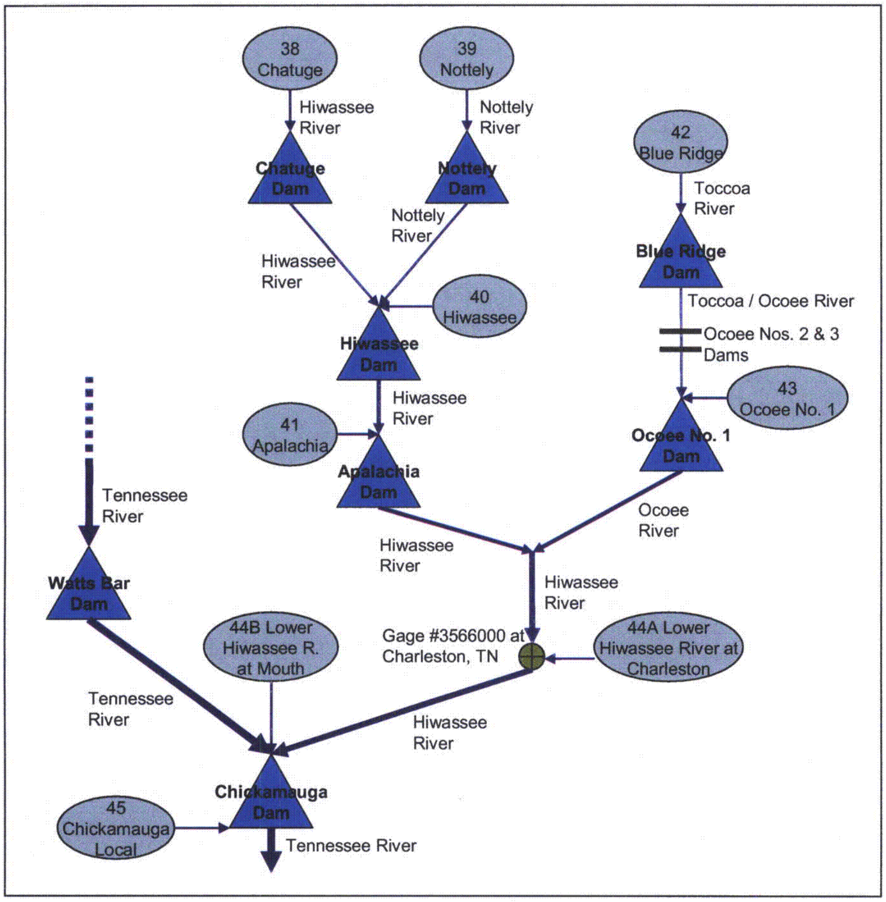

Figure 2: Schematic of the Hiwassee River and Ocoee River Portions of the Tennessee River System.

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

The drainage areas for the five subbasins covered in this calculation are provided in Table 1. Two different areas are shown for each subbasin: 1) area obtained from the Filebook Reference for the subbasin (Reference 10, Reference 11, Reference 12, Reference 13, and Reference 14); and 2) area calculated using GIS (Reference 15). The GIS-calculated areas are used in this calculation. The areas obtained from the two different sources agree within 0.4 percent or less for each subbasin.

Table 1: Subbasin areas

Subbasin	Area from Filebook References (mi^2)	Area from GIS (mi^2)
Chatuge Dam, Subbasin 38	189	189.1
Nottely Dam, Subbasin 39	214	214.3
Hiwassee Dam, Subbasin 40	564	565.1
Apalachia Dam, Subbasin 41	50	49.8
Ocoee No. 1 Dam, Subbasin 43	363	362.6

6.2 Unit Hydrograph Ordinates

The subbasin unit hydrographs (UHs), most of which were developed during the 1970's and early 1980's, are described in the corresponding TVA File Book References (Reference 10, Reference 11, Reference 12, Reference 13 and Reference 14). They were developed, for the most part, using the methodology proposed by Newton and Vinyard (Reference 16), which implements matrix algebra methods and deconvolution (Section 4) to calculate a unit hydrograph from observed direct runoff and excess precipitation.

6.2.1 Chatuge Dam Subbasin 38

The data used (by the TVA) to develop the subbasin UH include Chatuge Dam discharge and elevation records from the following historical floods:

- October 4, 1964 – peak discharge 15,578 cfs after removal of baseflow
- February 13, 1966 – peak discharge 13,890 cfs after removal of baseflow
- May 28, 1973 – peak discharge 16,187 cfs after removal of baseflow

The UH for Subbasin 38 was derived from analysis of these three floods in 1983. Subbasin local hydrographs (i.e., the inflow hydrographs to the Chatuge Reservoir) were computed by the TVA using reverse reservoir routing for each of these floods. Reverse reservoir routing (RRR) is discussed in detail in Section 7.1; RRR employs reservoir stage and discharge records to calculate or estimate inflows to a reservoir. A UH was obtained from the runoff hydrograph for each storm, and a composite UH was developed from the three runoff hydrographs (see "TVA 2-hr UH" in Figure 55 on page 72).

6.2.2 Nottely Dam Subbasin 39

Nottely Dam discharge and elevation records from the following historical floods were used by the TVA to develop unit hydrographs for Subbasin 39 in 1983.

- October 4, 1964 – peak discharge 32,276 cfs after removal of baseflow
- August 23, 1967 – peak discharge 19,100 cfs after removal of baseflow
- May 27, 1973 – peak discharge 17,251 cfs after removal of baseflow

Subbasin, local hydrographs were computed by the TVA using reverse reservoir routing for each of these floods (Section 7.1). A UH was obtained from the runoff hydrograph for each flood, and a composite UH was developed from the three runoff hydrographs (see "TVA 2-hr UH" in Figure 58 on page 76).

6.2.3 Hiwassee Dam Subbasin 40

The unit hydrograph for Subbasin 40 was derived by the TVA in 1979 from analysis of five floods using Hiwassee Dam discharge and elevation records and Chatuge and Nottely discharge records. These five floods were:

- March 29, 1951 – peak discharge 32,500 cfs after removal of baseflow
- January 16, 1954 – peak discharge 32,000 cfs after removal of baseflow
- January 31, 1957 – peak discharge 36,000 cfs after removal of baseflow
- April 7, 1964 – peak discharge 29,400 cfs after removal of baseflow
- May 28, 1973 – peak discharge 30,500 cfs after removal of baseflow

Subbasin local hydrographs for the Hiwassee Dam unit area (i.e., the inflow hydrographs to Hiwassee Reservoir originating within Subbasin 40) were computed by the TVA for each of these floods using reverse reservoir routing to calculate the reservoir inflow hydrograph (Section 7.1). The outflow hydrographs from the upstream subbasins, Nottely Dam and Chatuge Dam, were lagged six hours and then subtracted from the reservoir inflow hydrograph to obtain the subbasin local hydrograph. A UH was obtained from the subbasin local hydrograph for each storm, and a composite UH was developed from the five local hydrographs (see "6-hr UH" in Figure 53 on page 66).

6.2.4 Apalachia Dam Subbasin 41

Details of the development of this unit hydrograph are unknown. Reference 13 states, "The unit hydrograph for unit area 41 (Apalachia Local) was developed years ago by TVA's River Operations organization for use in operating the TVA river system. The calculations that went into the unit hydrograph development have not been found. Because of its small drainage, any changes to the unit graph would have insignificant impact on flood levels at BLN [Bellefonte Nuclear

Plant]."[1] Reference 13 provided a UH with a six-hour period with ordinates given at three-hour intervals (see "Original 6-hour UH" in Figure 60 on page 79).

Hiwassee Dam (Subbasin 40) lies upstream of the Apalachia Dam subbasin on the Hiwassee River; consequently, Hiwassee Dam outflows are subtracted from calculated Apalachia Reservoir inflows to obtain the subbasin local hydrographs used to develop the UH for this subbasin. A straight-lag routing with a zero hour lag was used to route Hiwassee Dam releases to the Apalachia Reservoir prior to subtraction from calculated Apalachia Reservoir inflows (Reference 17).

6.2.5 Ocoee No.1 Dam Subbasin 43

The data used (by TVA) to develop the UH for Subbasin 43 include Ocoee No. 1 Dam discharge and elevation records and Blue Ridge Dam discharge records from the following historical floods:

- February 10, 1946 – peak discharge 23,300 cfs after removal of baseflow
- November 28, 1948 – peak discharge 17,125 cfs after removal of baseflow
- March 29, 1951 – peak discharge 20,083 cfs after removal of baseflow
- October 4, 1964 – peak discharge 17,200 cfs after removal of baseflow

Subbasin local hydrographs (i.e., the inflow hydrographs to the reservoir behind Ocoee No. 1 Dam, known as Parkville Reservoir, originating within Subbasin 43) were computed by the TVA for each of these floods using reverse reservoir routing to calculate the reservoir inflow hydrograph (Section 7.1). The contribution from the upstream subbasin, Blue Ridge Dam, was then subtracted from the reservoir inflow hydrograph to obtain the subbasin local hydrograph. Blue Ridge Dam outflows were routed downstream across four river reaches using Muskingum routing (Section 7.1.2) prior to subtraction.

A UH was obtained from the subbasin local hydrograph for each flood. Two composite unit hydrographs were developed: one was derived from all four floods, and the other used only the latest three individual flood unit hydrographs (i.e. the unit hydrograph for the 1946 flood was not used). The composite UH developed from the three most recent floods was adopted (Reference 14). This composite is shown in Figure 54, on page 68, as "6-hour UH."

[1] Note that the flood level impact at other downstream TVA operating nuclear plant sites along the Tennessee River is similarly expected to be insignificant due to changes in the unit graph for Subbasin 41.

6.3 Observed Outflows and Headwater Elevations

The TVA provided hourly records of outflow from each dam at the downstream extent of the subbasins covered in this calculation along with corresponding hourly headwater elevations. Each outflow measurement represents the average observed outflow from the measurement time until the following measurement time. Each headwater elevation represents a discrete stage elevation collected at the measurement time. These records were obtained from the TVA in spreadsheet format. Reservoir outflow is provided on the tab "Total Q" of the corresponding spreadsheet while headwater elevation is given on the "HW" tab. Copies of these spreadsheets are enclosed as Attachment 1- 1 through Attachment 1- 5 (Reference 18, Reference 19, Reference 20, Reference 21, and Reference 22).

6.4 Stage-Volume Relationships

The stage-volume relationship for each reservoir was provided by the TVA in spreadsheet form. The stage-volume relationships for the reservoirs formed by Chatuge, Nottely, Hiwassee, and Apalachia Dams are presented in Figure 3 through Figure 6 (Attachment 1- 6; Reference 23). The Ocoee No. 1 Dam (Parksville Reservoir) stage-volume relationship is plotted in Figure 7 (Attachment 1- 7; Reference 24). The stage-volume relationship for each reservoir was used to convert observed changes in stage to changes in reservoir storage as part of the reverse reservoir routing calculations.

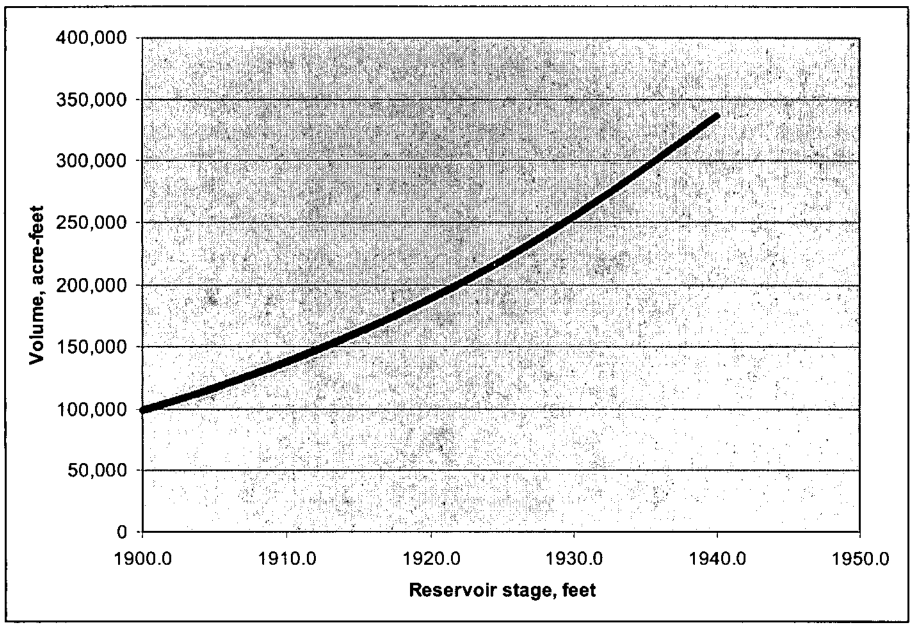

Figure 3: Stage-volume curve for Chatuge Reservoir

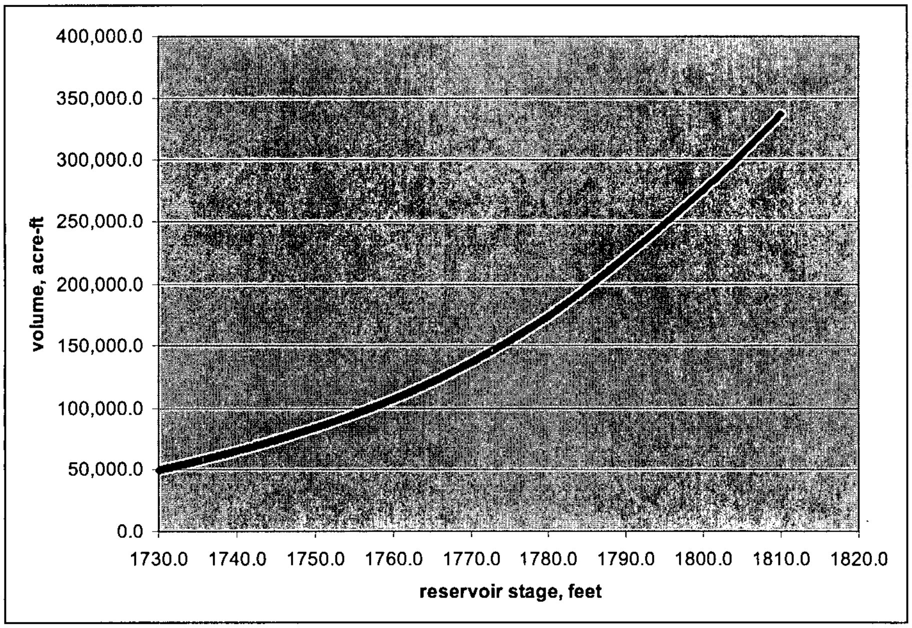

Figure 4: Stage-volume curve for Nottely Reservoir

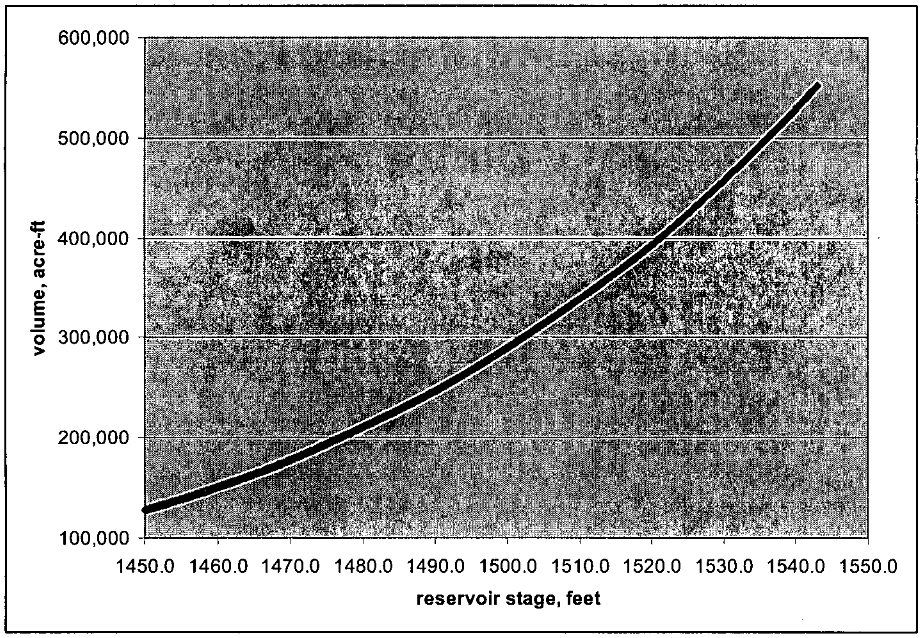

Figure 5: Stage-volume curve for Hiwassee Reservoir

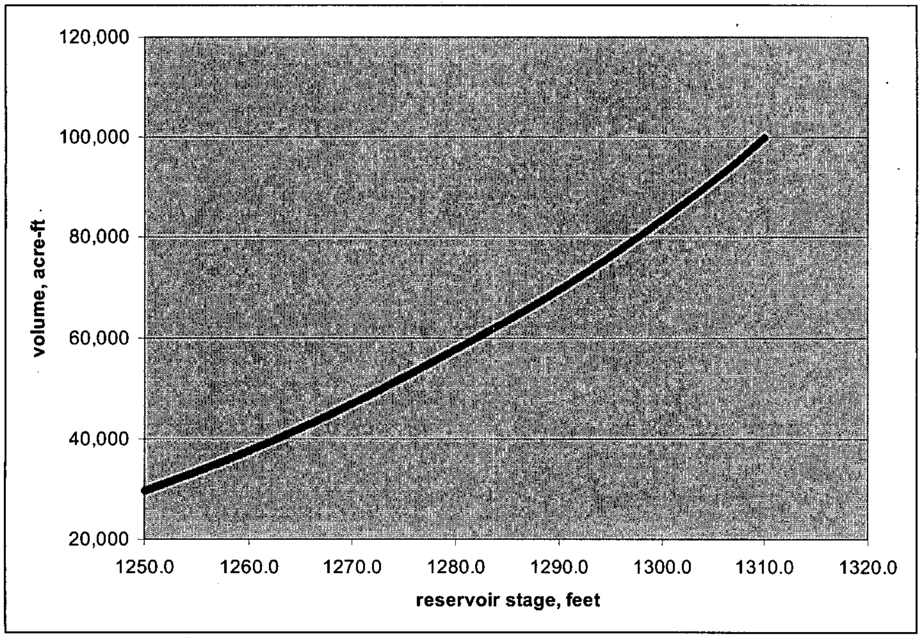

Figure 6: Stage-Volume curve for Apalachia Reservoir

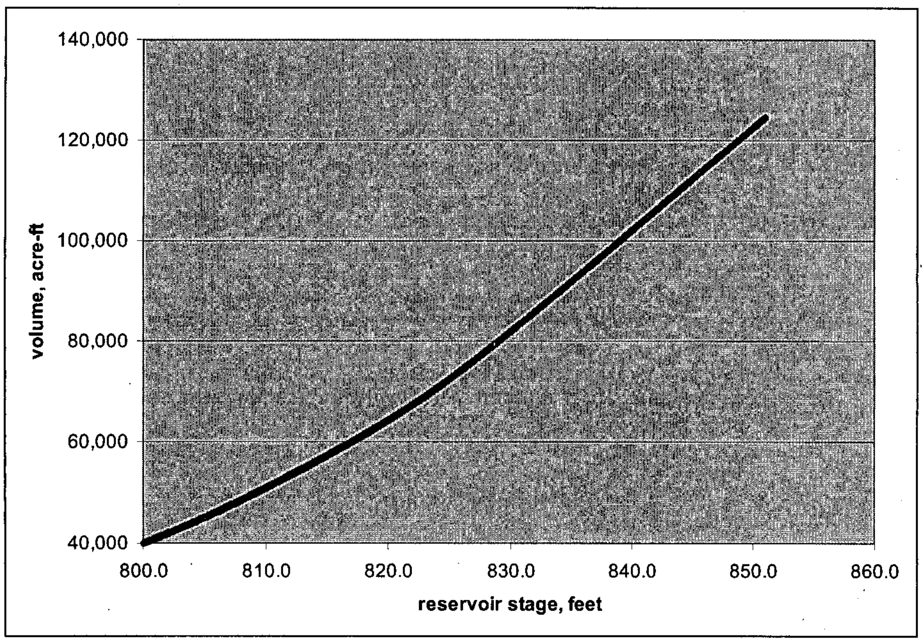

Figure 7: Stage-Volume curve for Ocoee No.1 Dam (Parksville Reservoir)

6.5 Observed Rainfall

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

NWS NEXRAD Stage III hourly precipitation data were obtained from the Lower Mississippi River Forecast Center (LMRFC) from January 1997 to April 2008 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 25). 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 25 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 "Observed" Subbasin Hydrograph Calculation Methods

The available streamflow data for the subbasins in this calculation consist primarily of observed outflows from the dams forming the downstream extents of the subbasins. Streamflow data exist for several gage locations along the Hiwassee and Ocoee Rivers (e.g. Ocoee River at Copperhill). Collection of these gage data stopped during 2002. Additionally, gage locations do not correspond to subbasin outlet locations, and these gage data would need to be adjusted to estimate discharges at the subbasin outlets. Observed outflows from the referenced dams are collected at the subbasin outlets. Consequently, the outflow data were used in these calculations.

For the purpose of unit hydrograph validation, it is necessary to estimate a reservoir inflow time series using the reservoir outflow time series and reservoir stage information. Reverse reservoir routing (RRR) is used to produce the reservoir inflow series, which is used as the "observed" hydrograph. For subbasins that have other subbasins upstream, inflows from the upstream subbasins will be subtracted from the RRR "observed" hydrograph to obtain the "observed" subbasin local hydrograph.

Reverse reservoir routing consists of solving the continuity equation for the reservoir, which can be stated as (Reference 3, Reference 26, and Reference 27):

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

where I is the inflow rate, O is the outflow rate, and S is storage. This equation can be expressed in discrete form using a centered, finite differencing scheme as presented in Equation (2) (Reference 28):

$$\bar{I}(t) = \overline{O}(t) + \frac{S(t+\Delta t) - S(t-\Delta t)}{2\Delta t} \tag{2}$$

where $\bar{I}$ and $\bar{O}$ denote the average inflow and outflow to and from the reservoir during the interval Δt from time t to time t+Δt. The solution provided in Eq. (2) requires level-pool conditions in the reservoir (Reference 28).

The outflows from the dam and the reservoir water surface elevations (or headwater stages) are observed by the TVA. The observed outflow represents the average outflow over the hour-long measurement period. The observed headwater stage can be used to determine the associated storage for the stage given the stage-volume curve for the reservoir. The average inflow for any given routing period is then obtained from Eq. (2).

For headwater subbasins, the RRR hydrograph provides the "observed" subbasin local hydrograph. For downstream subbasins that have other subbasins located upstream, inflows from upstream subbasins need to be removed from the RRR hydrographs to obtain "observed" subbasin local hydrographs. The contributions of upstream subbasins are removed by routing their discharges downstream to the subbasin outlets. The routed inflows are then subtracted from the RRR hydrographs to obtain the "observed" subbasin local hydrographs. This procedure is illustrated in Figure 8 using the example of Subbasin 40 (Hiwassee Dam).

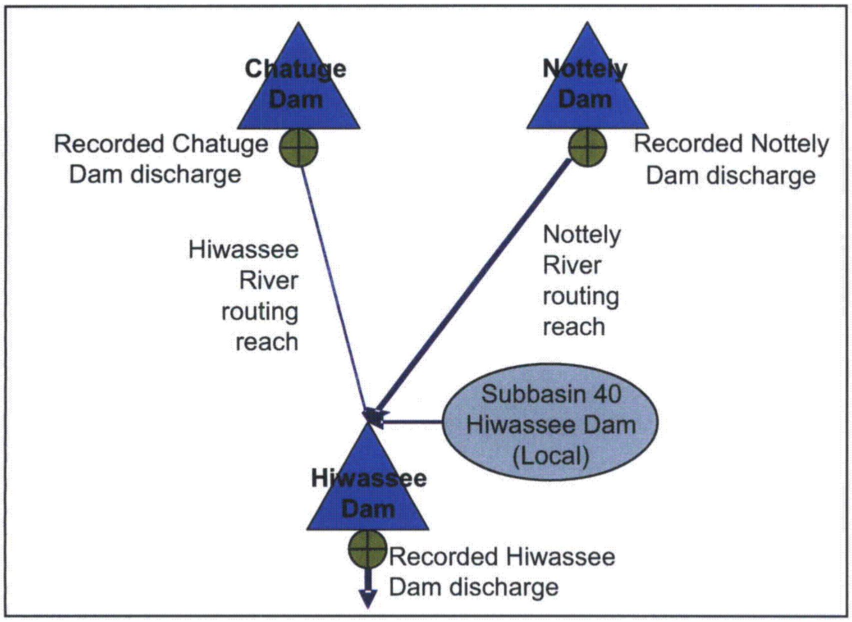

Figure 8: Schematic of the "Observed" Hydrograph Calculation for Subbasin 40

7.1.1 Straight Lag Routing

In straight lag routing, the observed upstream dam outflow hydrograph is translated the lag amount forward in time and then subtracted from the RRR inflow hydrograph. If the lag time is six hours, the observed dam outflow at 01:00 hours would be subtracted from the RRR hydrograph at 07:00 hours to obtain the "observed" subbasin local hydrograph. Since this routing method employs a linear translation, the method requires that flow velocities be constant and that there be no change in storage in the river channel between the upstream and downstream ends of the reach. Straight lag routing is used to subtract Chatuge and Nottely Dam outflows from the RRR hydrograph calculated for Hiwassee Dam to obtain the "observed" subbasin local hydrograph for Subbasin 40. Straight lag routing is also used to subtract Hiwassee Dam outflows from the RRR inflow hydrograph calculated for Apalachia Dam to obtain the "observed" Subbasin 41 hydrograph.

7.1.2 Muskingum Routing

Channel storage is the volume of water in a channel at any instant. The change in storage in a channel can be calculated by solving Eq. (1), if the inflows to and outflows from the channel are known. Channel storage is typically higher during rising stages than falling stages since some storage increase occurs within the reach, as the flood wave front passes through the reach, prior to an increase in outflow from the reach (Reference 27).

The Muskingum method of routing is a lumped flow routing technique derived for the simplified case of stage (and thus reach storage) being a monotonic function of discharge (Q). The method characterizes reach storage, s, as a function of weighted inflow and outflow as shown in Eq. (3):

$$s = K[XI + (1 - X)O] \tag{3}$$

where I is inflow; O is outflow; K is a storage constant with dimensions of time; and, X is a dimensionless constant indicating the relative performance of I in determining channel storage (Reference 26 and Reference 27). X varies between 0.0 and 0.5, and usually has a value between 0.1 and 0.3 for natural channels.

The Muskingum method is appropriate for moderate to slow rising floods propagating through mild to steeply sloping streams (Reference 27). In terms of limitations, the method may produce initial negative dips in computed hydrographs. It also neglects variable backwater effects due to downstream constrictions like dams (Reference 27).

For application of the method, X and K are determined by trial. An estimate is made for X and the portion of Eq. (3) within brackets, the discharge term, is plotted against the corresponding storage value. The value of X that provides the most linear relationship between discharge and storage is chosen. Then, K is calculated from Eq. (3). Once X and K are determined for the channel segment, the Muskingum routing equation, Eq. (4), and coefficient equations, Equations (5), (6), (7), and (8), provide the outflow (O_2) from the channel reach at time $t + \Delta t$ from the known inflows to the channel reach, I_2 and I_1, and the known outflow from the reach, O_1, at the current time, t (Reference 26).

$$O_2 = c_0 I_2 + c_1 I_1 + c_2 O_1 \tag{4}$$

$$c_0 = \frac{KX - 0.5\Delta t}{K - KX + 0.5\Delta t} \tag{5}$$

$$c_1 = \frac{KX + 0.5\Delta t}{K - KX + 0.5\Delta t} \tag{6}$$

$$c_2 = \frac{K - KX - 0.5\Delta t}{K - KX + 0.5\Delta t} \tag{7}$$

$$c_0 + c_1 + c_2 = 1 \tag{8}$$

Muskingum routing is employed by the TVA to translate Blue Ridge Dam outflows downstream to the Ocoee No. 1 Dam. Four reaches are used in this routing with each reach characterized by different *K*, *X*, routing time step (Δt), and coefficient values; of note, two of these four reaches are terminated by dams (i.e. constrictions). *K* and Δt in days are used in Equations (5), (6), and (7). The routed Blue Ridge Dam outflows are then subtracted from the RRR inflow hydrograph for the Ocoee No. 1 Reservoir to obtain the "observed" subbasin local hydrograph for Subbasin 43. Muskingum routing information, provided by the TVA (Reference 14), for each of the four reaches is listed in Table 2.

Table 2: Muskingum routing coefficients and parameters for Subbasin 43

Reach Description	K (hrs)	X	Δt (hrs)	c_0	c_1	c_2
Blue Ridge Dam to Copperhill gage	3	0.25	3	0.20	0.60	0.20
Copperhill gage to Ocoee No. 3 Dam	1	0.10	1	0.29	0.43	0.28
Ocoee No. 3 Dam to EMF gage	2	0.40	2	0.09	0.82	0.09
EMF gage to Ocoee No. 1 Dam	1	0.10	1	0.29	0.43	0.28

7.2 Floods for Unit Hydrograph Validation

Hourly "observed" subbasin local hydrographs were obtained following the methods presented in Section 7.1 for each subbasin. At least two large storms/floods were selected from the 11-year period for the validation of each subbasin unit hydrograph. This period was used because gridded hourly rainfall data for the period from 1997 to 2007 are available from the NWS LMRFC (Section 6.5).

The headwater stage data for each reservoir are provided to the nearest 0.01 foot. Each change in stage of 0.01 foot provides a change in reservoir storage that corresponds to a significant inflow to the reservoir based on Eq. (2). Numerous small magnitude oscillations (on the order of 0.01 – 0.05 ft) in observed headwater stage are evident in the data. These fluctuations occur when the water surface elevation of the reservoir is changing slowly and surface elevations are measured at discrete height intervals (i.e., to the nearest hundredth foot) or when external influences on stage elevation (e.g. wind, barometric pressure fluctuations, etc.) are not removed from the data. These oscillations create short period fluctuations in the calculated inflow that represent inaccuracies of the calculation method rather than actual inflows to reservoir.

Large floods, by contrast, have an increase in inflow magnitude that lasts for several to many hours before inflows start to decline. The corresponding decline in inflow magnitude also lasts for several to many hours. A simple moving average of the calculated inflows was used in the search for large floods during the 11-year period. A moving average window was identified for each subbasin. The duration of the window was selected to be long enough to remove spurious oscillations but short enough to capture the shortest duration flood that can be represented with the unit hydrograph. The period of the unit hydrograph (i.e., two-hours or six-hours for the unit hydrographs in this calculation) proved to be too short to successfully remove spurious oscillations. Consequently, the moving average window for each subbasin corresponds to the minimum duration flood that could feasibly be represented with the unit hydrograph (i.e. the time length or base length of the major portion of the unit hydrograph runoff mentioned in the appropriate sub-section of Section 6.2). This moving average window length successfully identified large floods for each local basin during each year without incorrectly identifying spurious oscillations created by the reverse reservoir routing calculation.

Observed subbasin local hydrographs were derived for Subbasins 38, 39, 40, 41, and 43 for the period 1997 to 2007 using the methods presented in Section 7.1. A central moving average hydrograph was then calculated from the "observed" subbasin local hydrograph to facilitate the search for large floods. The moving average window for each subbasin was chosen as the duration representing the major portion of the unit runoff in the original TVA unit hydrograph. If this duration was not odd-valued, then one hour was added to the duration to provide a symmetric central moving average window. For example, the major portion of the unit runoff for Subbasin 38 occurs during the first six hours of the unit hydrograph (see "TVA 2-hr UH" in Figure 55 on page 72). Since six is an even number of hours, the moving average window is increased by one hour to seven hours to obtain an odd-numbered, and thus centered, window. These calculations are enclosed in Attachment 1- 9 through Attachment 1- 17 (Attachment 1- 8, Reference 29, provides data used in calculations contained within several of these attachments).

The largest flood in each subbasin for each year of the 11-year period was identified from the moving average hydrographs. These calculations are included in Attachment 1- 18 through Attachment 1- 21. Tables showing the largest flood in each year for each of these subbasins are attached in the Appendix, Section 9. Table 3 provides a listing of the floods selected for unit hydrograph validation for these four subbasins. The selected floods are the largest by peak magnitude of the moving average hydrographs with reliable precipitation data in the NWS data set.

Table 3: Summary of selected floods for unit hydrograph validation of Subbasins 38, 39, 40, and 43

Subbasin	Flood Name	Central Moving Average Window (hours)	Peak Discharge (cfs)	Rank of Peak Discharge from 1997-2007	Peak Discharge from Moving Average (cfs)	Flood Period	Figure	Detailed Table (see Appendix, Section 9)
Chatuge Dam, Subbasin 38	May 2003	7	13,302	2	6,708	5/5/03 00:00 to 5/11/03 00:00	Figure 9	Table 20 (page 110)
	September 2004		19,916	1	17,285	9/16/04 00:00 to 9/23/03 00:00	Figure 10	
Nottely Dam, Subbasin 39	September 2004	11	11,300	2	9,400	9/16/04 00:00 to 9/21/04 00:00	Figure 11	Table 21 (page 112)
	July 2005		18,390	1	8,384	7/28/05 00:00 to 8/3/05 00:00	Figure 12	
Hiwassee Dam, Subbasin 40	May 2003	25	28,564	1	21,725	5/5/03 00:00 to 5/13/03 00:00	Figure 13	Table 22 (page 114)
	December 2004		19,321	3	12,140	12/5/04 00:00 to 12/12/04 00:00	Figure 14	
Ocoee No. 1 Dam, Subbasin 43*	April 1998	19	20,016	3	15,115	4/17/98 00:00 to 4/24/98 00:00	Figure 15	Table 23 (page 115)
	May 2003		22,353	2	14,003	5/5/03 00:00 to 5/12/03 00:00	Figure 16	
	September 2004		28,127	1	14,686	9/15/04 00:00 to 9/22/04 00:00	Figure 17	

* Three floods were used for the Subbasin 43 unit hydrograph validation (Section 7.7.5).

The calculated or "observed" subbasin local hydrographs are presented for each selected flood in Figure 9 through Figure 17. The "observed" subbasin local hydrographs are denoted by "I, RRR – local" in the plots.

TVA

Calculation No. CDQ000020080061	Rev: 0	Plant: GEN	Page: 33
Subject: Subbasins 38, 39, 40, 41, and 43 Unit		Prepared	N.D.M.
Hydrograph Validations		Checked	M.C.C.

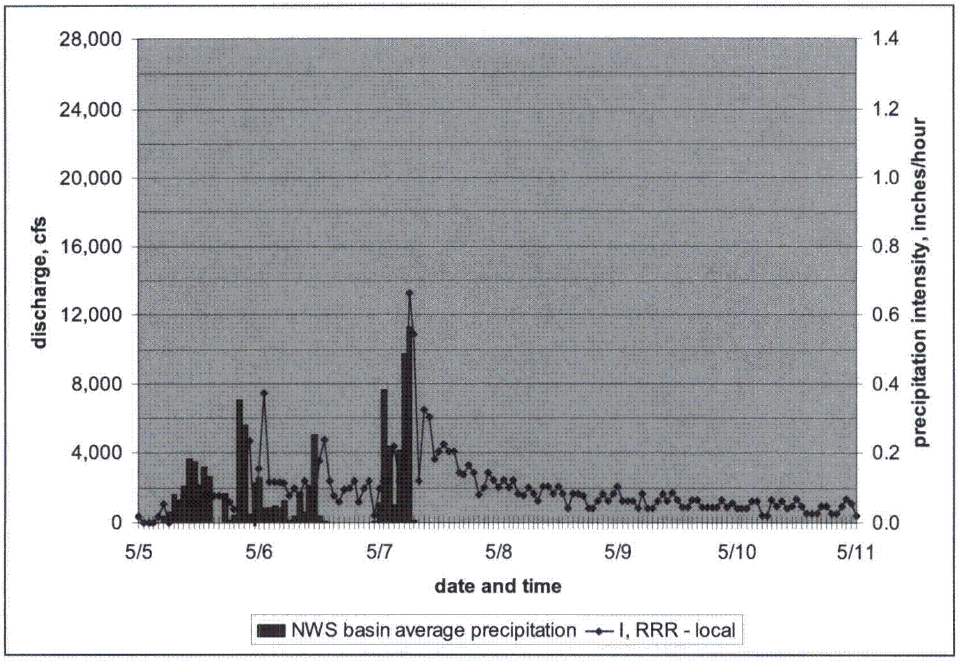

Figure 9: Chatuge Dam "observed" subbasin local hydrograph for May 2003 flood

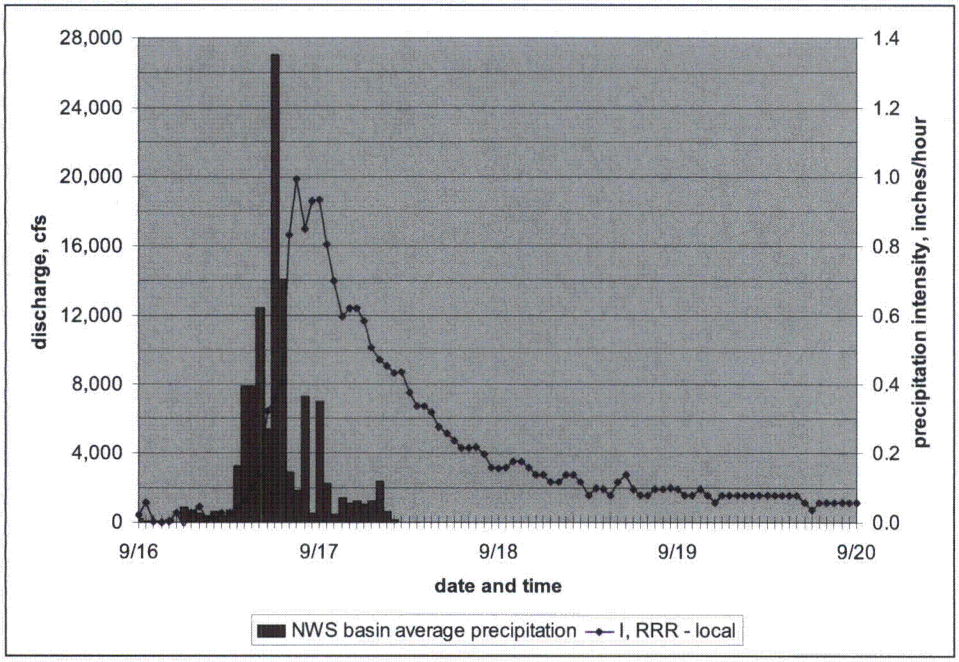

Figure 10: Chatuge Dam "observed" subbasin local hydrograph for September 2004 flood

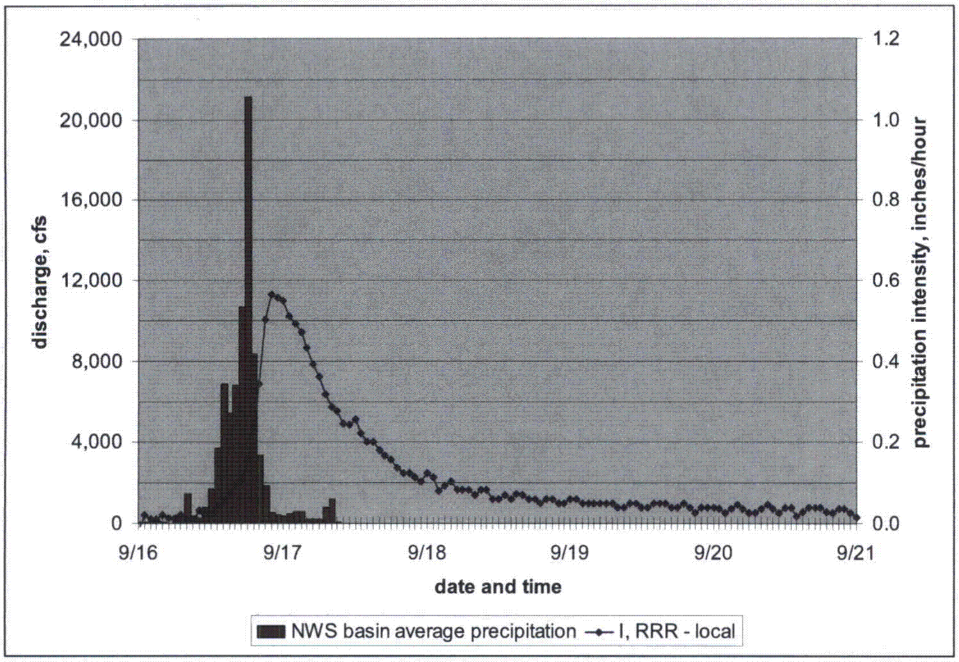

Figure 11: Nottely Dam "observed" subbasin local hydrograph for September 2004 flood

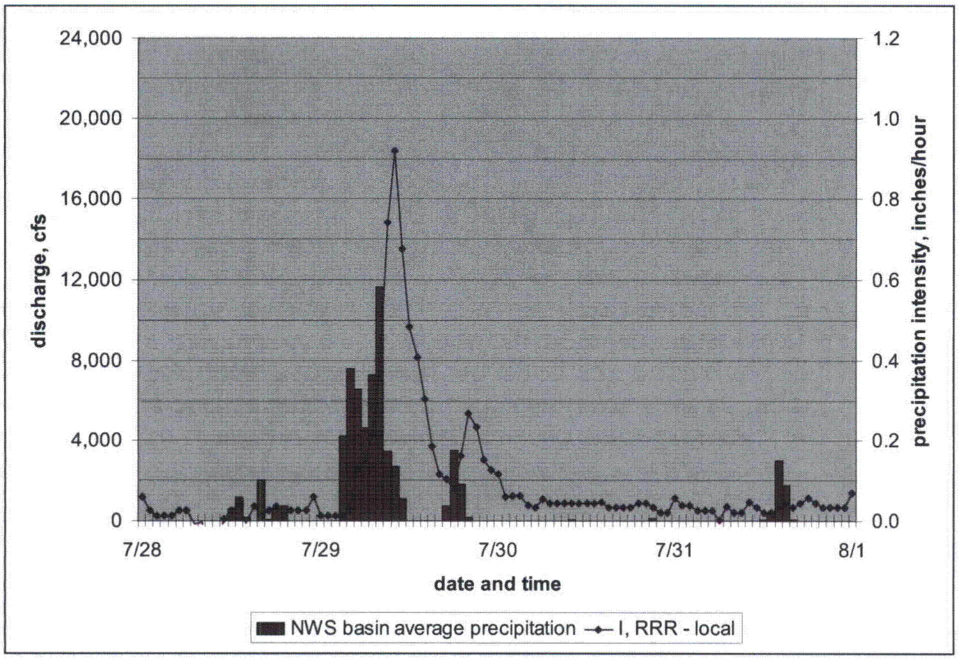

Figure 12: Nottely Dam "observed" subbasin local hydrograph for July 2005 flood

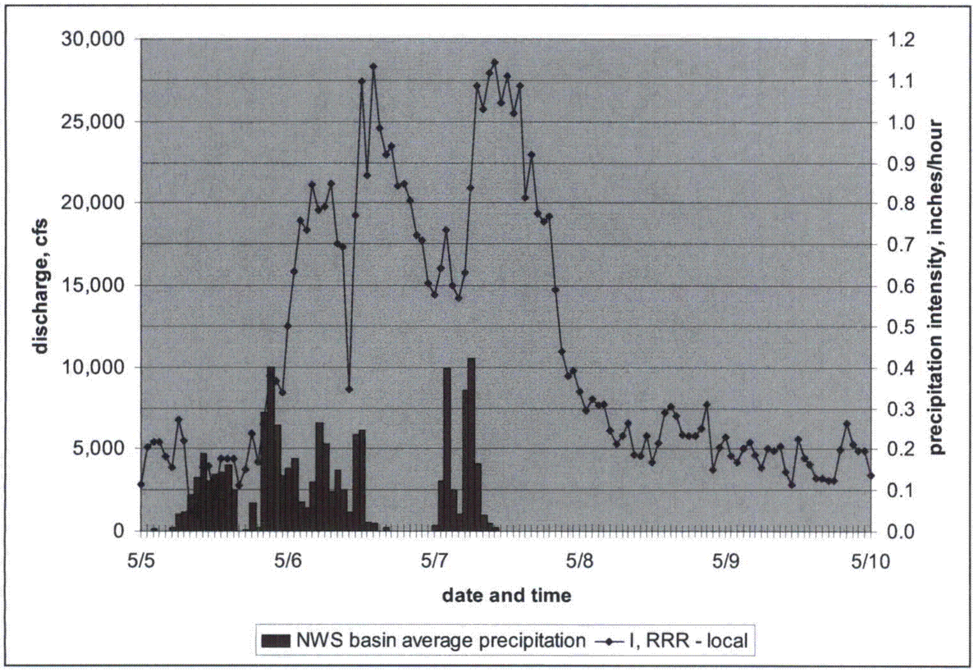

Figure 13: Hiwassee Dam "observed" subbasin local hydrograph for May 2003 flood

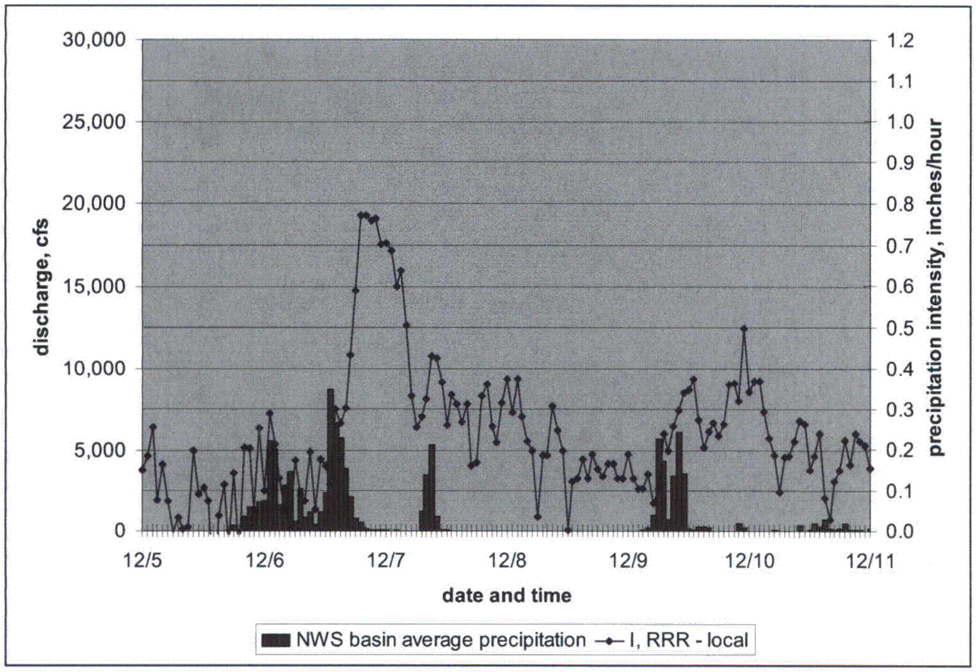

Figure 14: Hiwassee Dam "observed" subbasin local hydrograph for December 2004 flood

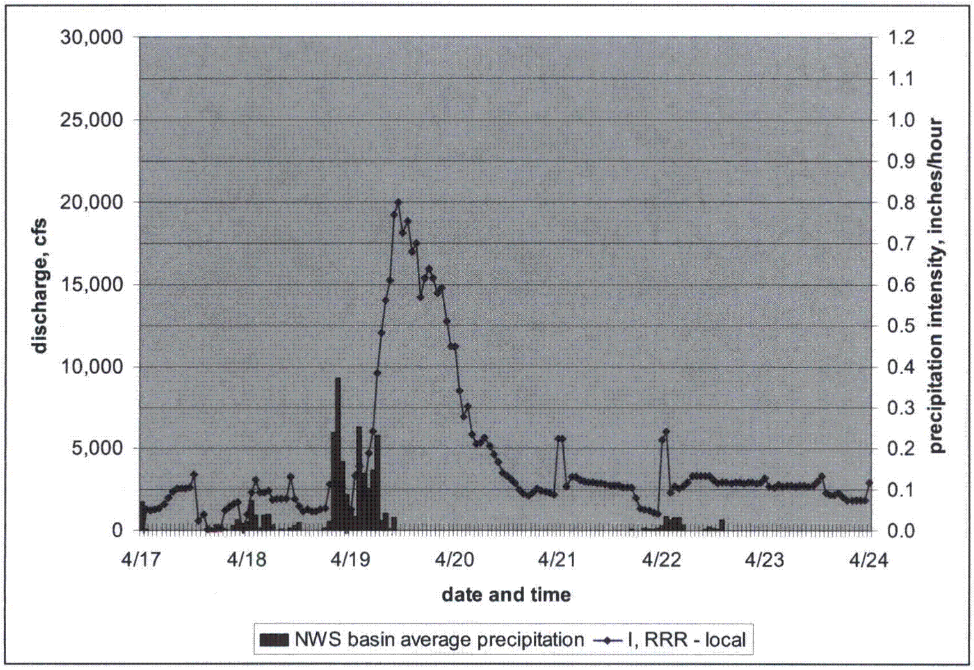

Figure 15: Ocoee No. 1 Dam "observed" subbasin local hydrograph for April 1998 flood

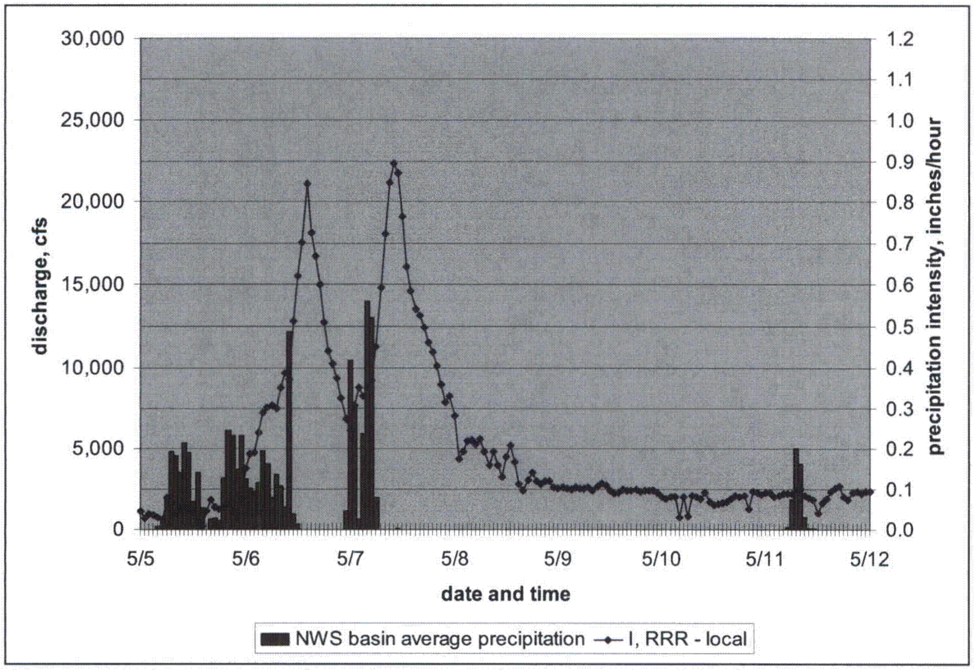

Figure 16: Ocoee No. 1 Dam "observed" subbasin local hydrograph for May 2003 flood

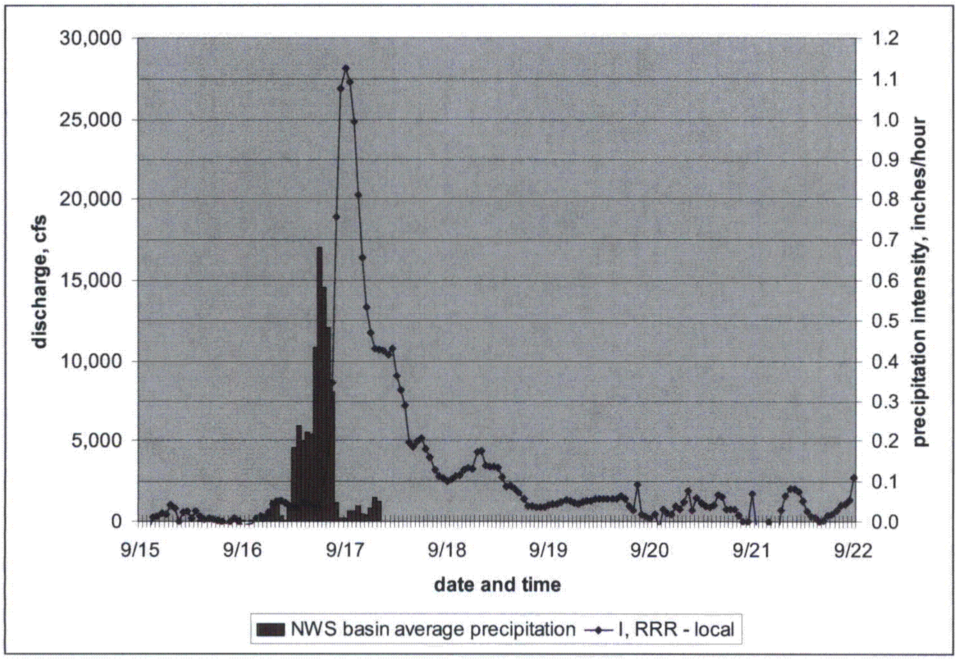

Figure 17: Ocoee No. 1 Dam "observed" subbasin local hydrograph for September 2004 flood

7.2.1 Apalachia Dam Subbasin 41

Hourly records of outflow and headwater stage for Apalachia Dam and the stage-volume relationship for the reservoir were employed in RRR of the Apalachia Dam outflow records to obtain "observed" inflow hydrographs for the period 1997 to 2007. To obtain "observed" subbasin local hydrographs, the outflow from Hiwassee Dam, Subbasin 40, located upstream was removed from the inflow hydrograph. Hiwassee Dam releases were subtracted from calculated Apalachia Reservoir inflows using straight-lag routing with a zero-hour lag (Reference 17).

Hiwassee Dam outflow data and inflow to Apalachia Dam calculated with RRR are shown in Figure 18 for the May 2003 flood. This flood was chosen since it was significant in nearby subbasins (Table 3) and likely to be a significant flood in the Apalachia Dam local unit area. In Figure 18, Hiwassee Dam outflows[2] are in phase with the calculated inflows to Apalachia Dam on May 3 and 4 which supports the use of the zero-lag routing recommended by the TVA.

The observed inflow hydrographs from RRR were adjusted by subtracting the Hiwassee Dam outflows to obtain the "observed" subbasin local hydrographs. These calculations are attached; see Attachment 1- 22 and Attachment 1- 23. Table 4 provides the ten largest "observed" subbasin local discharge values calculated for each year by taking a 37-hour moving average of

[2] The outflows are not routed; they are the measured releases at Hiwassee Dam.

the hourly discharge values. A 37-hour moving average window was used for Subbasin 41 since the major portion (i.e. the peak) of the unit runoff occurs in the first 36 hours (see "Original 6-hr UH" in Figure 60 on page 79) and since an odd-value period is required for a symmetric moving average calculation.

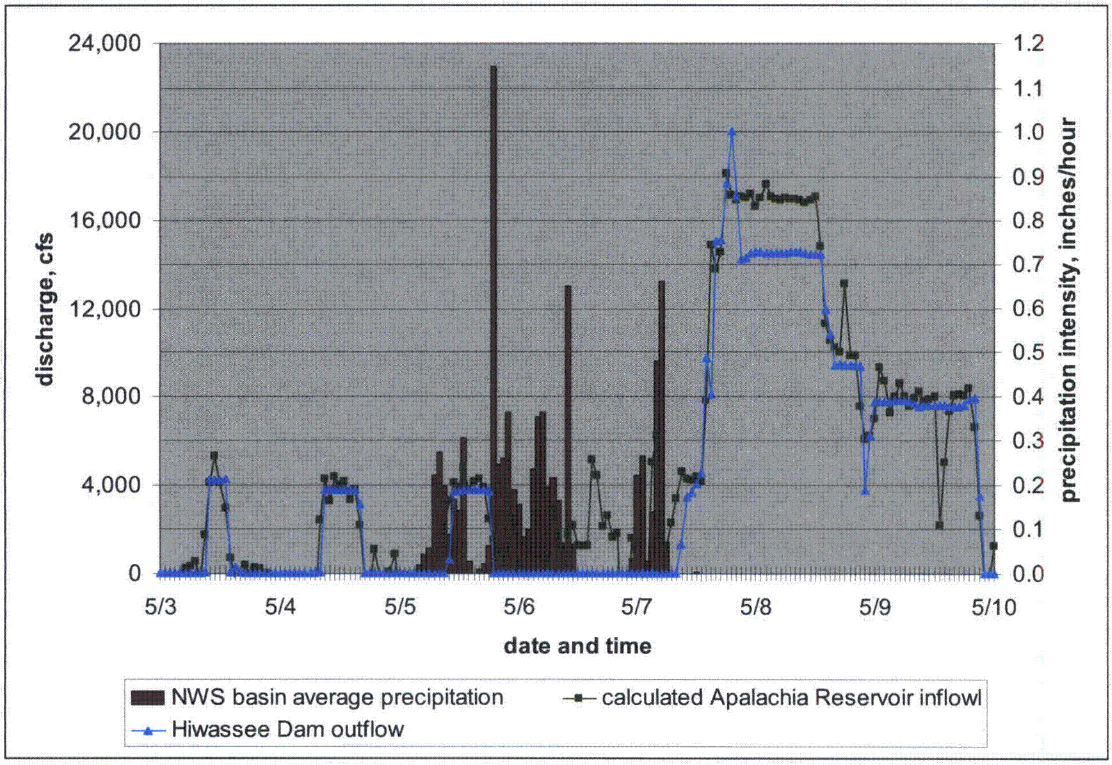

Figure 18: Subbasin 41 comparison of calculated Apalachia Dam inflows and Hiwassee Dam outflow data for the May 2003 flood

Two floods were chosen based on the magnitudes of the 37-hour moving average peak discharges and the availability of concurrent gridded precipitation data (see Attachment 1- 24 for calculations). The following two floods were selected for unit hydrograph validation:

- May 5, 2003, 00:00 hrs to May 11, 2003, 00:00 hrs, the "May 2003" flood which has the highest calculated peak discharge during 1997 - 2007
- April 18, 1998, 00:00 hrs to April 22, 1998, 00:00 hrs, the "April 1998" flood which has the second highest peak discharge during 1997 - 2007

The calculated or "observed" subbasin local hydrographs (denoted by "I, RRR – local") are presented for the selected floods in Figure 19 and Figure 21. In these figures, the spurious oscillations created by the calculation methods are of the same order of magnitude as the peak flows due to the small size of the subbasin relative to the upstream watershed (i.e. Subbasins 38, 39, and 40). In Figure 19, a coherent period of rainfall driven runoff, with a discernable rising limb and falling limb, is not readily discernable amidst the fluctuations for the calculated local, inflow values. Several of these fluctuations result in calculated negative discharge values as shown in Figure 20. Figure 21 shows a discrete runoff event starting on April 19, 1998 at a time when Hiwassee Dam outflows do not occur.

Table 4: Ten largest "observed", 37-hour moving average discharge values for Subbasin 41 for each year from 1997-2007

Rank	Description	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	Discharge (cfs)	921	1,196	794	405	696	739	2,167	612	918	572	765
	Date*	3/4/97 1:00	4/19/98 13:00	9/25/99 0:00	9/28/00 23:00	10/2/01 1:00	1/24/02 21:00	5/7/03 19:00	12/9/04 1:00	7/16/05 22:00	10/30/06 0:00	7/11/07 0:00
2	Discharge (cfs)	855	1,195	781	404	689	725	2,147	564	812	554	729
	Date*	3/4/97 0:00	4/19/98 16:00	9/24/99 23:00	9/29/00 2:00	10/1/01 21:00	1/24/02 20:00	5/7/03 18:00	12/9/04 0:00	7/13/05 20:00	10/29/06 17:00	7/10/07 20:00
3	Discharge (cfs)	846	1,190	688	402	682	657	2,118	514	776	512	722
	Date*	3/1/97 0:00	4/19/98 14:00	8/20/99 2:00	9/29/00 0:00	10/1/01 20:00	1/24/02 22:00	5/7/03 17:00	12/8/04 23:00	7/13/05 0:00	11/29/06 22:00	7/10/07 23:00
4	Discharge (cfs)	834	1,189	672	395	678	595	2,084	512	764	493	717
	Date*	3/1/97 1:00	4/19/98 15:00	8/20/99 1:00	9/29/00 1:00	10/1/01 16:00	1/24/02 19:00	5/7/03 20:00	11/30/04 23:00	7/13/05 19:00	10/30/06 1:00	7/10/07 21:00
5	Discharge (cfs)	833	1,187	663	351	674	529	2,066	496	749	486	713
	Date*	7/22/97 23:00	4/19/98 17:00	8/13/99 22:00	10/4/00 1:00	10/1/01 22:00	1/24/02 23:00	5/7/03 21:00	12/8/04 22:00	7/15/05 23:00	10/29/06 1:00	7/10/07 22:00
6	Discharge (cfs)	818	1,177	656	348	673	520	1,997	468	742	480	698
	Date*	7/22/97 22:00	4/19/98 18:00	9/25/99 1:00	10/4/00 2:00	10/2/01 0:00	1/24/02 18:00	5/7/03 16:00	11/30/04 22:00	7/13/05 1:00	10/29/06 16:00	7/11/07 1:00
7	Discharge (cfs)	792	1,175	647	331	669	511	1,951	467	738	474	698
	Date*	7/22/97 20:00	4/19/98 12:00	9/22/99 22:00	12/1/00 0:00	10/1/01 18:00	1/26/02 13:00	5/7/03 0:00	11/27/04 18:00	7/16/05 23:00	11/29/06 23:00	7/10/07 19:00
8	Discharge (cfs)	786	1,169	636	329	669	511	1,920	457	732	474	645
	Date*	7/22/97 21:00	4/19/98 11:00	9/24/99 22:00	9/29/00 3:00	10/1/01 17:00	1/24/02 17:00	5/7/03 1:00	12/9/04 2:00	7/16/05 18:00	1/18/06 1:00	7/11/07 4:00
9	Discharge (cfs)	759	1,162	613	325	666	504	1,916	444	728	468	633
	Date*	4/5/97 17:00	4/19/98 10:00	9/23/99 1:00	9/28/00 0:00	10/1/01 19:00	1/24/02 15:00	5/7/03 9:00	11/27/04 19:00	7/17/05 19:00	11/27/06 0:00	7/11/07 5:00
10	Discharge (cfs)	742	1,156	611	324	662	503	1,913	413	705	458	610
	Date*	7/23/97 0:00	4/19/98 19:00	9/22/99 23:00	9/28/00 1:00	10/1/01 23:00	1/24/02 16:00	5/7/03 22:00	11/26/04 18:00	7/16/05 17:00	11/26/06 23:00	7/11/07 2:00

* Central Time

Largest storm by peak magnitude from 37-hour central moving average hydrograph

Second largest storm by peak magnitude from 37-hour central moving average hydrograph

The 11-year hydrograph period was examined for additional floods with no Hiwassee Dam outflow; the April 1998 flood was the only flood discovered. The other floods listed in Table 4 all display the same issues with oscillations as the May 2003 flood and as shown in Figure 20. The average of the calculated inflows for these floods is approximately zero because of the negative oscillations. Consequently, the April 1998 flood will be the only one analyzed for this subbasin during the interval from 1997 to 2007.

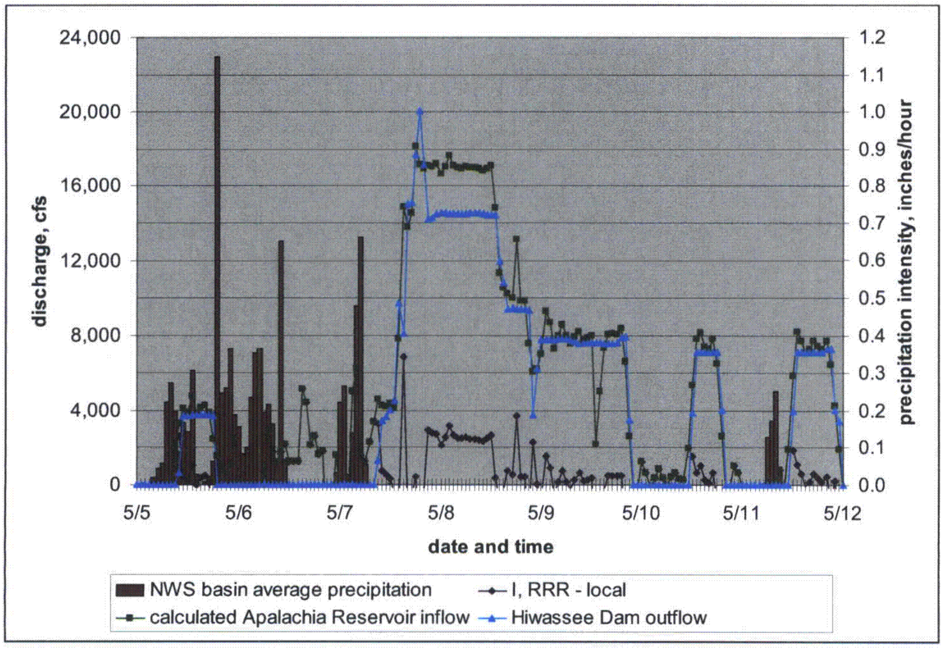

Figure 19: Apalachia Dam “observed” subbasin local hydrograph for the May 2003 flood

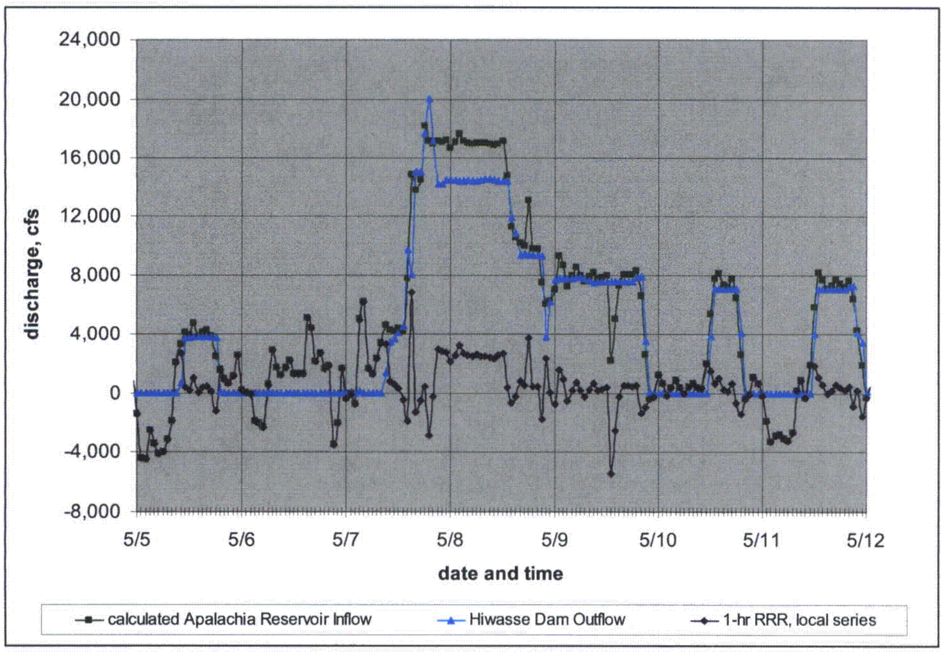

Figure 20: Apalachia Dam "observed" subbasin local hydrograph showing negative oscillations for the May 2003 flood

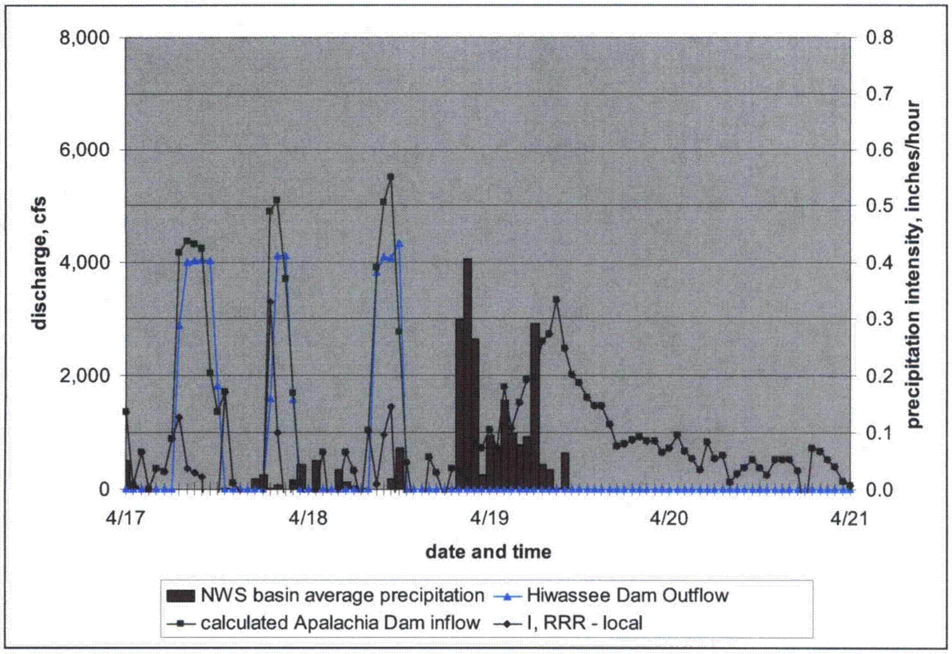

Figure 21: Apalachia Dam "observed" subbasin local hydrograph for the April 1998 flood

7.3 Baseflow Separation

Baseflow separation is required to provide an estimate of direct runoff associated with the flood of interest. For this calculation, the three-point (ABC) method was employed (see Figure 22 or page 45, Reference 26). Here, the recession of flow existing prior to the storm was extended from the starting point of runoff (point A) to a point immediately beneath the peak (point B). The starting point, point A, was selected via visual examination of the calculated hydrograph. Recession, in this calculation, was estimated by fitting a line to the observed hydrograph across one to three days prior to the flood; calculated hydrograph points were omitted from the line fitting process as necessary to obtain a trend line with a negative slope (i.e. recession) and to provide the best "visual" fit. Point B was then connected to the point on the receding limb of the hydrograph when storm runoff ends, point C (Reference 26). The approximate location of the point on the hydrograph when storm runoff ends (point C) was estimated using Eq. (9) (Reference 26) where N is the length between point B and C in days, and A is the basin area in square miles.

$$N = A^{0.2} \tag{9}$$

Baseflow was removed from the "observed" subbasin local hydrographs via baseflow separation to calculate the direct runoff volume. This volume is used in adjusting the excess rainfall volume, as noted in Section 5. Direct runoff volume, V, is calculated from period average flow rate, Q, and the length of the period, Δt, as:

$$V(ac-ft) = \sum Q(cfs)\ x \left(\Delta t(hr) * \frac{3{,}600(s/hr)}{43{,}560(ft^2/ac)} \right) \qquad (10)$$

Table 5 provides a summary of the direct runoff obtained from baseflow separation for each flood.

Table 5: Direct runoff (RO) volume obtained from baseflow and hydrograph separation for each flood

Subbasin	Drainage Area (sq. mi.)	Flood	Total Direct Runoff Volume (acre-ft)	Direct Runoff Depth (in)
Chatuge Dam, Subbasin 38	189.1	May 2003	17,895	1.77
		September 2004	28,668	2.84
Nottely Dam, Subbasin 39	214.3	September 2004	17,332	1.52
		July 2005	10,919	0.96
Hiwassee Dam, Subbasin 40	565.1	May 2003	85,946	2.85
		December 2004	39,022	1.29
Apalachia Dam, Subbasin 41	49.8	April 1998	3,438	1.29
Ocoee No. 1 Dam, Subbasin 43	362.6	April 1998	32,159	1.66
		May 2003	48,773	2.52
		September 2004	33,499	1.73

As mentioned in Section 7.2.1, the only flood in Subbasin 41 during the 11-year period to have a discrete period of runoff with decipherable rising and falling limbs occurred in April 1998. Consequently, this is the only flood listed in Table 5 for this subbasin.

Local hydrographs for each flood along with estimated baseflow and direct runoff are provided in Figure 22 through Figure 31. Baseflow separation calculations are enclosed as Attachment 1-25 through Attachment 1- 29. Some of the short period oscillations present in the calculated subbasin local hydrographs for the selected floods would have resulted in negative direct runoff values. These oscillations in the local hydrographs were smoothed using linear interpolation from the point just prior to the oscillation to just after the oscillation.

Both floods in Subbasin 40 and the May 2003 flood in Subbasin 43 were further separated by dividing the flow into separate peaks based on discrete periods of rainfall. These separations can be seen in Figure 26, Figure 27, and Figure 30 as the lines denoted "flood separation line." This additional flow separation was used to calculate excess precipitation for two bursts of rainfall during the May 2003 storms in Subbasins 40 and 43. Excess precipitation for each burst was then combined to create excess precipitation time series associated with the flood. For the 2004 flood in Subbasin 40, only the initial peak was used, after separation, because the two peaks and the associated rainfall were about 1.5 days apart.

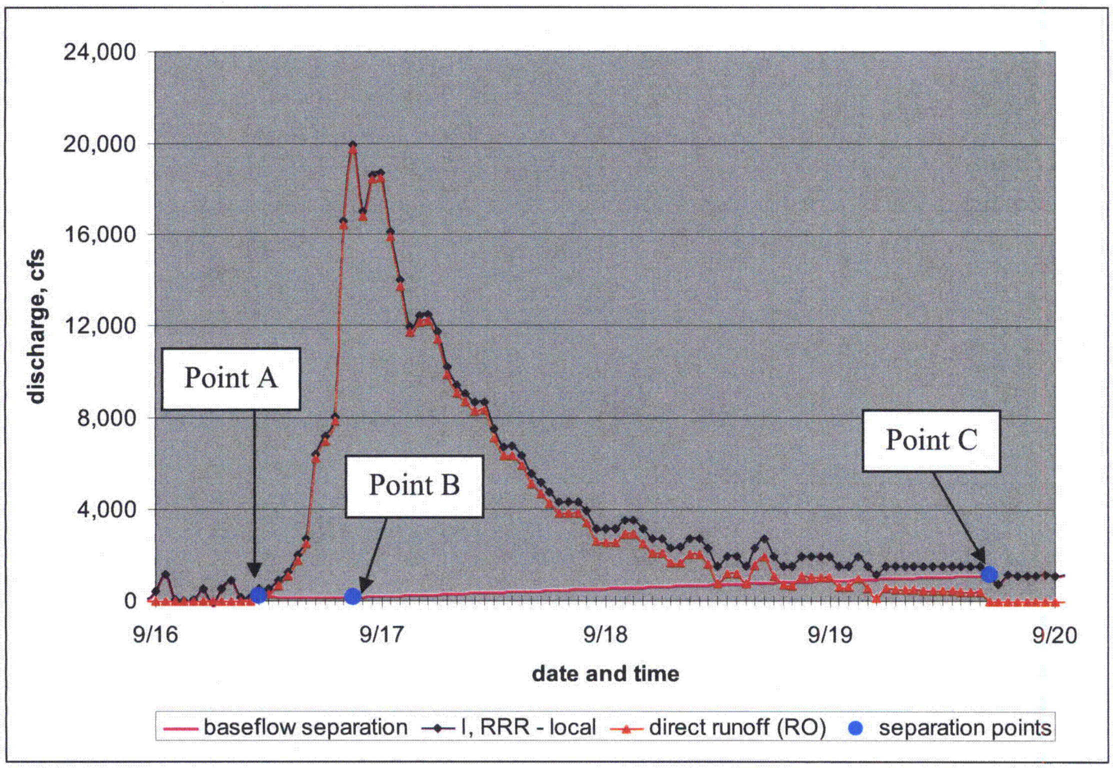

Figure 22: Chatuge Dam baseflow separation for September 2004 flood

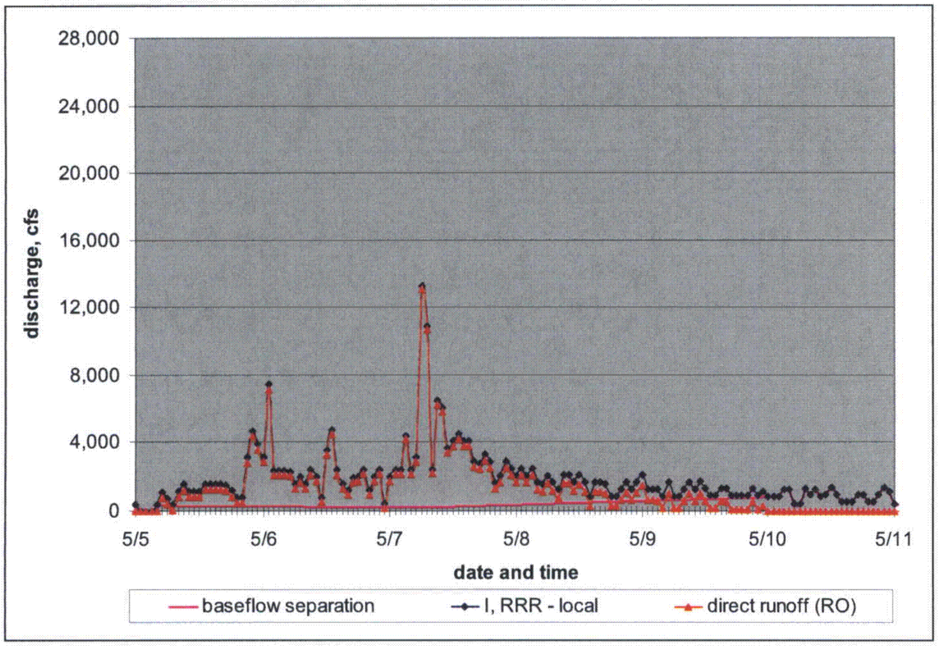

Figure 23: Chatuge Dam base flow separation for May 2003 flood

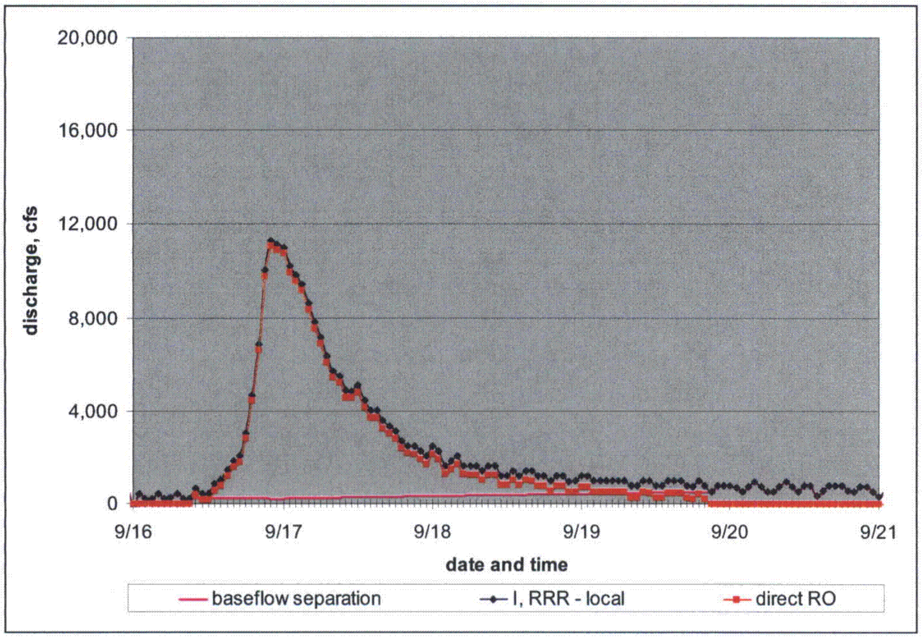

Figure 24: Nottely Dam baseflow separation for the September 2004 flood

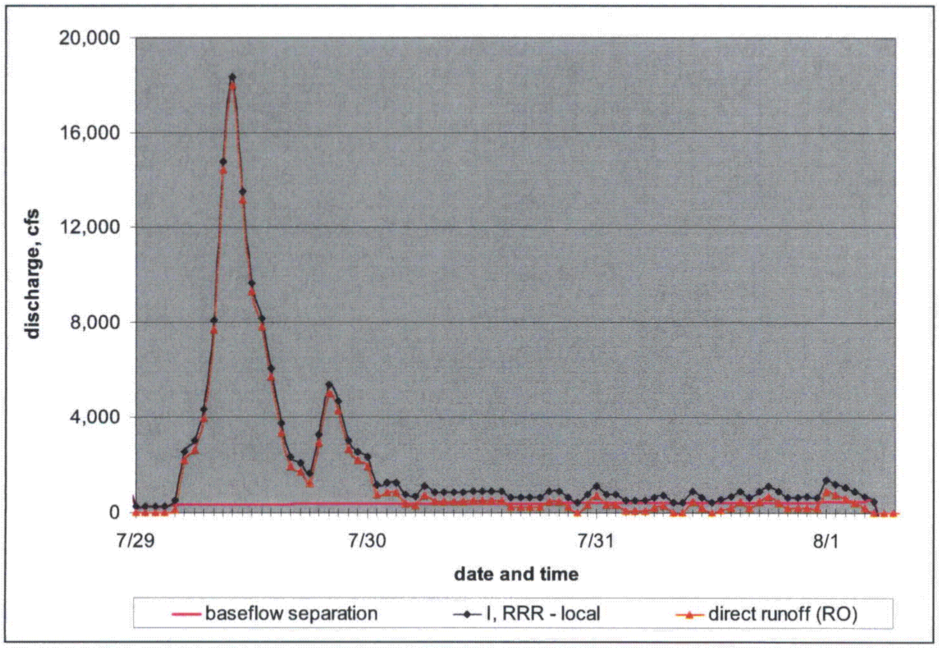

Figure 25: Nottely Dam baseflow separation for the July 2005 flood

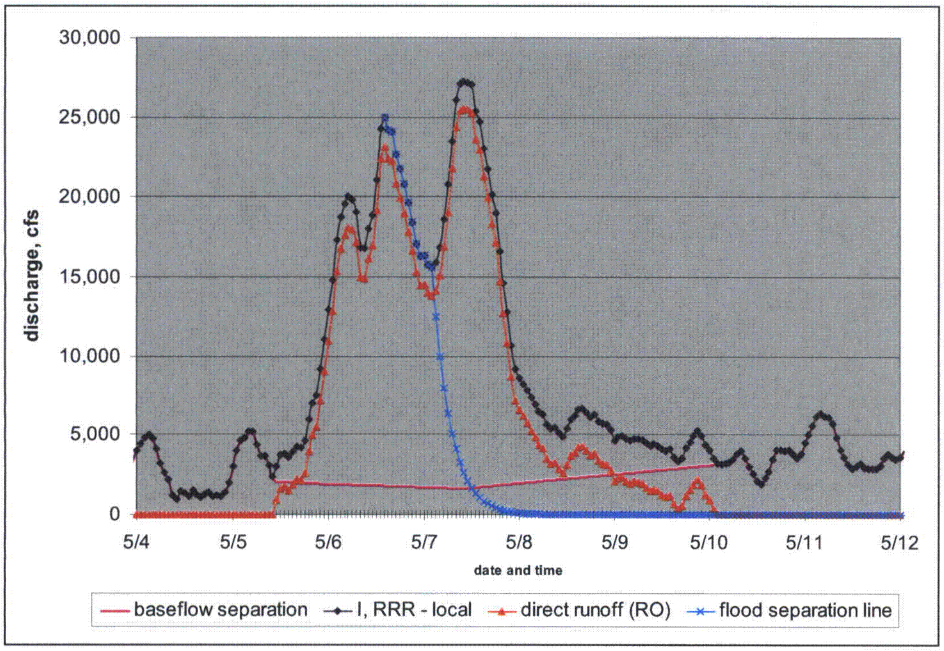

Figure 26: Hiwassee Dam baseflow separation for the May 2003 flood

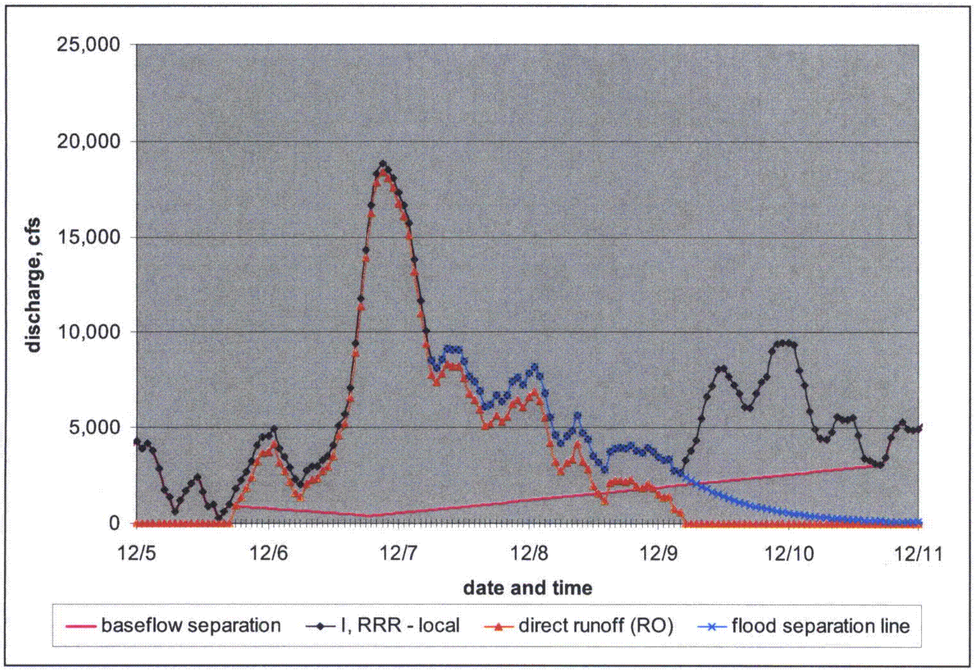

Figure 27: Hiwassee Dam baseflow separation for the December 2004 flood

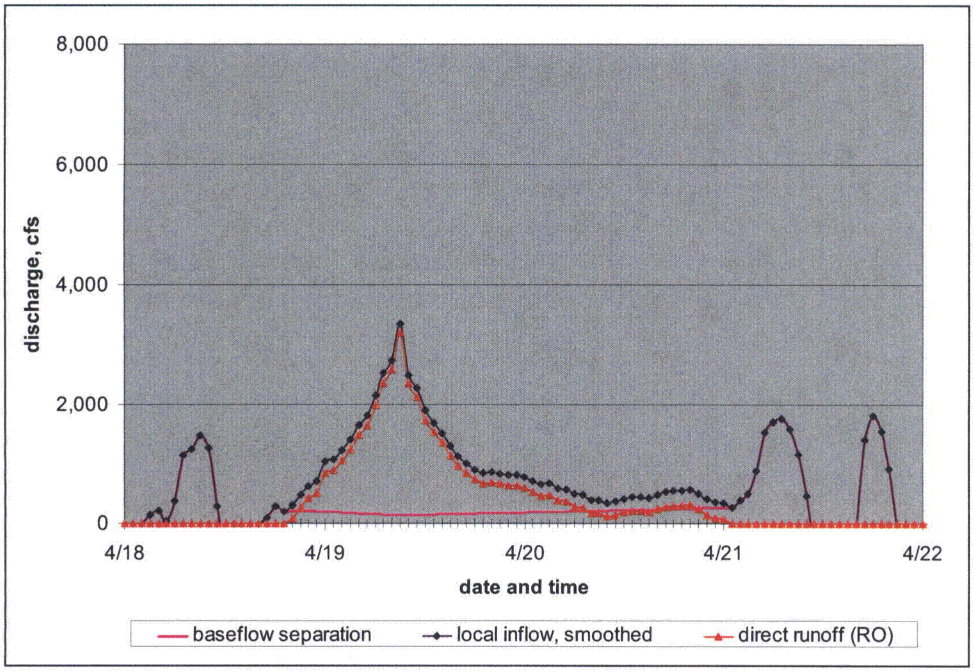

Figure 28: Apalachia Dam baseflow separation for the April 1998 flood

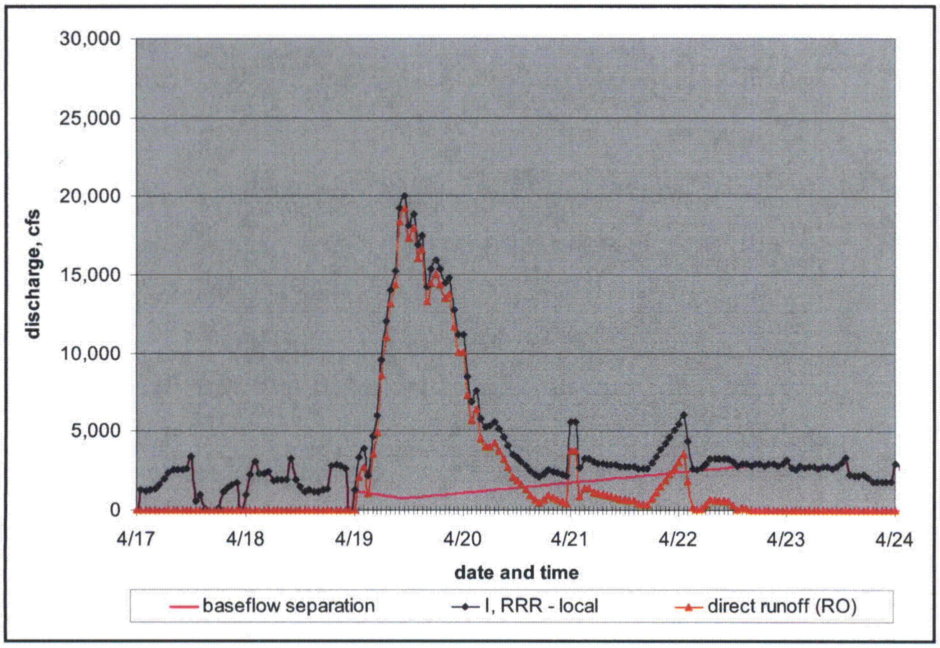

Figure 29: Ocoee No. 1 Dam baseflow separation for the April 1998 flood

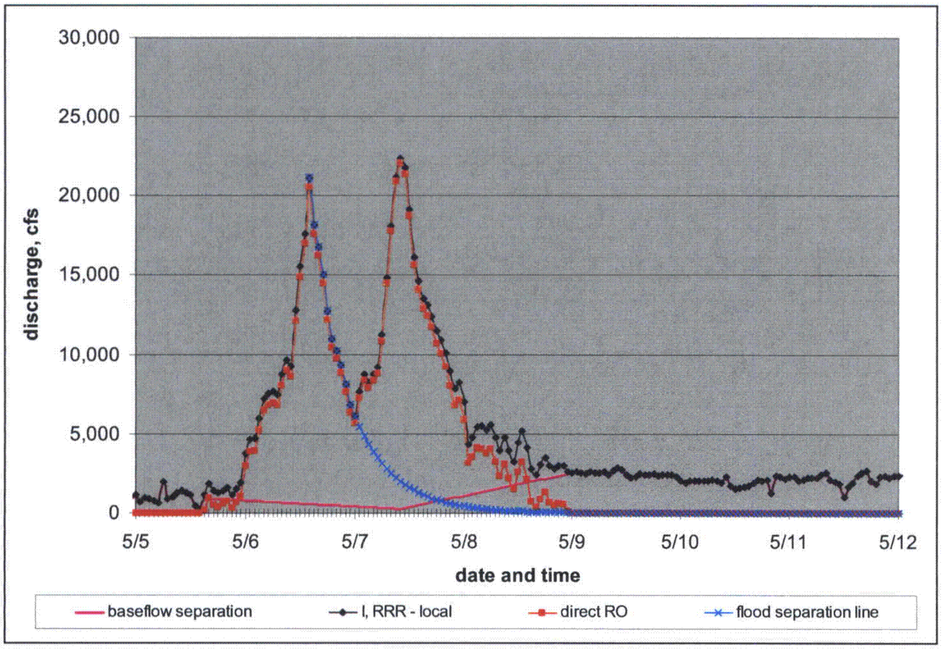

Figure 30: Ocoee No. 1 Dam baseflow separation for the May 2003 flood

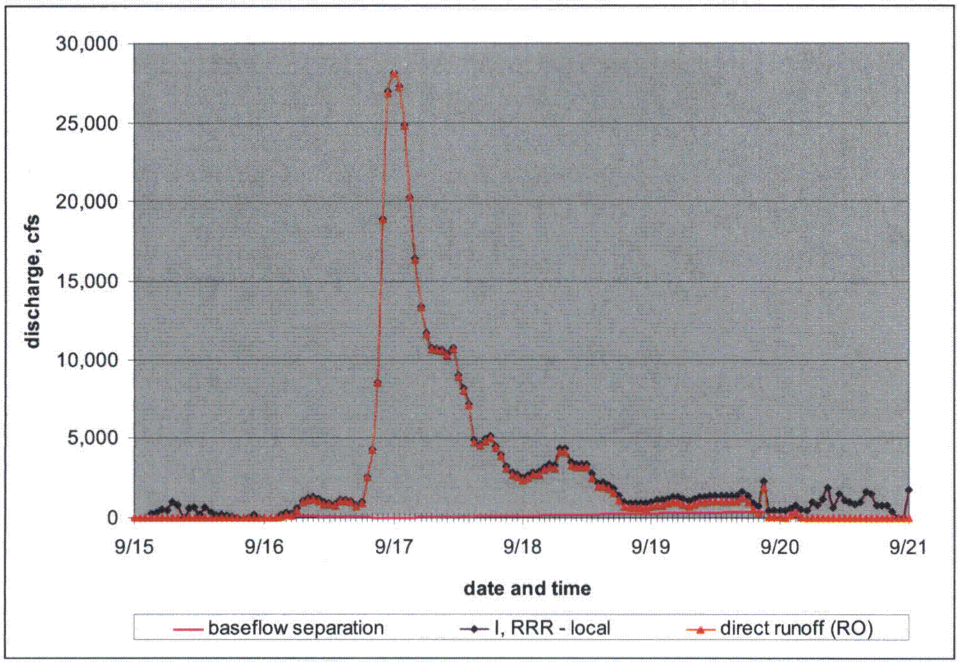

Figure 31: Ocoee No. 1 Dam baseflow separation for the September 2004 flood

7.4 Observed Basin Average Rainfall

Observed basin average rainfall for the selected storms in each subbasin was obtained from Reference 25. The hourly precipitation series developed from NWS gridded data for each subbasin in this calculation is provided in Attachment 1- 30 along with adjustments to Central time and unit conversion.

7.5 Basin Average Excess Precipitation

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 the application of a loss function which incorporates the hydrologic abstractions of evaporation and transpiration, interception, depression storage, and infiltration (Reference 2). The amount of excess precipitation, or 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 30). 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 6) to estimate excess precipitation from a given rain storm for use with the unit hydrographs for runoff prediction. 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 30 and Reference 31. 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.

7.5.1 FLDHYDRO Operation

FLDHYDRO can be employed in two different ways to generate excess precipitation. One way, hereafter the "forward excess precipitation estimation mode" uses the Antecedent Precipitation Index (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 (see Reference 31, page 243). The API is used to obtain a Runoff Index (RI) that has been determined for the Tennessee River Valley region as a function of location and season. The RI is then used to obtain precipitation losses for each increment of rainfall. The forward excess precipitation estimation mode was not used in this calculation.

The other FLDHYDRO excess precipitation estimation method, hereafter the "CHKVOL mode", distributes and scales excess precipitation so that the total volume of excess precipitation approximately matches the calculated direct runoff volume. The direct runoff volume comes from the baseflow separation calculations and is provided to the program with the CHKVOL parameter. The time distribution of rainfall excess within the storm interval occurs according to the region provided to the FLDHYDRO model. Excess precipitation is also scaled by the program so that excess precipitation as a percentage of observed rainfall is larger as the storm progresses. The CHKVOL mode was used to estimate excess precipitation for all storms and subbasins covered in this calculation.

FLDHYDRO, regardless of operation mode, requires a region specification in order to provide excess precipitation for a storm. Figure 32 displays the regions and the subbasins, by number, that fall within each region. The majority of the subbasins in this calculation fall within the southeast (SE) region; portions of Subbasins 41 and 43 lie in the east (E) region. Reference 6 provides information concerning the methods of specifying the region within the model.

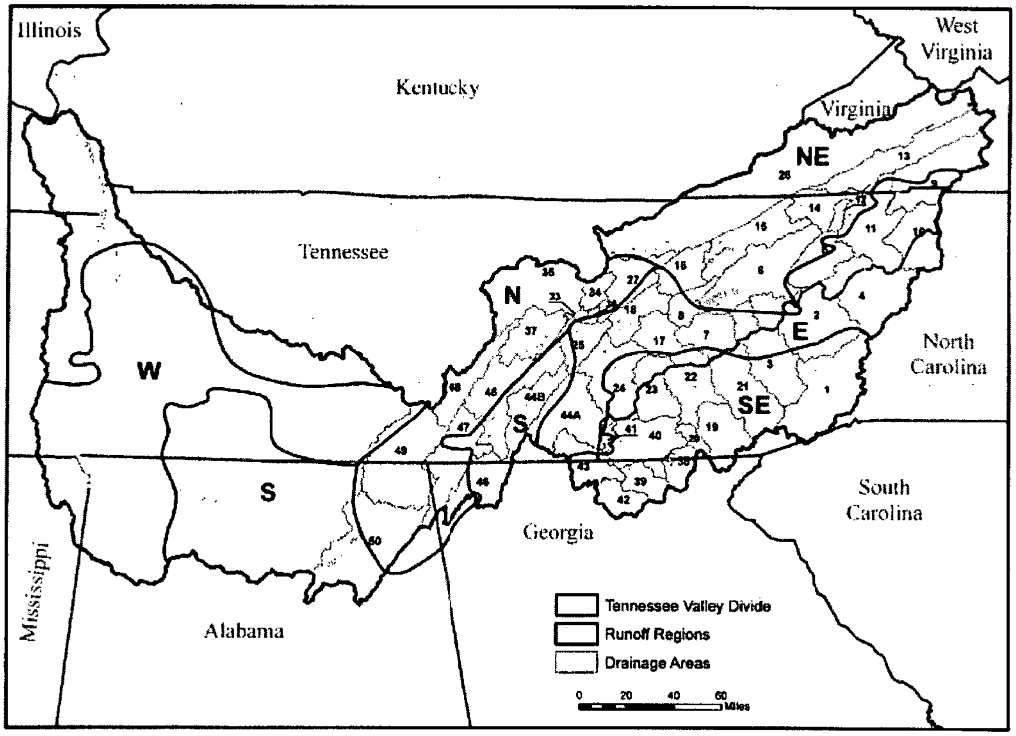

Figure 32: Regions of the Tennessee Valley watershed used by the FLDHYDRO model

7.5.2 FLDHYDRO Input and Output

Table 6 provides a listing of the FLDHYDRO input files and assigned FLDHYDRO regions for the storms and subbasins, and the resulting calculated excess precipitation volumes. As mentioned above, the CHKVOL mode was used in all cases. The input files and corresponding outputs files for FLDHYDRO are enclosed as Attachment 2- 1 through Attachment 2- 20.

The Runoff Index (RI) tables that FLDHYDRO uses were employed directly to determine excess precipitation for the May 2003 flood in Subbasin 40. As mentioned in Section 7.3, the hydrograph for this flood was separated to identify runoff volumes corresponding with two separate bursts of rainfall. Excess precipitation values for each burst were calculated separately with the RI tables utilized in FLDHYDRO. In this calculation, cumulative excess precipitation depths were calculated from the cumulative rainfall depths for each burst using the RI tables. The values for the bursts were then combined to create an excess precipitation time series for use in HEC-HMS. This method of calculating excess precipitation is discussed in Reference 6. These calculations for Subbasin 40 are enclosed in Attachment 1- 27.

Subbasins 41 and 43 straddle the Southeast (SE) and East (E) regions as shown in Figure 32. The East region was used to generate excess precipitation for both basins because it gave more reasonable estimates of excess precipitation than did the Southeast region.. Specification of the East region generated a total volume of excess precipitation in accordance with the CHKVOL input. Similar behavior was observed for the May 2003 flood in Subbasin 40. As a result, the East region was also specified for the May 2003 storm in Subbasin 40.

The time series of NWS basin average precipitation provides the main FLDHYDRO input for each storm. FLDHYDRO derives the time distribution of excess precipitation from the precipitation input. Comparisons of cumulative precipitation and excess precipitation and of the distribution over time of precipitation and excess precipitation are provided in Figure 33 through Figure 52.

Table 6: Selected FLHDYRO inputs and output excess precipitation volume

Subbasin	Storm/Flood	FLDHYDRO Input File	Region	FLDHYDRO Excess Precipitation Volume (in)
Chatuge Dam, Subbasin 38	May 2003	Bas38_03.dat	SE	1.78
	September 2004	Bas38_04.dat	SE	2.82
Nottely Dam, Subbasin 39	September 2004	Bas39_04.dat	SE	1.51
	July 2005	Bas39_05.dat	SE	0.96
Hiwassee Dam, Subbasin 40	May 2003	Runoff Index (RI) tables used directly	E	2.73
	December 2004	Bas40_04.dat	SE	1.31
Apalachia Dam, Subbasin 41	April 1998	B4198nle.dat	E	1.29
Ocoee No. 1 Dam, Subbasin 43	April 1998	B43_98-E.dat	E	1.70
	May 2003*	B43P1_03-M2.dat B43P2_03-M2.dat	E	2.53
	September 2004	B43_04-E.dat	E	1.76

* Rainfall for the May 2003 flood was analyzed with two FLDHYDRO runs and by separating the two peaks (Figure 30).

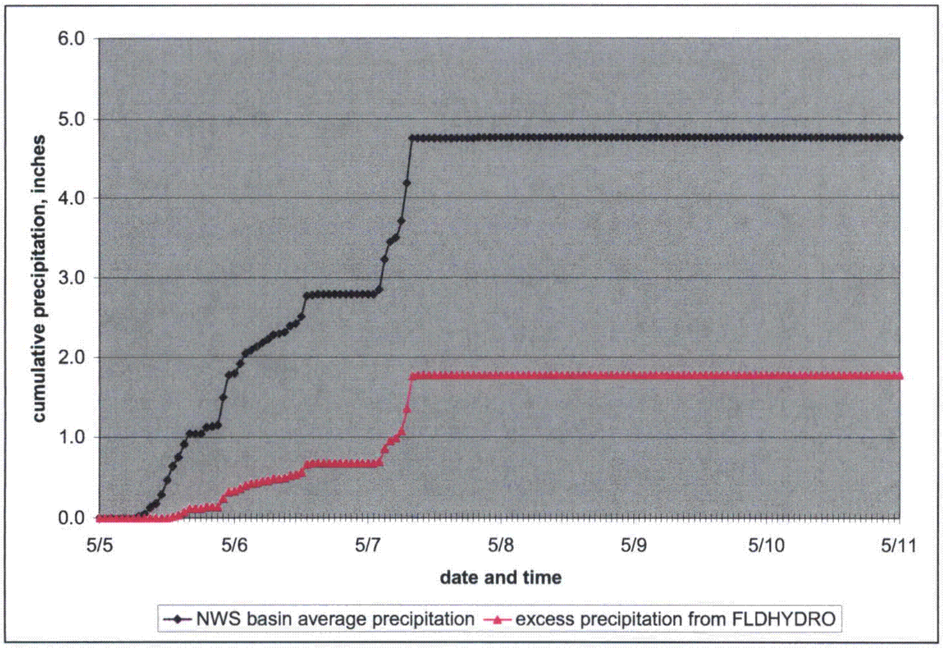

Figure 33: Chatuge Dam cumulative precipitation and excess precipitation for the May 2003 storm

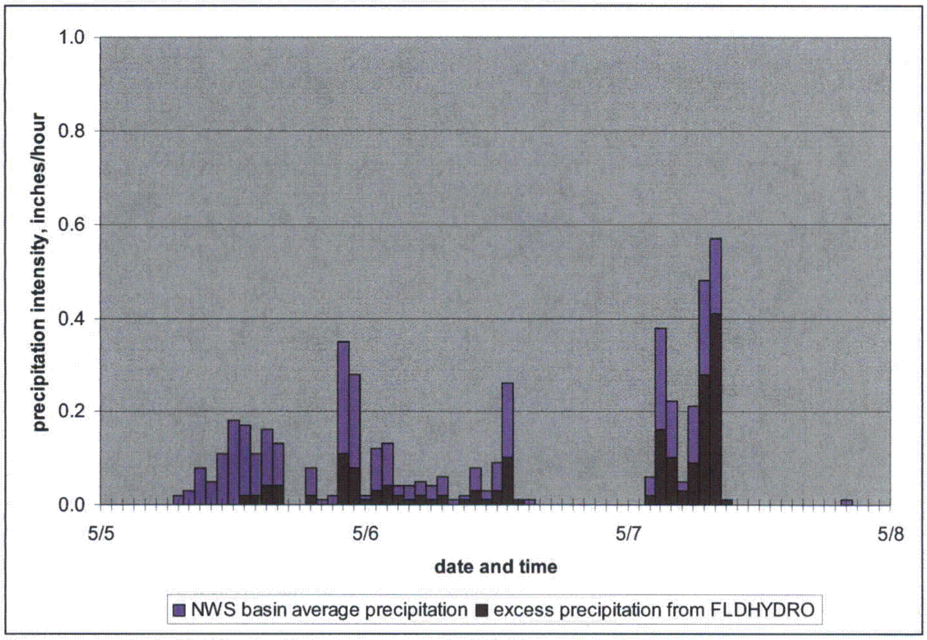

Figure 34: Chatuge Dam precipitation and excess precipitation time series for the May 2003 storm

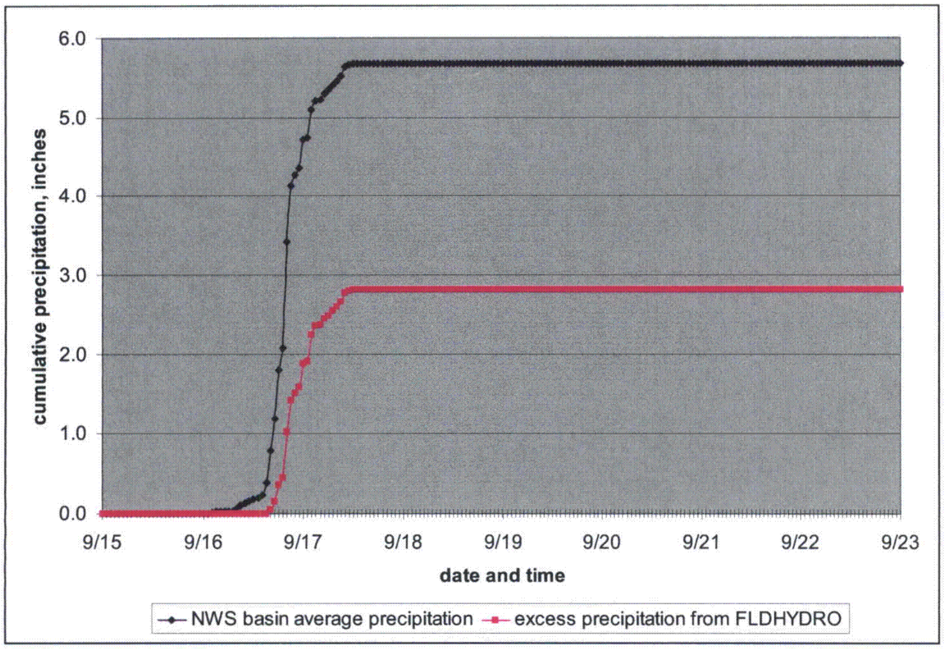

Figure 35: Chatuge Dam cumulative precipitation and excess precipitation for the Sept. 2004 storm

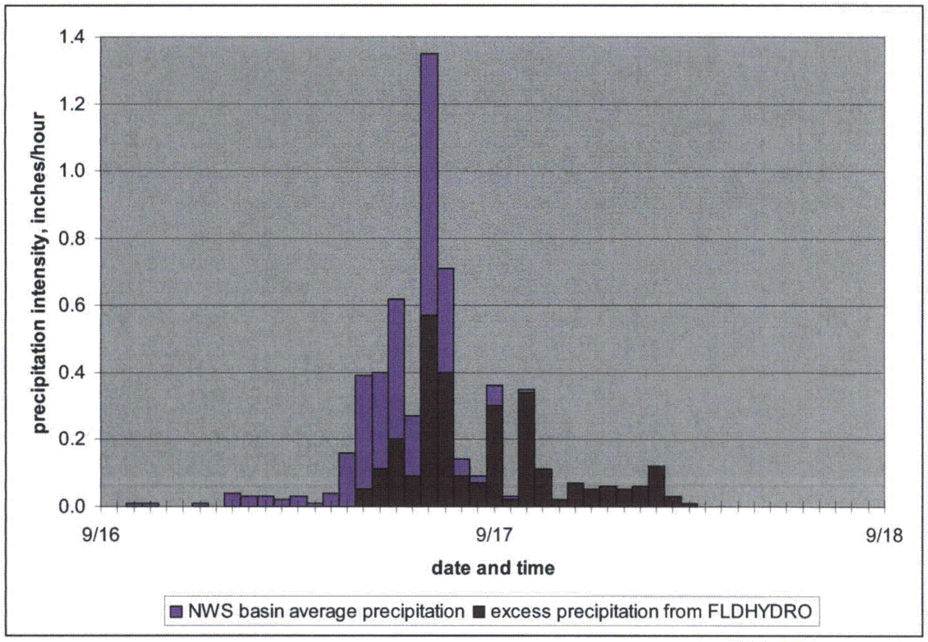

Figure 36: Chatuge Dam precipitation and excess precipitation time series for the Sept. 2004 storm

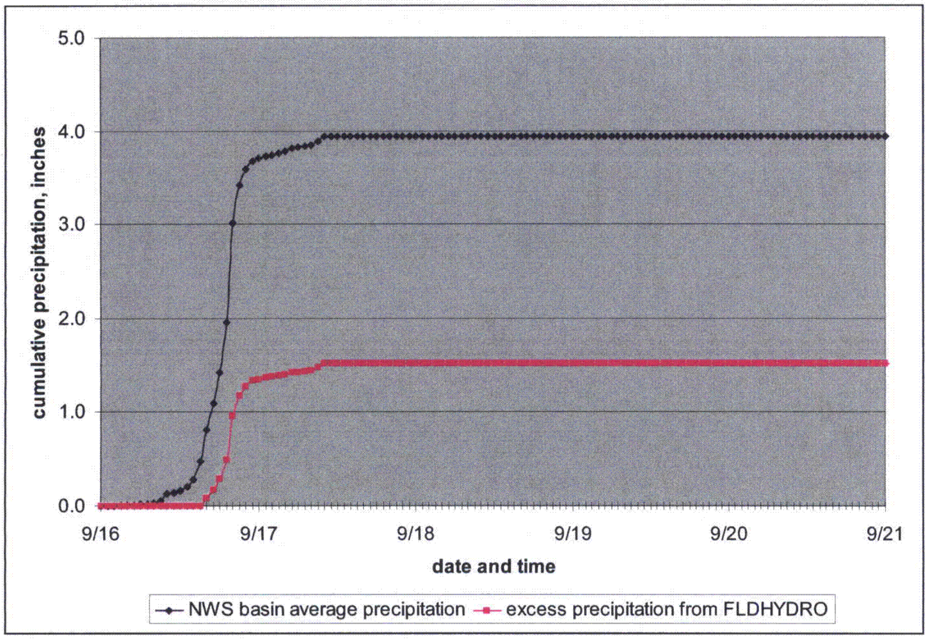

Figure 37: Nottely Dam cumulative precipitation and excess precipitation for the Sept. 2004 storm

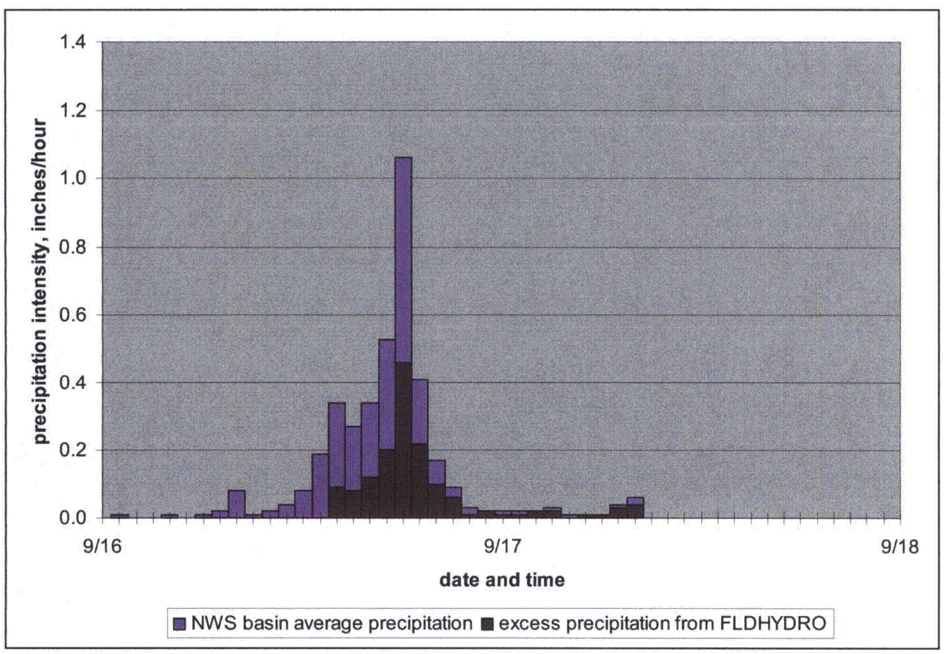

Figure 38: Nottely Dam precipitation and excess precipitation time series for the September 2004 storm

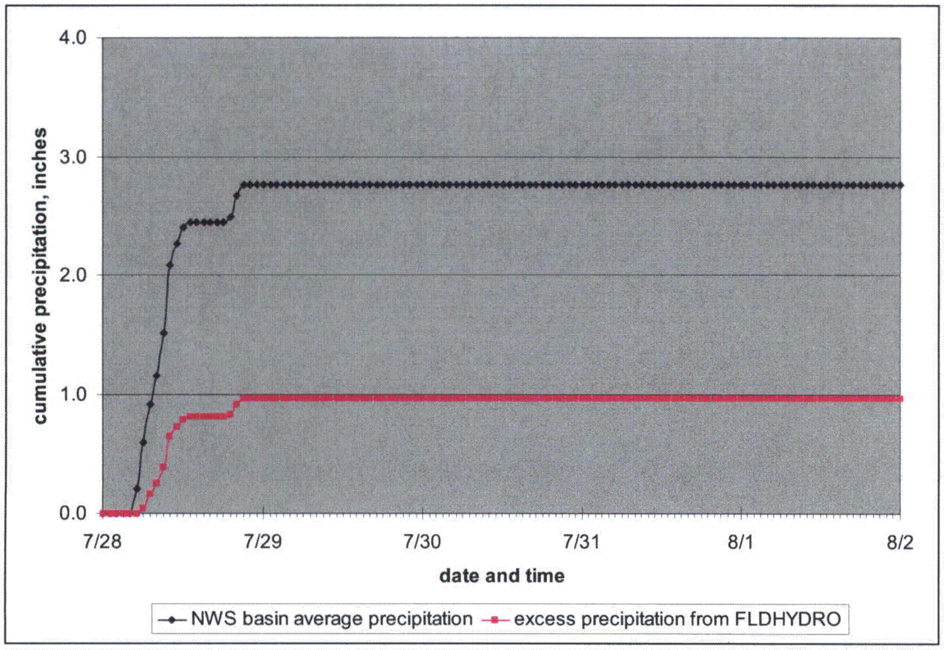

Figure 39: Nottely Dam cumulative precipitation and excess precipitation for the July 2005 storm

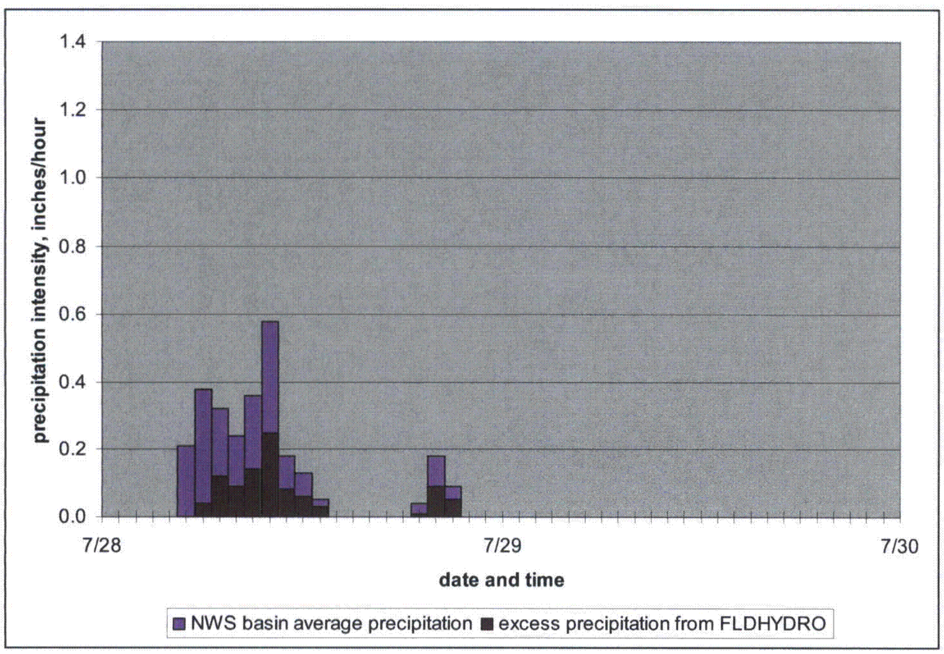

Figure 40: Nottely Dam precipitation and excess precipitation time series for the July 2005 storm

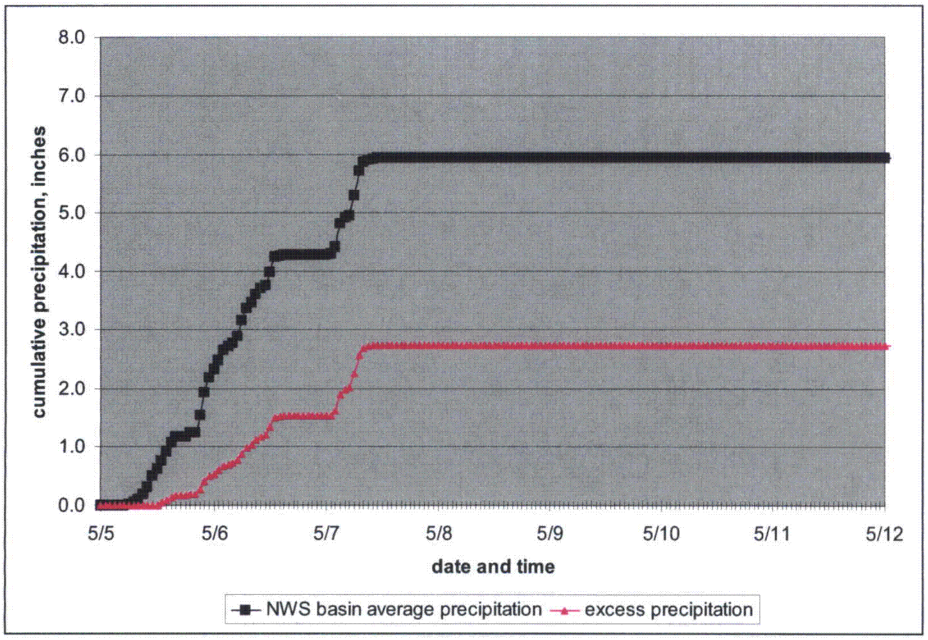

Figure 41: Hiwassee Dam cumulative precipitation and excess precipitation for the May 2003 storm

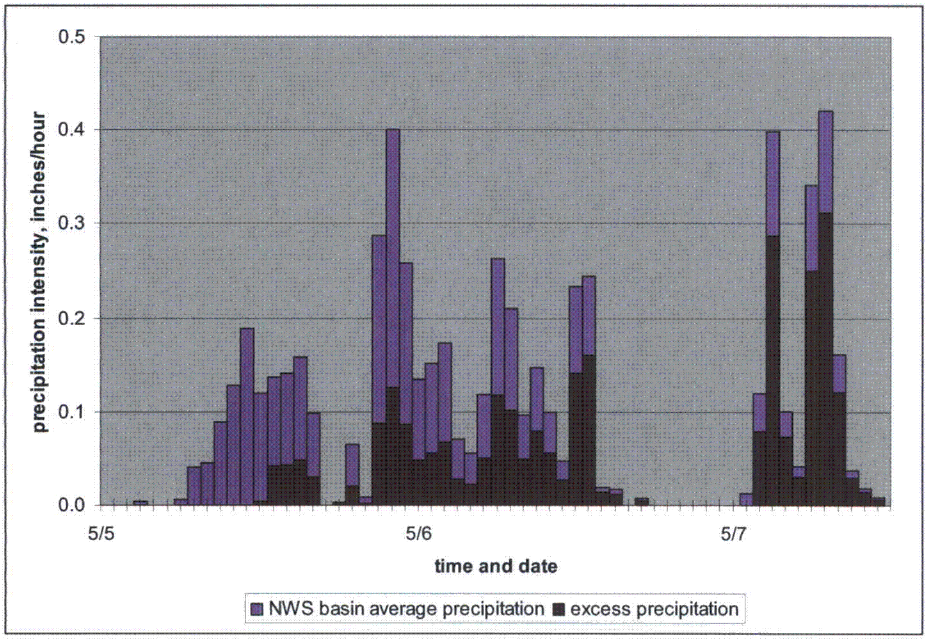

Figure 42: Hiwassee Dam precipitation and excess precipitation time series for the May 2003 storm

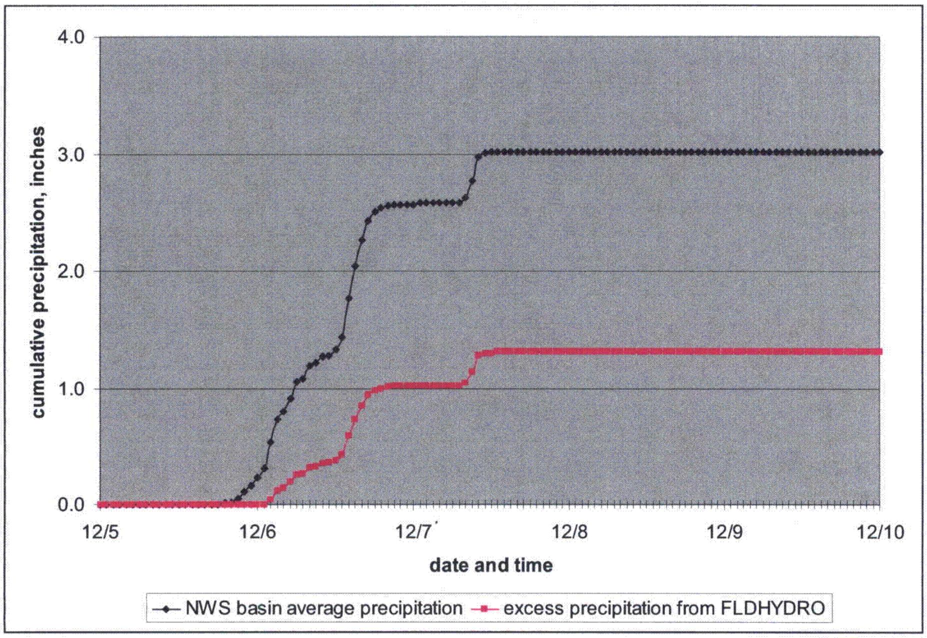

Figure 43: Hiwassee Dam cumulative precipitation and excess precipitation for the December 2004 storm

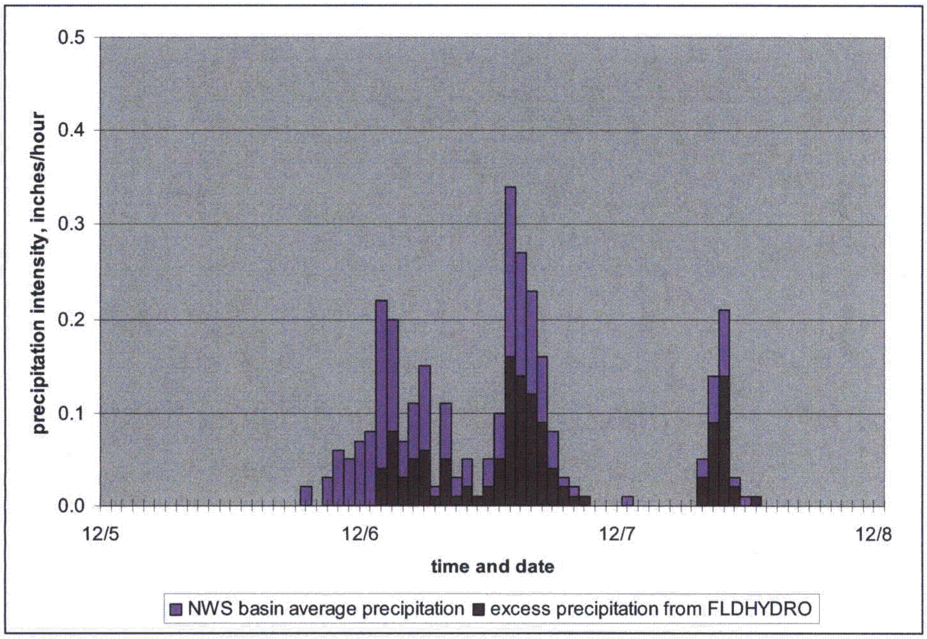

Figure 44: Hiwassee Dam precipitation and excess precipitation time series for the December 2004 storm

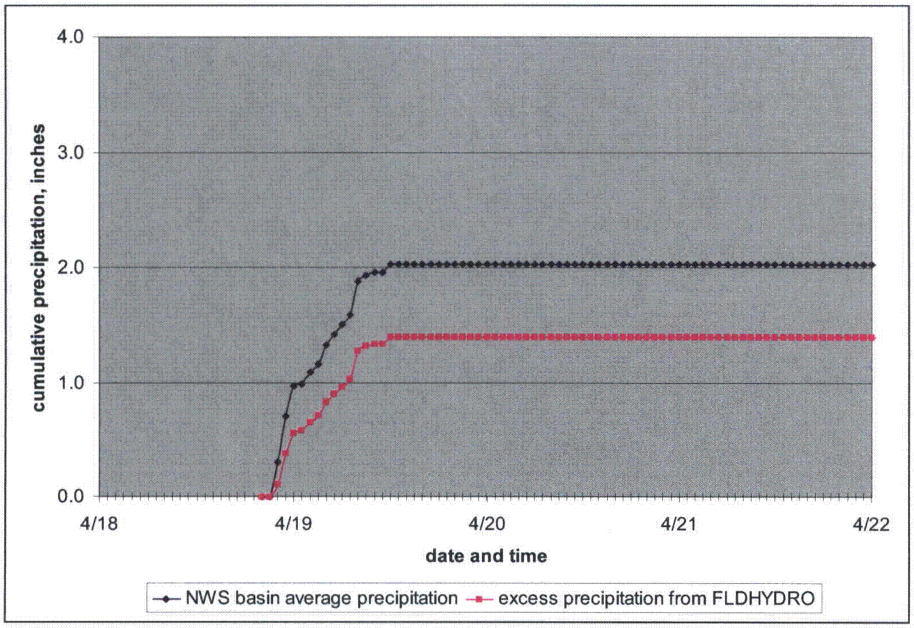

Figure 45: Apalachia Dam cumulative precipitation and excess precipitation for the April 1998 storm

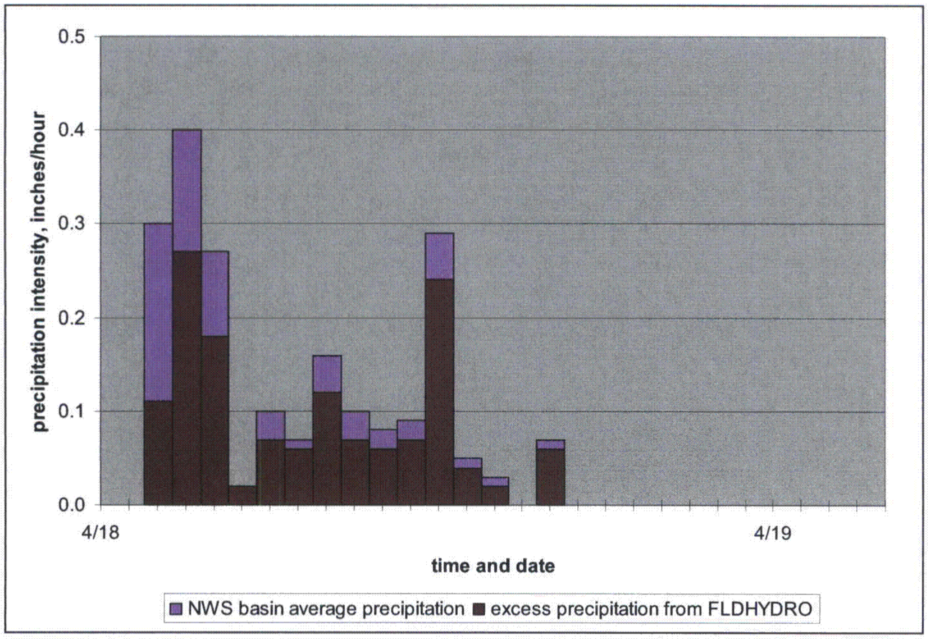

Figure 46: Apalachia Dam precipitation and excess precipitation time series for the April 1998 storm

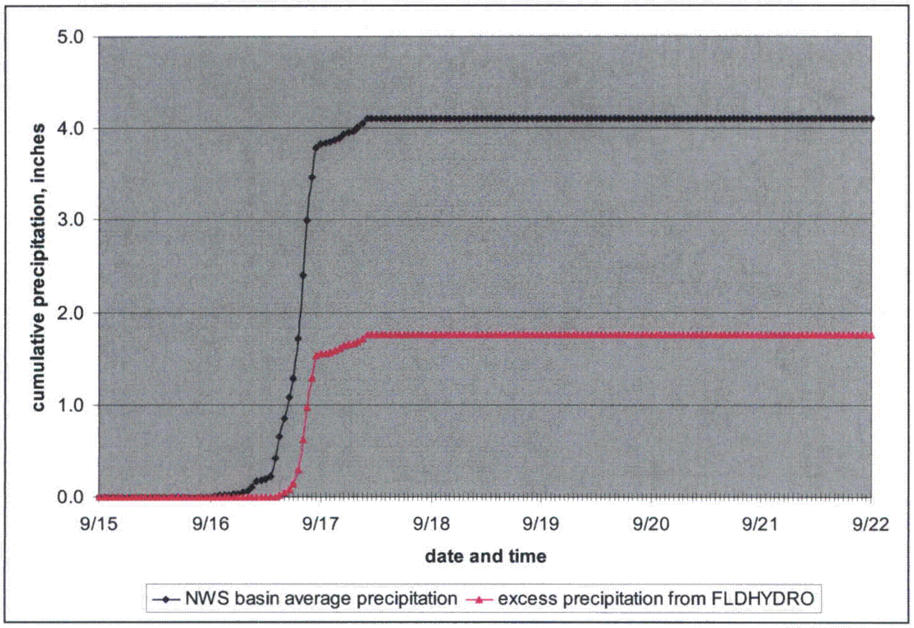

Figure 47: Ocoee No.1 Dam cumulative precipitation and excess precipitation for the September 2004 storm

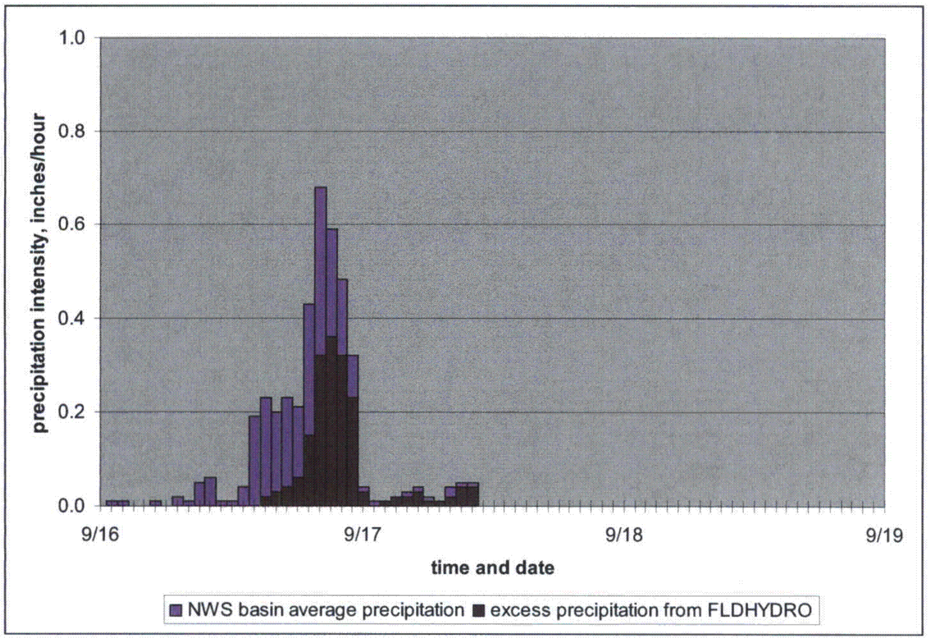

Figure 48: Ocoee No. 1 Dam precipitation and excess precipitation time series for the September 2004 storm

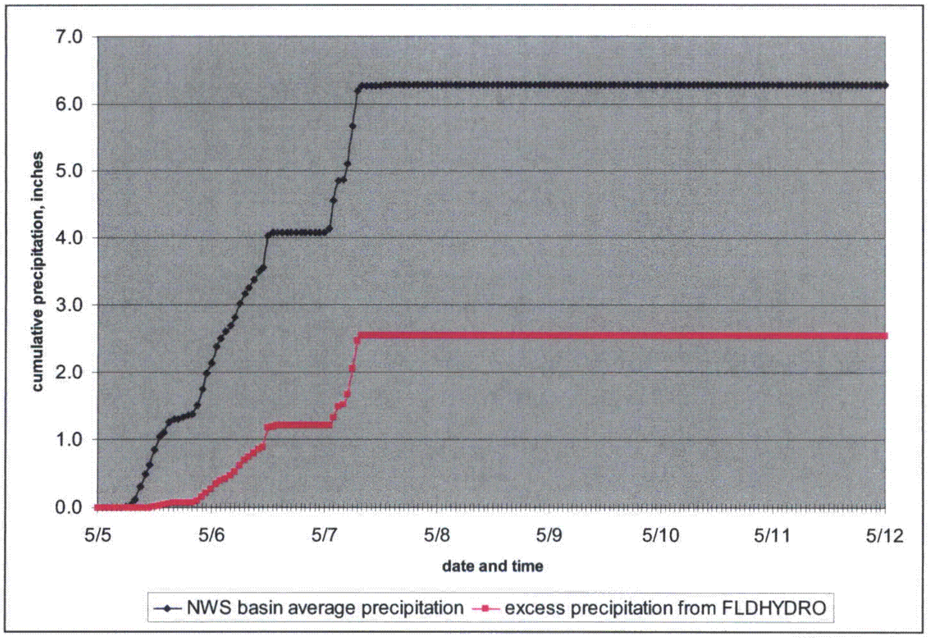

Figure 49: Ocoee No. 1 Dam cumulative precipitation and excess precipitation for the May 2003 storm

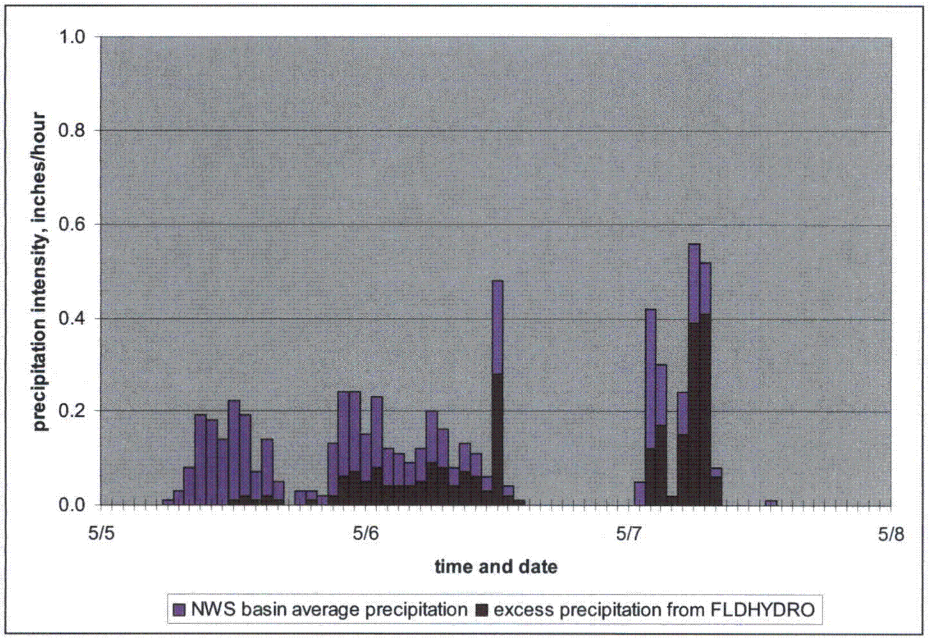

Figure 50: Ocoee No. 1 Dam precipitation and excess precipitation time series for the May 2003 storm

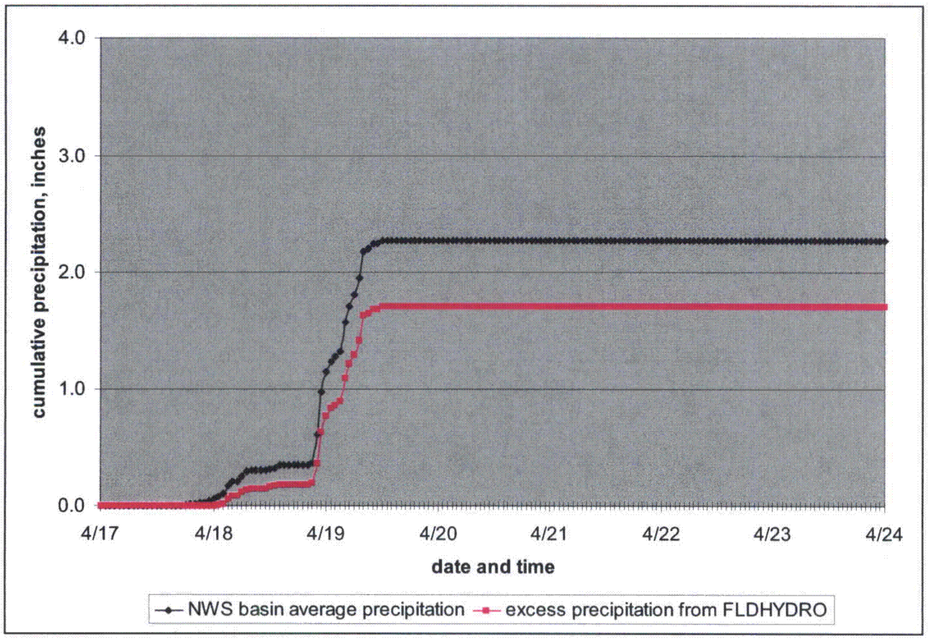

Figure 51: Ocoee No. 1 Dam cumulative precipitation and excess precipitation for the April 1998 storm

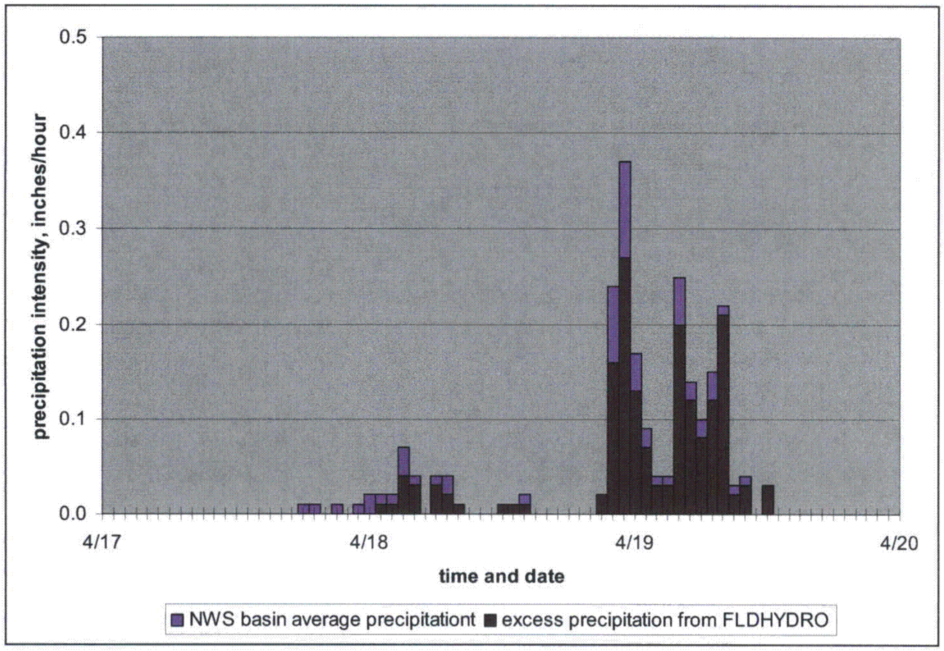

Figure 52: Ocoee No. 1 Dam precipitation and excess precipitation time series for the April 1998 storm

7.6 Unit Hydrograph Regeneration and Revision

The TVA developed unit hydrographs for Subbasins 38, 39, 40, and 43 using the computer program UNITGRPH (Reference 6). The Subbasin 41 unit hydrograph was not developed with the UNITGRPH program. The UNITGRPH program was revised in 2008. Because the unit hydrographs (UHs) for the four subbasins (38, 39, 40, and 43) were developed prior to 2008, UHs for these four subbasins were regenerated using the revised UNITGRPH program using the same UNITGRPH inputs originally used by the TVA. Initial analysis of the UHs for Subbasins 38, 39, and 41 were not adequately predicting the peak discharges in recent floods. Consequently, revised UHs for Subbasins 38, 39, and 41 were created using the revised UNITGRPH program and floods that occurred in the 1997 to 2007 period.

7.6.1 UNITGRPH Program

UNITGRPH employs the methodology proposed by Newton and Vinyard (Reference 16) for estimating a UH from complex floods using matrix algebra and statistical curve fitting techniques. In the method, the UH ordinates are determined from estimates of direct runoff and excess precipitation. The method determines the best fit unit hydrograph from a single or a series of floods. The Newton and Vinyard method (Reference 16) also provides a means to adjust, if necessary, excess precipitation, based on the excess precipitation required to generate the observed direct runoff. Implicit in the adjustment is the requirement that the estimated time series of direct runoff (e.g. streamflow with baseflow removed) be more accurate than the estimated time series of excess precipitation.

To develop a UH using the methods of Newton and Vinyard contained within the UNITGRPH program, the flood or floods of interest are identified. Baseflow is removed from the flood(s) to obtain observed direct runoff. Excess precipitation is estimated from observed rainfall for each flood. Direct runoff and excess precipitation are then determined for time intervals that match the desired UH period. These values are provided to the program along with the "list" of ordinates to be computed directly. The remaining ordinates are linearly interpolated from the "listed" ordinates. Suggestions for deriving the list values are provided in Reference 32.

The UNITGRPH program first estimates UH ordinates using matrix inversion. The first iteration UH is then used to estimate a runoff correction which is simply an estimate of the excess precipitation that would provide a better match to the observed direct runoff when convolved with the first iteration UH. In the second iteration, the program computes a new UH using the adjusted excess precipitation and the observed direct runoff. The updated UH is used to estimate a new series of adjusted runoff, and the process is repeated for the specified number of iterations or until a specified average error criterion is met. Newton and Vinyard (Reference 16) suggest that five iterations or an average error of five percent be adopted as limits.

7.6.2 S-Graph Method

A UH is derived for a specific effective duration. Often the UH is applied to rainfall data that may be better represented with a different effective duration than that used to derive the UH. A UH for any effective duration can be derived from an existing UH using the summation hydrograph, or S-graph, method (Reference 33).

In this method, a summation hydrograph is constructed from a series of unit hydrographs (all of the same effective duration) using the principle of superposition. This involves successively displacing the original UH by the effective duration and summing the ordinates of the original and displaced unit hydrographs. The S-graph represents the runoff that would result from a continuous, constant excess rainfall rate per specified period that produces a unit depth runoff volume. The UH with the desired effective duration is derived from the S-graph by offsetting the S-graph an amount equal to the desired effective duration and subtracting the offset S-graph from the original S-graph.

Derivation of a short-period hydrograph from one of longer duration does not work as well as derivation of a long-period hydrograph from one of shorter duration (Reference 33). The S-graph process involves averaging of ordinates; consequently, small errors in the ordinates of a shorter duration hydrograph are smoothed as part of the calculation. However, small errors in a longer duration unit hydrograph may lead to larger errors in the derived, shorter-period UH (Reference 33). Also, errors in the original UH may result in oscillations in the S-graph (Reference 33). These errors come about if the original UH is not the "true" UH in the sense that the watershed response may be nonlinear (Reference 33).

Derivation of a one-hour period UH from the two- to six-hour period UHs for several of the subbasins in this calculation involves derivation of a short-period UH from one of longer duration. The rainfall data used suggests that constant intensity rainfall and thus constant intensity excess precipitation can be more closely approximated by using periods shorter than the effective durations of the calculated UHs. Consequently, one-hour period UHs were derived for use with one-hour precipitation data in order to minimize potential errors associated with the constant rainfall intensity condition underlying the UH method (Section 4).

7.6.3 Regenerated Unit Hydrograph Ordinates

Unit hydrographs were regenerated for Subbasins 40 and 43 using the revised UNITGRPH program and following the methods originally used by the TVA to derive unit hydrographs for these basins. Excess precipitation and observed direct runoff inputs to the UNITGRPH program were taken from the TVA File Book (Reference 12 and Reference 14). The UNITGRPH program was run using several different sets of list values. Individual runs were analyzed by average absolute error. The unit hydrograph with a hydrologically reasonable shape and from the run with the lowest average absolute error was adopted as the regenerated unit hydrograph.

A hydrologically reasonable shape is defined here as monotonically increasing to the peak and then monotonically decreasing to zero.

7.6.3.1 Subbasin 40 Hiwassee Dam

A regenerated UH was created for Subbasin 40 using the revised UNITGRPH program and following the methodology originally used by the TVA to create the UH for this subbasin. As mentioned in Section 6.2.3, the original UH was a five flood composite. The same five floods (March 1951, January 1954, January 1957, April 1964, and May 1973) were used to create the regenerated UH. Estimated excess precipitation and observed direct runoff were obtained from Reference 12 for each flood. These data are provided at six-hour intervals; consequently, the regenerated UH has a six-hour period.

The UNITGRPH program was run with five different sets of list values. List values were derived according to suggestions provided in Reference 32 and were varied on a trial and error basis. The UH obtained from the set of list values providing the lowest total average absolute error for the main portion of the observed direct runoff (i.e. observed direct runoff values exceeding 2,000 cfs) was selected. The various UNITGRPH runs are summarized in Attachment 1- 31. The input file and output files for the adopted UNITGRPH run are enclosed as Attachment 2- 21, Attachment 2- 22, and Attachment 2- 23.

The regenerated UH for Subbasin 40 is shown in Figure 53; Table 7 provides the time base and ordinates. A one-hour period UH was derived from the six-hour UH using the S-graph method (Section 7.6.2) to facilitate convolution with one-hour (Section 7.4) excess precipitation values derived from rainfall data recorded at one-hour intervals. The HEC-HMS software was used to calculate the one-hour UH with the S-graph method; this UH is shown in Figure 53 as "HMS derived 1-hour UH." A one-hour UH was also calculated in a spreadsheet, Attachment 1- 32, as a check on the HEC-HMS calculations and is shown as "S-graph derived 1-hour UH" in Figure 53.

As mentioned in Section 7.6.2, the derivation of a shorter-period UH from a longer-period UH using the S-graph method does not work as well as derivation of a longer-period UH from a shorter-period UH. The HEC-HMS software uses the S-hydrograph method, but also applies some internal smoothing / shaping. This smoothing accounts for the variations between the calculated one-hour UH and the HMS derived one-hour UH.

Table 7: Time base and ordinates of regenerated UH for Subbasin 40

	Hour	Discharge (Q), cfs	
	0	0	
	6	15,095	
	12	23,349	
	18	5,388	
	24	2,825	
	30	2,450	
	36	2,075	
	42	1,992	
	48	1,910	
	54	1,362	
	60	813	
	66	772	
	72	731	
	78	689	
	84	669	
	90	650	
	96	0	
Total Volume (1)		30,133.9	acre-ft
Basin Area		565.1	mi^2
Runoff Depth (2)		0.9998	in

Notes:

1) $$Volume = \sum Q \frac{ft^3}{\sec} \times 3600 \frac{\sec}{hr} \times (period\ in\ hrs) \times \frac{1 acre-ft}{43560 ft^3}$$

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

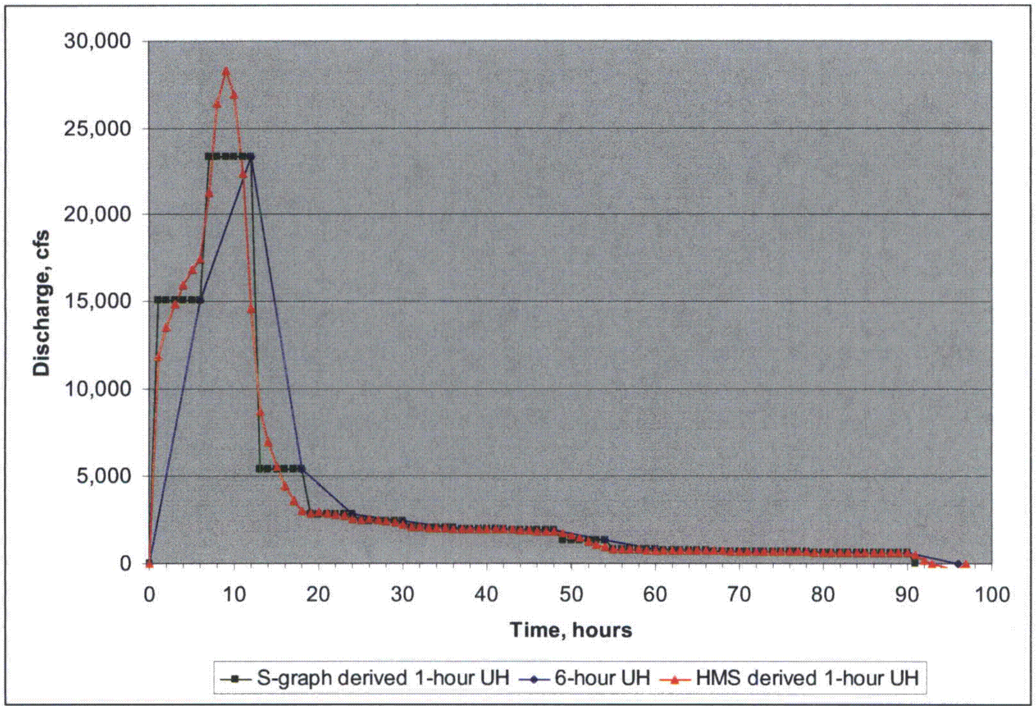

Figure 53: Regenerated six-hour UH for Subbasin 40 shown along with derived one-hour UHs

7.6.3.2 Subbasin 43 Ocoee No.1 Dam

The UNITGRPH program was also used to regenerate a UH for Subbasin 43 following the methods used by the TVA to create the UH for this subbasin in 1970. The original UH was a three flood composite, derived from floods in November 1948, March 1951, and October 1964. Estimated excess precipitation and observed direct runoff were taken from Reference 14 for each of these floods. Six-hour excess precipitation and direct runoff intervals were employed in the original UH calculations and were used in regeneration of the UH. Consequently, the regenerated UH for Subbasin 43 has a six-hour period.

The UNITGRPH program was run with three different sets of list values. The unit hydrograph for Subbasin 43 only has five nonzero ordinates, so the available combination of list values was limited. The UH obtained from the set of list values providing both the lowest total average absolute error for the main portion of the observed direct runoff (i.e. observed direct runoff values exceeding 1,500 cfs) and a monotonic increase in discharge to the peak followed by a monotonic decrease to zero was selected. The various UNITGRPH runs are summarized in Attachment 1- 33. The input file and output files for the adopted UNITGRPH run are enclosed as Attachment 2- 24, Attachment 2- 25, and Attachment 2- 26.

The regenerated UH is shown in Figure 54; Table 8 provides the time base and ordinates of the UH. The HEC-HMS software was used to calculate the one-hour UH with the S-graph method, and a one-hour UH was calculated in a spreadsheet to provide check on the HEC-HMS results (Attachment 1- 32). Differences between the HEC-HMS one-hour UH and the calculated one-hour UH are due to the smoothing algorithm used in HMS as discussed in Section 7.6.3.1.

Table 8: Time base and ordinates of regenerated UH for Subbasin 43

Hour	Discharge, cfs
0	0
6	17,517
12	14,516
18	3,407
24	2,336
30	1,266
36	0

Total Volume (1)*	19,359.7	acre-ft
Basin Area	362.6	mi^2
Runoff Depth (2)*	1.001	in

*See notes section of Table 7 for definitions

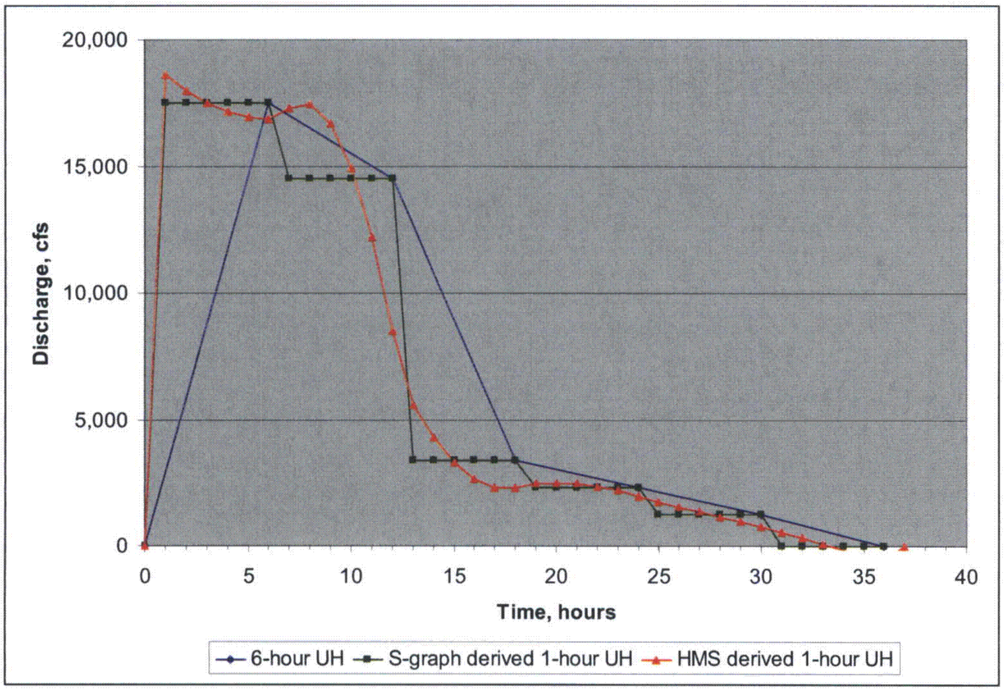

Figure 54: Regenerated UH for Subbasin 43 shown along with derived one-hour UHs

7.6.4 Revised Unit Hydrographs

Unit hydrographs for Subbasins 38, 39, and 41 were revised using the updated UNITGRPH program. The largest flood by peak discharge occurring from 1997 to 2008, with corresponding precipitation data available from the NWS, was used to calculate the revised unit hydrograph. Where possible, the revised unit hydrographs were generated from two or more floods. Additional floods, if used, were ones employed in the original unit hydrograph calculation.

The UNITGRPH program requires that the input observed direct runoff (RO) and estimated excess precipitation (EP) for each flood satisfy Equation 11 when a composite unit hydrograph is generated. The initial estimates of excess precipitation and observed direct runoff for two or more floods rarely jointly satisfy Equation 11. Consequently, UNITGRPH inputs for composite unit hydrographs were adjusted using hydrologic judgment.

$$\#of\ \ non-zero\ ordinates = \#\ of\ \ periods\ RO - (\#of\ \ periods\ EP - 1) \qquad (11)$$

The UNITGRPH program was run multiple times using different sets of list values. Two criteria were employed in analyzing the acceptability of unit hydrographs produced by the UNITGRPH program for different list sets: 1) lowest average absolute error for observed direct runoff; and 2) acceptable unit hydrograph shape which is defined here as a monotonic increase to the peak followed by a monotonic decrease to zero. The UH obtained from the UNITGRPH run which best met these two criteria was adopted as the revised UH.

7.6.4.1 Subbasin 38 Chatuge Dam

In preliminary analysis, the original UH for Subbasin 38, developed in 1983, systematically over-estimated flood peaks for the May 2003 and September 2004 floods by approximately 50%. As a result, this UH was revised using the updated version of the UNITGRPH program. The revised UH was derived using the September 2004 flood and the February 1966 flood; therefore, the revised UH is a two flood composite. The September 2004 flood was the largest flood by peak magnitude during 1997- 2007 and was larger than the three floods employed to generate the original UH. The February 1966 flood was the smallest, by peak magnitude, of the three floods used in original UH calculations.

The revised UH has a one-hour period. Derivation of one-hour excess precipitation for the September 2004 flood is presented in Section 7.5; calculation of observed direct runoff for this flood is presented in Section 7.3. One-hour excess precipitation for the February 1966 flood was extracted from Reference 10. One-hour observed direct runoff for this flood was estimated using linear interpolation between the two-hour values given in Reference 10. Direct runoff and excess precipitation values for September 2004 and February 1966 were adjusted to satisfy Eq. 11. These adjustments are enclosed in Attachment 1- 34, Attachment 1- 35, and Attachment 1- 36.

The UNITGRPH program was run with six different sets of list values. Initial list values were derived following the recommendations of Reference 32. The UH which best met the two acceptance criteria was adopted as the revised UH. The selected list set had fewer values than suggested by Reference 32, so fewer ordinates were obtained by direct solution, and relatively more ordinates were derived based on linear interpolation among direct solution ordinates. The need for additional linear interpolation, relative to suggested list sets, is likely due to oscillations in the one-hour observed discharge series which are artifacts of the reverse reservoir routing calculation. The various UNITGRPH runs used to derive the revised UH are summarized in Attachment 1- 37. The input file and output files for the adopted UNITGRPH run are enclosed as Attachment 2- 27, Attachment 2- 28, and Attachment 2- 29.

The revised UH is shown in Figure 55 along with the TVA two-hour UH, which was developed in 1983, for comparison. A two-hour period UH was derived using the S-graph method from the revised UH for comparison to the original two-hour period UH and for use with estimated excess precipitation for the October 1964 flood (Reference 10 only provides two-hour excess precipitation for this flood). As in Sections 7.6.3.1 and 7.6.3.2, S-graph calculations were completed in a spreadsheet (Attachment 1- 32) and within the HEC-HMS software. In this case, the S-graph transformation involves deriving a longer-period UH from a shorter period UH; consequently, both of the two-hour period UHs match exactly. The two-hour period UHs are also shown in Figure 55. Table 9 provides the time base and ordinates of the revised UH for Subbasin 38.

The revised UH was validated using the May 2003, May 1973, and October 1964 floods as discussed in Sections 7.7.1 and 8.1. The May 2003 flood is the second largest flood by peak magnitude during the interval from 1997 through 2007. The May 1973 and October 1964 floods were the other two floods used to create the three-flood composite UH in 1983.

Table 9: Time base and ordinates of revised UH for Subbasin 38

Revised 1-hr UH		Revised 2-hr UH	
Hour	Discharge, cfs	Hour	Discharge, cfs
0	0	0	0
1	18,360	2	18,711
2	19,062	4	11,798
3	17,135	6	5,580
4	6,460	8	4,406
5	5,873	10	3,232
6	5,286	12	2,671
7	4,699	14	2,315
8	4,112	16	1,959
9	3,525	18	1,604
10	2,938	20	1,399
11	2,760	22	1,244
12	2,582	24	1,090
13	2,404	26	960
14	2,226	28	908
15	2,048	30	856
16	1,870	32	804
17	1,692	34	752
18	1,515	36	699
19	1,437	38	0
20	1,360		
21	1,283		
22	1,205		
23	1,128		
24	1,051		
25	973		
26	947		
27	921		
28	895		
29	869		
30	843		
31	817		
32	791		
33	765		
34	738		
35	712		
36	686		
37	0		

Revised 2-hr UH:

Total Volume (1)*	10,080.0	acre-ft
Basin Area	189.1	mi^2
Runoff Depth (2)*	0.999	in

Revised 1-hr UH:

Total Volume (1)*	10,080.0	acre-ft
Runoff Depth (2)*	0.999	in

* See notes section of Table 7 for definitions

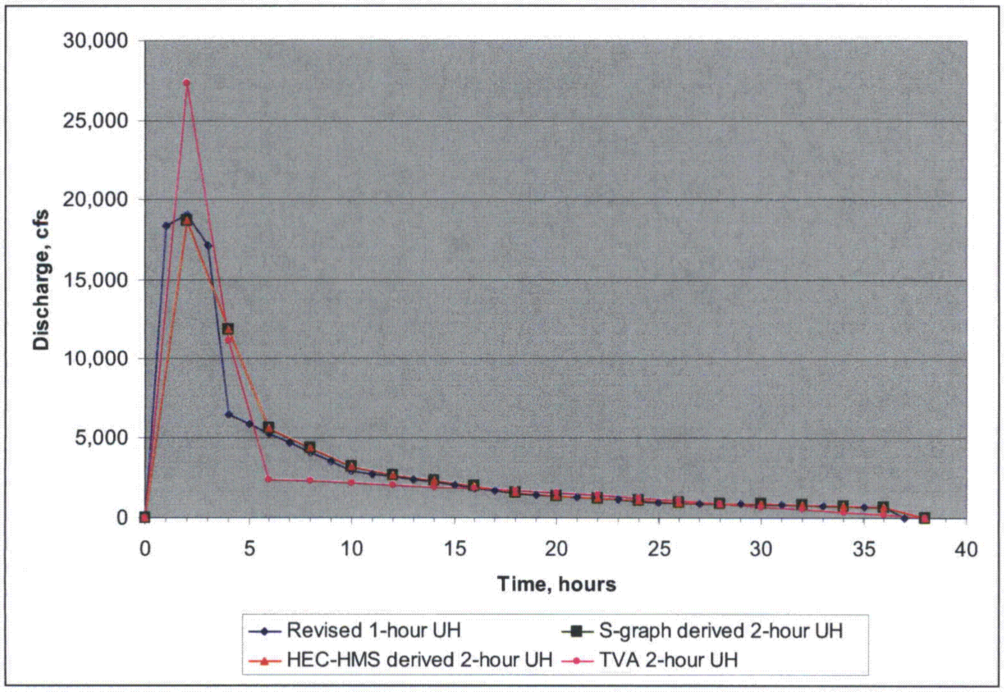

Figure 55: Revised UH for Subbasin 38 shown with two-hour UHs for comparison

7.6.4.2 Subbasin 39 Nottely Dam

In preliminary analysis, the original TVA UH for Subbasin 39 under-predicted the peak discharge for the July 2005 flood by more than 20 percent. As a result, this UH was revised using the updated version of the UNITGRPH program. The July 2005 flood had the largest peak discharge during 1997-2007.

During the initial phase of the UH revision process, problems were encountered with the October 1964 storm. Specifically, the estimated excess precipitation and observed direct runoff extracted from Reference 11 were not providing a UH, when used in the UNITGRPH program, that could reasonably reproduce the observed runoff given the estimated excess precipitation. Consequently, reservoir data, for reverse reservoir routing, and rainfall data for the October 1964, August 1967, and May 1973 floods were requested from the TVA (Reference 34).

Flood hydrographs for the August 1967 and May 1973 floods calculated from Reference 34 are similar to those obtained from Reference 11; these calculations are enclosed as Attachment 1- 38 and Attachment 1- 39. However, the October 1964 flood hydrograph and time distribution of excess precipitation calculated from the data in Reference 34 are significantly different from those provided in Reference 11; these calculations are enclosed as Attachment 1- 40.

Comparisons of series of direct runoff and excess precipitation for the October 1964 flood are provided in Figure 56 and Figure 57.

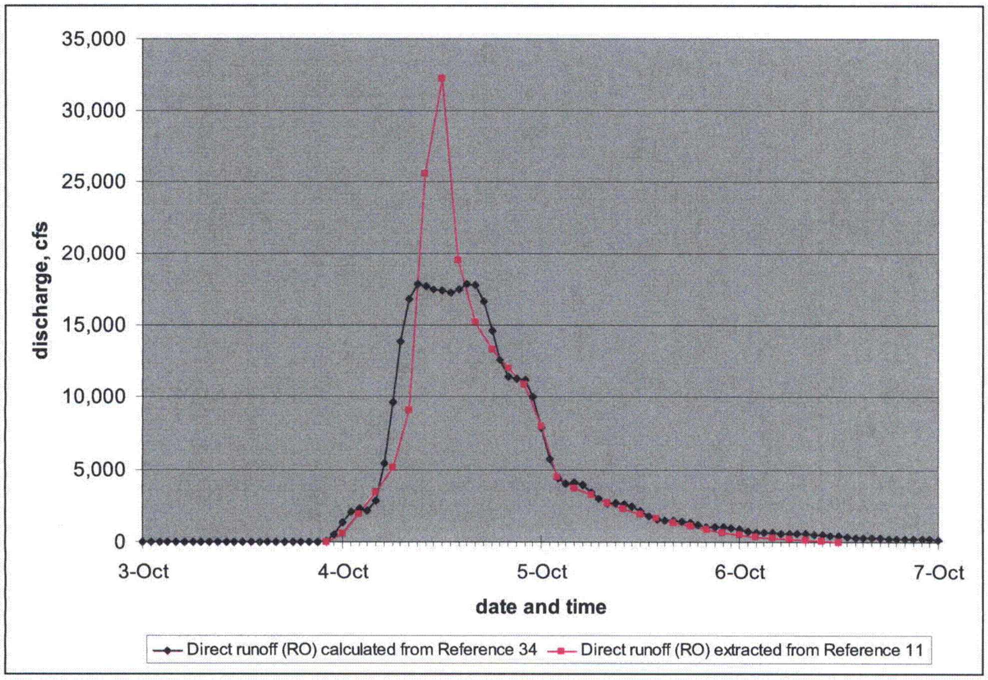

Figure 56: Comparison of direct runoff (RO) calculated from Reference 34 and that obtained from Reference 11

Headwater elevation data for Nottely Reservoir are provided at six-hour intervals in Reference 11 during the October 1964 flood with elevations at two-hour intervals interpolated. The headwater elevation data in Reference 34 agree with the corresponding elevations provided in Reference 11 for hours that are multiples of six (e.g. 6, 12, 18, 24). However, the original interpolated headwater elevation values do not agree with the published values in Reference 34. Consequently, the difference in the two series of direct runoff presented in Figure 56 results from the original estimate of the intervening two-hour headwater elevation levels versus using the published two-hour levels. The total volume of direct runoff is approximately equal to 2.6 inches for both cases (i.e. for both hydrographs shown in Figure 56).

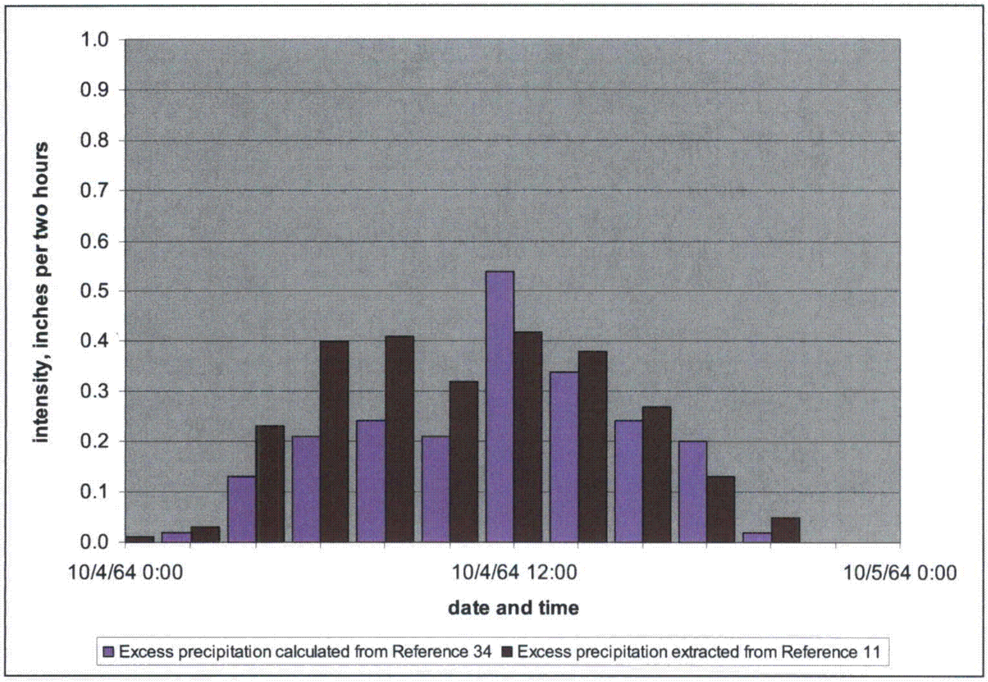

Figure 57: Comparison of excess precipitation calculated from Reference 34 and that obtained from Reference 11

The floods that could be used to revise the UH for Subbasin 39 are listed in Table 10. Two floods occurred during 1997-2007 when NWS precipitation data are available (July 2005 and September 2004). The other three floods are those used in 1983 to derive the original UH. The revised UH was calculated using the July 2005 flood and the October 1964 flood. The July 2005 flood was the largest by peak discharge magnitude between 1997 and 2007. The October 1964 flood, as derived from data in Reference 34, was the second largest flood used in 1983 to calculate the UH for Subbasin 39. The revised UH is a two flood composite.

Table 10: Comparison of floods in Subbasin 39 used for UH derivation and validation

Descriptive Name	Time Period (Central Time)	Peak Direct Runoff Discharge (cfs)
October 1964	10/3/1964 22:00 to 10/6/1964 12:00	17,839*
August 1967	08/22/1967 02:00 to 08/25/1967 12:00	19,100
July 2005	07/29/2005 05:00 to 7/31/2005 05:00	17,914
May 1973	05/27/1973 18:00 to 5/29/1973 20:00	16,639
September 2004	09/16/2004 09:00 to 9/19/2004 21:00	11,025

* Peak discharge calculated from data in Reference 34

The revised UH has a one-hour period. Derivation of one-hour excess precipitation for the July 2005 flood is presented in Section 7.5; calculation of observed direct runoff for this flood is presented in Section 7.3. Direct runoff and excess precipitation values for July 2005 and October 1964 were selected to satisfy Eq. (11). This information is enclosed in Attachment 1-41.

The UNITGRPH program was run with six different sets of list values. Initial list values were derived following the recommendations of Reference 32. The UH which best met the two acceptance criteria was adopted as the revised UH. The various UNITGRPH runs used to derive the revised UH are summarized in Attachment 1- 42. The input file and output files for the adopted UNITGRPH run are enclosed as Attachment 2- 30, Attachment 2- 31, and Attachment 2- 32.

The revised UH is shown in Figure 58 along with the original TVA two-hour UH for comparison. A two-hour period UH was derived using the S-graph method from the revised UH for comparison to the original two-hour period UH and for use with estimated excess precipitation for the August 1967 and May 1973 floods (Reference 11 only provides two-hour excess precipitation for these floods). S-graph calculations were completed in a spreadsheet (Attachment 1- 32) and within the HEC-HMS software. The two-hour period UHs are also shown in Figure 58. Table 11 provides the time base and ordinates of the revised UH for Subbasin 39.

The revised UH was validated using floods that occurred in August 1967, and May 1973 as discussed in Sections 7.7.2 and 8.2. The September 2004 flood was the second largest flood by peak discharge during 1997 through 2007; this flood is significantly smaller than the other floods used in UH revision and validation. Consequently, the August 1967 and May 1973 floods are used to validate the revised UH. The August 1967 and May 1973 were the other two floods used to calculate the original UH for Subbasin 39 in 1983. The August 1967 flood was the largest by peak discharge of the five analyzed floods.

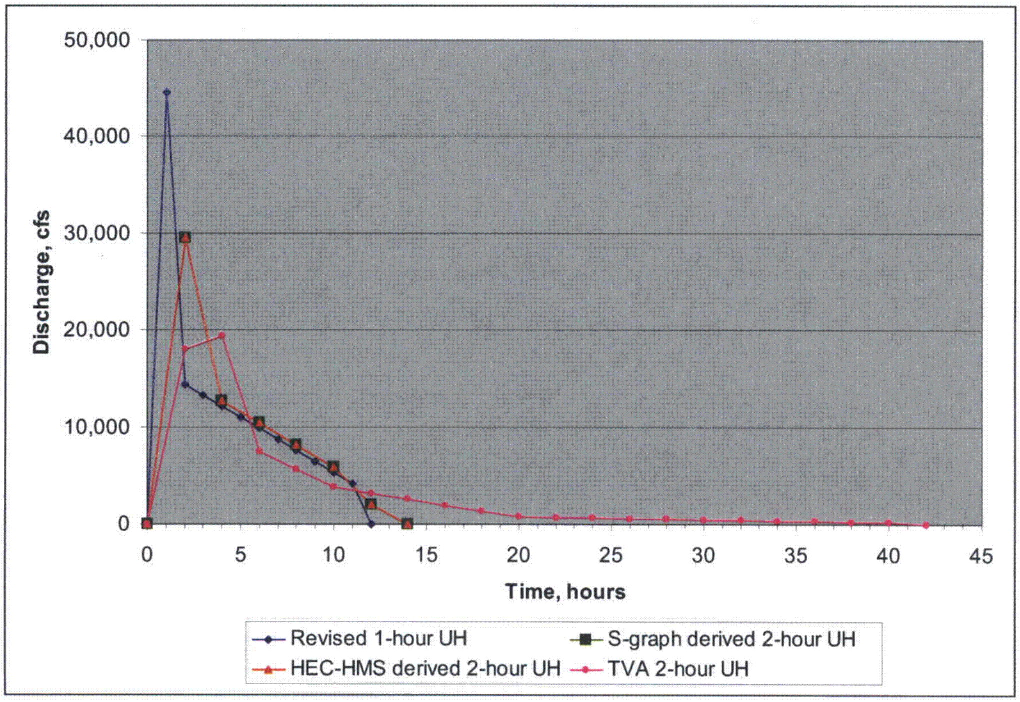

Figure 58: Revised UH for Subbasin 39 shown with two-hour UHs for comparison

Table 11: Time base and ordinates of revised UH for Subbasin 39

Revised 1-hr UH		Revised 2-hr UH	
Hour	Discharge, cfs	Hour	Discharge, cfs
0	0	0	0
1	44,477	2	29,497
2	14,517	4	12,799
3	13,372	6	10,508
4	12,226	8	8,217
5	11,081	10	5,926
6	9,935	12	2,104
7	8,790	14	0
8	7,644		
9	6,499		
10	5,353		
11	4,208		
12	0		

Total Volume (1)*	11,413.4	11,413.4	acre-ft
Basin Area	214.3	214.3	mi^2
Runoff Depth (2)*	0.999	0.999	in

* See notes section of Table 7 for definitions

7.6.4.3 Subbasin 41 Apalachia Dam

One "local" flood was identified during 1997-2007 as discussed in Section 7.2.1. In preliminary analysis, the original TVA UH for Subbasin 41 under-estimated the peak discharge of the April 1998 flood by approximately 40%. As a result, this UH was revised using the updated version of the UNITGRPH program. The revised UH was calculated from the April 1998 flood.

The revised UH has a one-hour effective duration. Derivation of one-hour excess precipitation for the April 1998 flood is presented in Section 7.5; calculation of observed direct runoff for this flood is presented in Section 7.3. These excess precipitation and direct runoff values were adjusted so that the initial interval of observed direct runoff coincided with the initial interval of excess precipitation for use in the UNITGRPH program. Enclosed Attachment 1- 43 provides the calculations supporting these adjustments, and Attachment 2- 33 and Attachment 2- 34 are the corresponding FLDHYDRO input and output files.

The UNITGRPH program was run with five different sets of list values. Initial list values were derived following the recommendations of Reference 32. The UH obtained from the UNITGRPH run which best met the two acceptance criteria was adopted as the revised UH. The various UNITGRPH runs used to derive the revised UH are summarized in Attachment 1- 44. The input file and output files for the adopted UNITGRPH run are enclosed as Attachment 2- 35, Attachment 2- 36, and Attachment 2- 37.

The revised UH is shown in Figure 60 along with the original six-hour UH for comparison. A six-hour period UH was derived using the S-graph method as implemented in the HEC-HMS software. The derived six-hour period UH was checked with a spreadsheet calculation (Attachment 1- 32). The derived six-hour period UH is used for comparison to the original six-hour period UH. The six-hour UHs are also shown in Figure 60.

For validation, the revised UH was applied to predict one other flood. Reference 13 provides no information concerning the generation of the original UH; consequently, no information is available from this source for historical floods. The hourly reservoir data for Apalachia Dam and Hiwassee Dam provided by the TVA extend from 1985 – 2007. These data were used in reverse reservoir routing to estimate local flows during 1997-2007 (Section 7.2.1, Attachment 1-3, and Attachment 1- 4).

The period 1985 – 1996 was examined in an attempt to isolate an additional "local" flood in Subbasin 41. One flood on March 27, 1994 was identified. The calculated "local" flow for this flood is shown in Figure 59; calculations are enclosed as Attachment 1- 45. Observed direct runoff for this flood was obtained via baseflow separation following the methods discussed in Section 7.3 (Attachment 1- 28). Six-hour rainfall data are available for March 1994 (Reference 35). Excess precipitation corresponding to this flood was derived using FLDHYDRO following the methods presented in Section 7.5; FLDHYDRO input and output files are attached, Attachment 2- 38 and Attachment 2- 39. Table 12 provides the time base and ordinates of the revised UH for Subbasin 41.

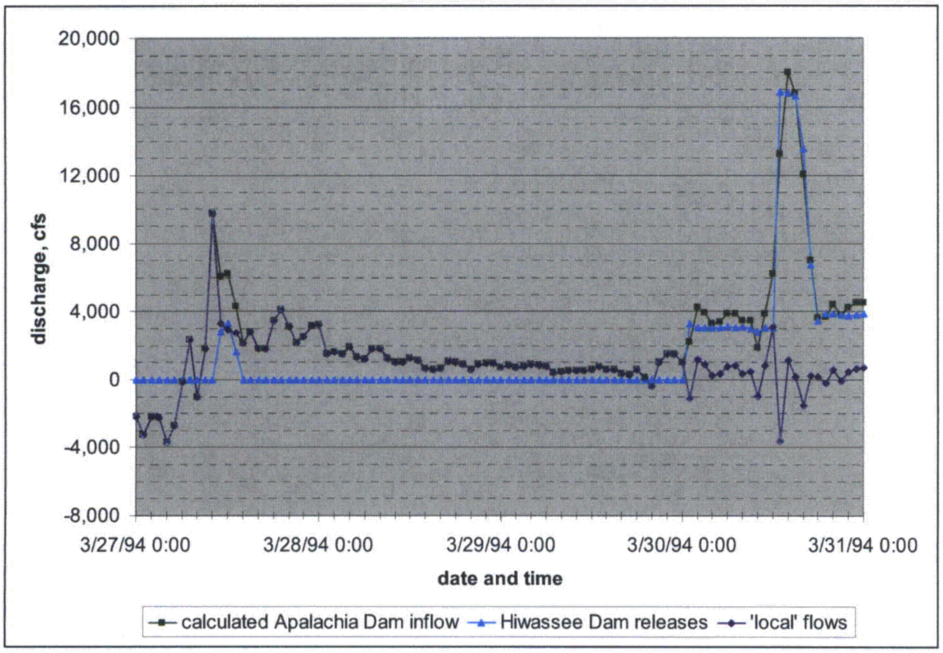

Figure 59: Apalachia Dam estimated "local" flood flow for the March 27, 1994 flood

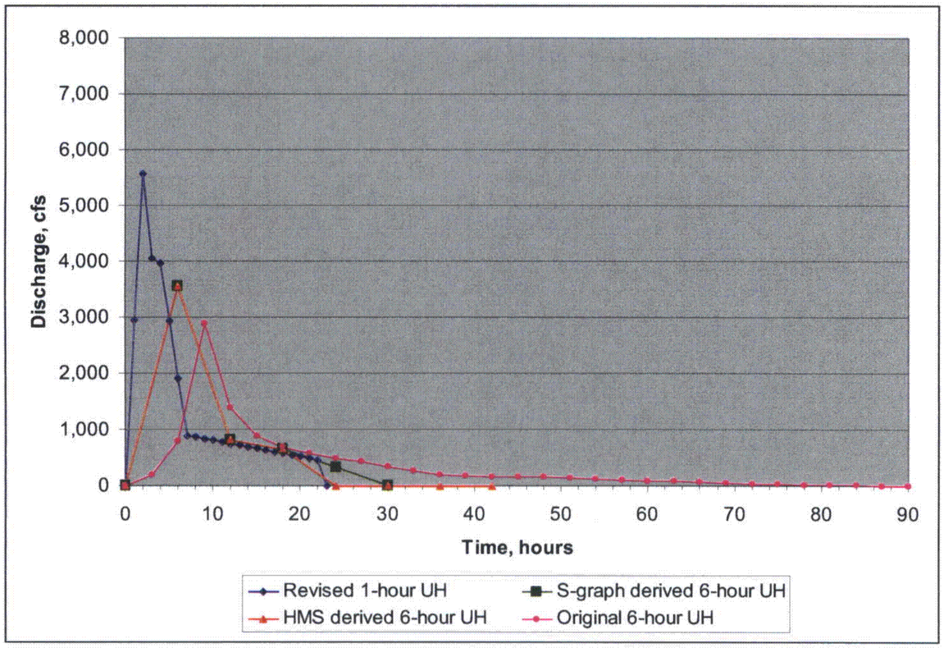

Figure 60: Revised UH for Subbasin 41 shown with six-hour UHs for comparison

Table 12: Time base and ordinates for revised UH for Subbasin 41

Revised 1-hr UH		Revised 6-hr UH	
Hour	Discharge, cfs	Hour	Discharge, cfs
0	0	0	0
1	2,952	6	3,560
2	5,563	12	829
3	4,047	18	652
4	3,949	24	337
5	2,933	30	0
6	1,918		
7	902		
8	873		
9	843		
10	814		
11	785		
12	755		
13	726		
14	696		
15	667		
16	637		
17	608		
18	579		
19	549		
20	520		
21	490		
22	461		
23	0		

Revised 6-hr UH:

Total Volume (1)*	116,161,200	cf
Basin Area	49.8	mi^2
Runoff Depth (2)*	1.004	in

Revised 1-hr UH:

Total Volume (1)*	116.161,200	cf
Basin Area	49.8	mi^2
Runoff Depth (2)*	1.004	in

* See notes section of Table 7 for definitions

7.7 HEC-HMS Simulations of Floods

HEC-HMS simulations were completed for the selected floods in each subbasin (Reference 7). The goal of each simulation was to reproduce local flood runoff by convolving the revised or regenerated unit hydrograph with estimated excess precipitation. In the simulations, excess basin average rainfall (or runoff) output from FLDHYDRO was utilized as "precipitation data" and local direct flood runoff was used as observed streamflow. The regenerated or revised unit hydrograph with a period matching the interval of the available excess precipitation data was used. When the interval of excess precipitation was different from the period of the calculated unit hydrograph, the S-graph method was used within the HEC-HMS software to obtain a unit hydrograph with a matching period (Section 7.6).

For subbasins with regenerated unit hydrographs (i.e. Subbasins 40 and 43), the unit hydrograph was validated by simulating floods selected from 1997-2008. Estimated excess precipitation for these floods is discussed in Section 7.5. The calculation of observed direct runoff is presented in Sections 7.1 and 7.3.

For subbasins with revised unit hydrographs (i.e. Subbasins 38, 39, and 41), the unit hydrograph was derived using the largest flood by peak discharge during 1997-2008. If a composite unit hydrograph was generated, then one of the floods used to derive the original unit hydrograph was also employed in the revision. Revised unit hydrographs were validated using HEC-HMS simulations of the second largest flood during 1997-2008, if the second largest flood was comparable in magnitude to those floods used to derive the original unit hydrograph. Any floods used to calculate the original unit hydrograph which were not used to derive the revised unit hydrograph were also used in validation. The flood or floods employed to generate the revised unit hydrograph were also simulated because the UNITGRPH program employs adjusted excess precipitation to generate a best fit unit hydrograph. Section 7.5 details the estimation of excess precipitation, and Sections 7.1 and 7.3 discuss the calculation of observed direct runoff for the selected floods occurring during 1997-2008. Estimated excess precipitation and direct runoff were obtained from the appropriate Filebook Reference for the floods used to derive the original unit hydrograph, with the exception of Subbasin 41 where this information is not available (Reference 13).

7.7.1 Chatuge Dam Subbasin 38

A HEC-HMS project file was developed for testing the revised UH for the Chatuge Dam subbasin. The following basin models were developed:

- Chatuge_38-1964
- Chatuge_38-1966
- Chatuge_38-1973
- Chatuge_38-2003
- Chatuge_38-2004

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 "Effect_Oct1964" with two-hour incremental depths of excess rainfall
- Precipitation Gage "Effect_Feb1966" with hourly incremental depths of excess rainfall
- Precipitation Gage "Effect_May1973" with hourly incremental depths of excess rainfall
- Precipitation Gage "Effect_May2003" with hourly incremental depths of excess rainfall
- Precipitation Gage "Effect_Sep2004" with hourly incremental depths of excess rainfall
- Discharge Gage "ObsDRO_ Oct1964" with two-hour subbasin local direct runoff discharge in cfs
- Discharge Gage "ObsDRO_ Feb1966" with hourly subbasin local direct runoff discharge in cfs
- Discharge Gage "ObsDRO_ May1973" with hourly subbasin local direct runoff discharge in cfs
- Discharge Gage "ObsDRO_May2003" with hourly subbasin local direct runoff discharge in cfs
- Discharge Gage "ObsDRO_Sep2004" with hourly subbasin local direct runoff discharge in cfs

The revised one-hour unit hydrograph for the Chatuge Dam subbasin was input to HEC-HMS with the Paired Data Manager as "TVA UH." HEC-HMS generated a two-hour UH for use with the October 1964 flood which only has two-hour estimated excess precipitation in Reference 10. HEC-HMS basin model component files are enclosed as Attachment 3- 1.

Simulated hydrographs are compared to the observed hydrographs for the May 2003, May 1973, and October 1964 floods which are used for UH validation in Figure 61, Figure 62, and Figure 63 obtained from the HEC-HMS GUI. Graphical HEC-HMS output for the September 2004 and February 1966 floods which were used to derive the revised UH are provided in the Appendix, Section 9 (Figure 75 and Figure 76), and provide confirmation of the revised UH using the estimated excess precipitation associated with these two floods. This confirmation is necessary because the UNITGRPH program used adjusted excess precipitation values to calculate the unit hydrograph for this subbasin and because the two floods used to calculate the unit hydrograph needed to be adjusted slightly to agree with Eq. (11). As a result, the performance of the revised unit hydrograph should be checked by applying it with estimated excess precipitation to predict observed direct runoff. An assessment of the results of the simulations is presented in Table 13.

Table 13: Chatuge Dam comparison of HEC-HMS results

Flood		**Revised UH Validation**			**Revised UH Confirmation**	
		May 2003	**May 1973**	**October 1964+**	**September 2004**	**February 1966**
Volume (in)	HMS	1.78	1.52	2.15	2.82	1.59
	Observed RO	1.77	1.56	2.16	2.84	1.58
	Residual	0.001	-0.04	-0.01	-0.02	0.01
	% Error*	0.5	-2.6	-0.5	-0.7	0.6
Peak Discharge (cfs)	HMS	16,646	16,232	15,171	21,954	13,121
	Observed RO	13,088	16,187	15,578	19,757	13,890
	Residual	3,558.2	45.3	-407.5	2,196.8	-768.9
	% Error*	27.2	0.3	-2.6	11.1	-5.5
Time of Peak (hrs)	HMS	5/7/03 8:00	5/27/73 22:00	10/4/64 12:00	9/16/04 21:00	2/13/66 8:00
	Observed RO	5/7/03 7:00	5/28/73 2:00	10/4/64 12:00	9/16/04 21:00	2/13/66 8:00
	Residual (hrs)	1.00	-4.00	0.00	0.00	0.00
	% Error**	-1.1	50.0	0.0	0.0	0.0

* % Error is the Residual divided by Observed RO value as a percentage.

** % Error is the observed time to peak less the simulated time to peak divided by the observed time to peak. The time to peak is measured from the onset of excess precipitation.

\+ October 1964 only has 2-hr excess precipitation data so 2-hr UH used that was obtained via S-graph transform.

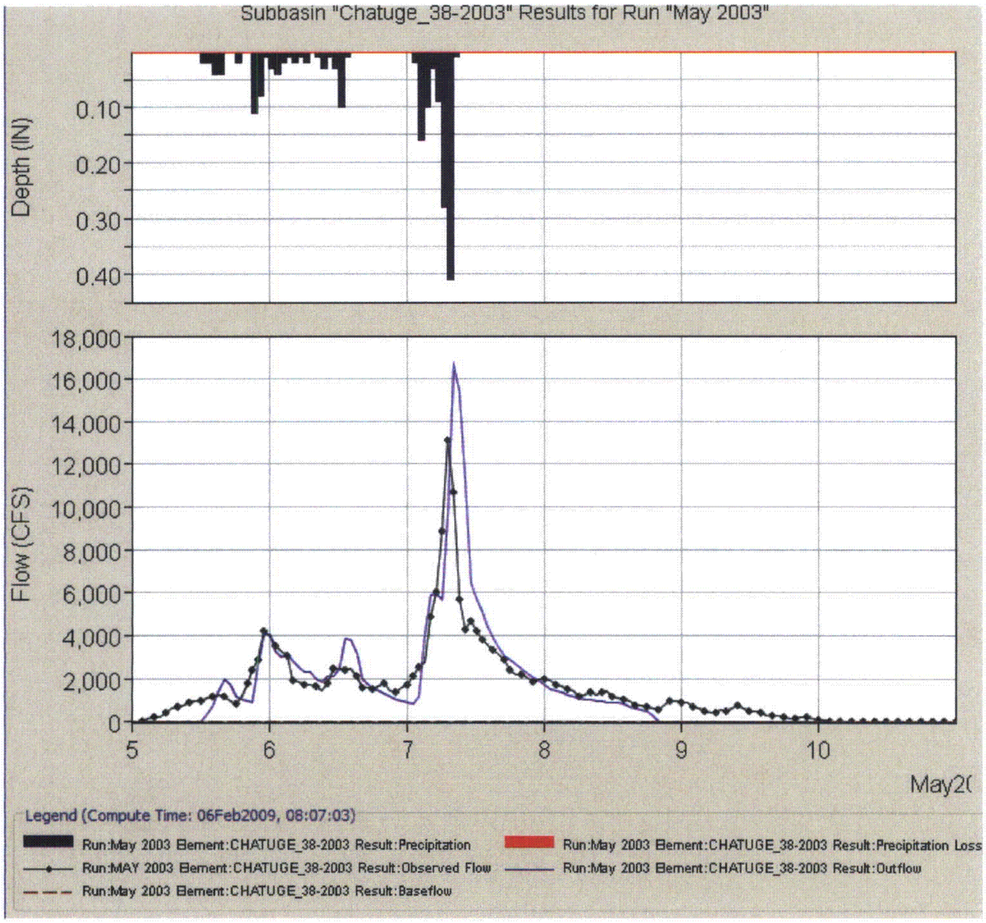

Figure 61: Chatuge Dam HEC-HMS output for May 2003 flood

From the May 2003 simulation:

1. The simulated peak discharge occurred one hour after the observed peak.
2. The magnitude of the peak was 27 percent higher in the simulation than in the observed hydrograph.

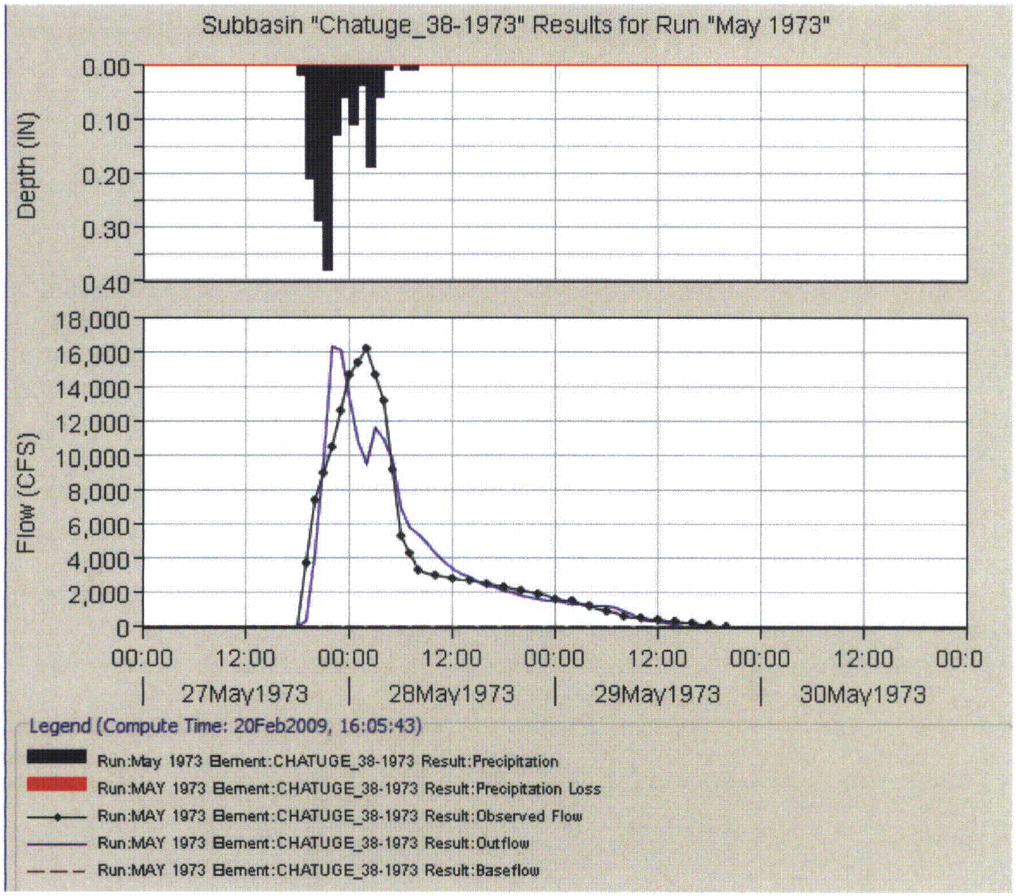

Figure 62: Chatuge Dam HEC-HMS output for May 1973 flood

From the May 1973 simulation:

1. The simulated peak discharge occurred four hours prior to the observed peak discharge.
2. The magnitude of the simulated peak was approximately equal to the observed peak.

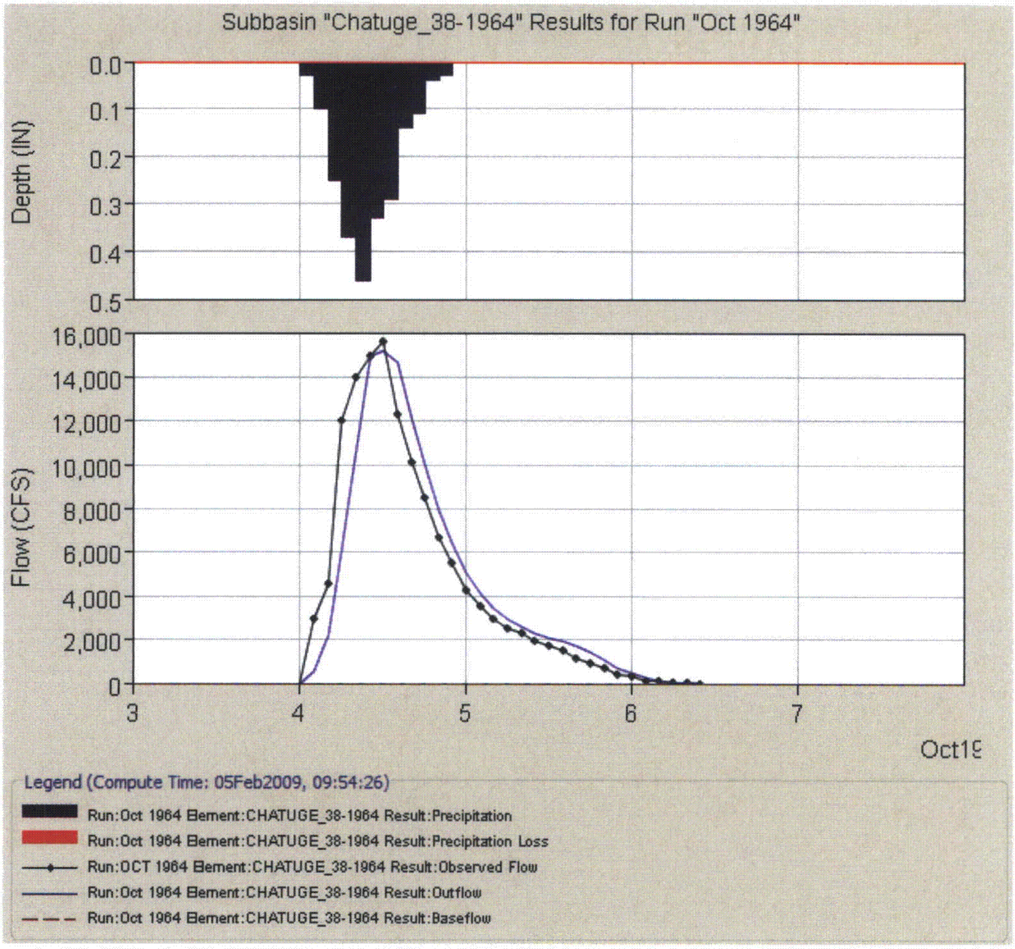

Figure 63: Chatuge Dam HEC-HMS output for October 1964 flood

From the October 1964 simulation:

1. The simulated and observed peak discharge occurred simultaneously.
2. The magnitude of the simulated peak was three percent lower than the observed peak.

7.7.2 Nottely Dam, Subbasin 39

A HEC-HMS project file was developed for testing the revised UH for the Nottely Dam subbasin. The following basin models were developed:

- Nottely_39-1964
- Nottely_39-1967
- Nottely_39-1973
- Nottely_39-2005

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 "Effect_Aug1967" with two-hour incremental depths of excess rainfall
- Precipitation Gage "Effect_Oct1964" with hourly incremental depths of excess rainfall
- Precipitation Gage "Effect_May1973" with two-hour incremental depths of excess rainfall
- Precipitation Gage "Effect_Jul2005" with hourly incremental depths of excess rainfall
- Discharge Gage "ObsDRO_ Aug1967" with two-hour subbasin local direct runoff discharge in cfs
- Discharge Gage "ObsDRO_ Oct1964" with hourly subbasin local direct runoff discharge in cfs
- Discharge Gage "ObsDRO_ May1973" with two-hour subbasin local direct runoff discharge in cfs
- Discharge Gage "ObsDRO_Jul2005" with hourly subbasin local direct runoff discharge in cfs

The revised one-hour unit hydrograph for the Nottely Dam subbasin was input to HEC-HMS with the Paired Data Manager as "TVA UH." HEC-HMS generated a two-hour UH for use with the August 1967 and May 1973 floods which only have two-hour estimated excess precipitation in Reference 11. HEC-HMS basin model component files are enclosed as Attachment 3- 2.

Simulated hydrographs are compared to the observed hydrographs for the August 1967 and May 1973 floods used for UH validation in Figure 64 and Figure 65. Graphical HEC-HMS output for the July 2005 and October 1964 floods, which were used to derive the revised UH, are provided in the Appendix, Section 9 (Figure 77 and Figure 78), and provide confirmation of the revised UH using the estimated excess precipitation associated with these two floods. The October 1964 flood comparison in Figure 78 and Table 14 employs data from Reference 34. An assessment of the results of the simulations is presented in Table 14. HEC-HMS output for the October 1964 flood is also compared with the direct runoff obtained from Reference 11 in Figure 79 in the Appendix, Section 9.

Table 14: Nottely Dam comparison of HEC-HMS results

Event		Revised UH Validation		Revised UH Confirmation	
		August 1967+	May 1973+	July 2005	October 1964***
Volume (in)	HMS	2.53	1.68	0.96	2.62
	Observed RO	2.53	1.79	0.96	2.61
	Residual	0.00	-0.11	0.00	0.01
	% Error*	0.0	-6.1	0.0	0.4
Peak Discharge (cfs)	HMS	24,123	24,188	16,265	24,033
	Observed RO	19,100	17,251	18,036	17,839
	Residual	5,022.8	6,936.5	-1,770.5	6,193.9
	% Error*	26.3	40.2	-9.8	34.7
Time of Peak (hrs)	HMS	8/23/67 12:00	5/27/73 20:00	7/29/05 10:00	10/4/64 15:00
	Observed RO	8/23/67 12:00	5/27/73 22:00	7/29/05 10:00	10/4/64 15:00
	Residual (hrs)	0.00	-2.00	0.00	0.00
	% Error**	0.0	50.0	0.0	0.0

* % Error is the Residual divided by Observed RO value as a percentage.

** % Error is the observed time to peak less the simulated time to peak divided by the observed time to peak. The time to peak is measured from the onset of excess precipitation in the FLDHYDRO output.

*** October 1964 simulation is compared to Observed Runoff (RO) calculated from the data provided in Reference 34

+ August 1967 and May 1973 only have 2-hr excess precipitation data so 2-hr UH used that was obtained via S-graph transform.

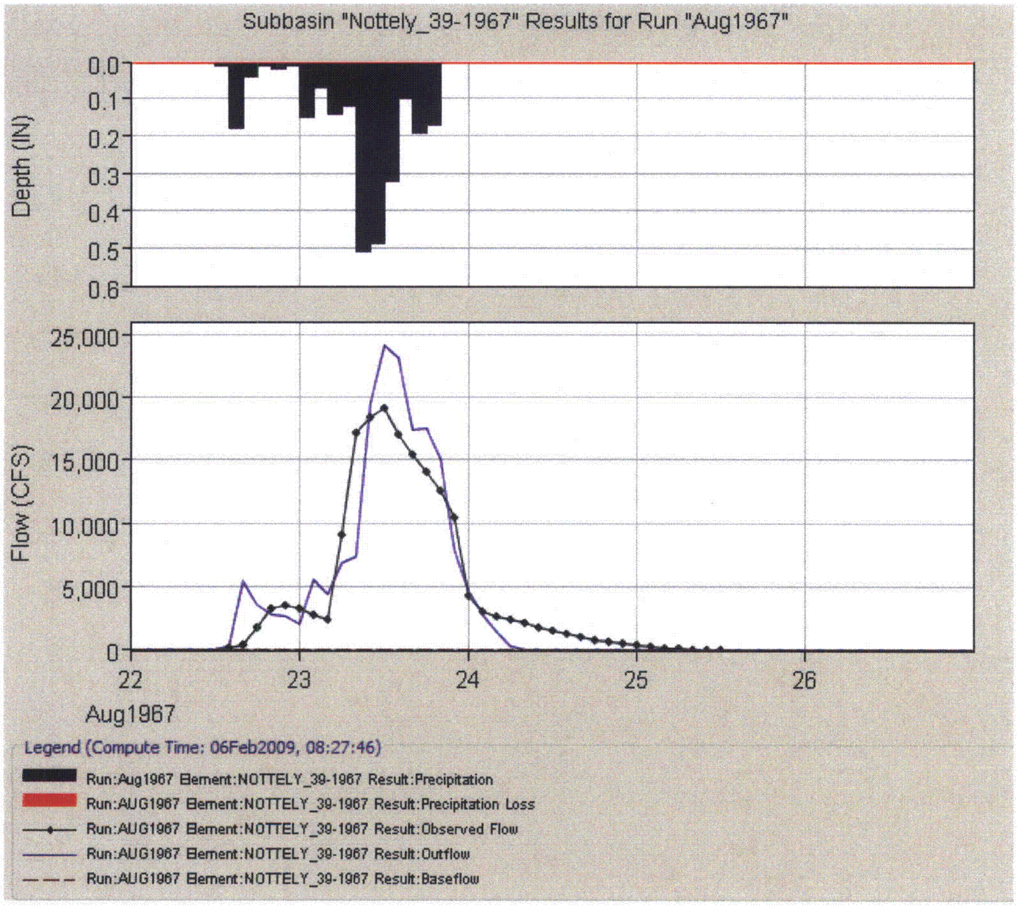

Figure 64: Nottely Dam HEC-HMS output for August 1967 flood

From the August 1967 simulation:

1. The simulated peak discharge occurred simultaneously with the observed peak.
2. The magnitude of the simulated peak was 26 percent higher than the observed peak.

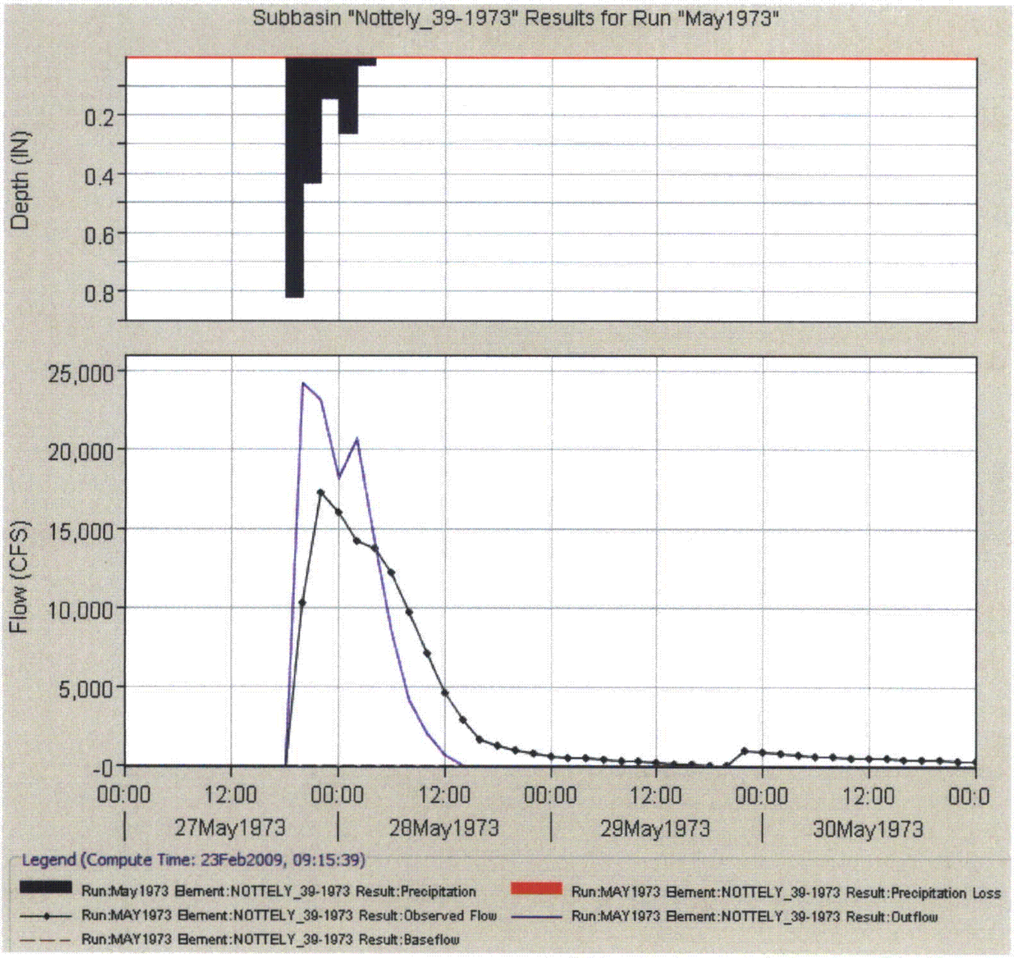

Figure 65: Nottely Dam HEC-HMS output for May 1973 flood

From the May1973 simulation:

1. The simulated peak discharge occurred two hours prior to the observed peak.
2. The magnitude of the simulated peak was 40 percent higher than the observed peak.

7.7.3 Hiwassee Dam, Subbasin 40

A HEC-HMS project file was developed for testing the unit hydrograph developed for Hiwassee Dam. This project is enclosed as Attachment 3- 3. The following basin models were developed in this project file:

- Hiwassee_40-2003
- Hiwassee_40-2004

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 "Effect_May2003" with hourly incremental depths of excess precipitation
- Precipitation Gage "Effect_Dec2004" with hourly incremental depths of excess precipitation
- Discharge Gage "RRR_Local_May2003" with hourly subbasin local direct runoff discharge in cfs
- Discharge Gage "RRR_Local_Dec2004" with hourly subbasin local direct runoff discharge in cfs

The regenerated six-hour unit hydrograph for the Hiwassee Dam subbasin was input to HEC-HMS with the Paired Data Manager as "TVA UH." HEC-HMS generated a one-hour UH for use with the May 2003 and December 2004 floods. The simulated hydrographs for the May 2003 and December 2004 floods are compared to the observed hydrographs in Figure 66 and Figure 67. An assessment of the results of the simulations is presented in Table 15.

Table 15: Hiwassee Dam comparison of HEC-HMS results

Flood		1-hr UH	
		May 2003	**December 2004**
Volume (in)	HMS	2.73	1.31
	Observed RO	2.85	1.29
	Residual	-0.12	0.02
	% Error*	-4.2	1.6
Peak Discharge (cfs)	HMS	29,914	17,436
	Observed RO	25,556	18,408
	Residual	4,358.0	-972.3
	% Error*	17.1	-5.3
Time of Peak (hrs)	HMS	5/7/03 13:00	12/6/04 23:00
	Observed RO	5/7/03 10:00	12/6/04 21:00
	Residual (hrs)	3.00	2.00
	% Error**	-6.4	-10.0

* % Error is the Residual divided by Observed RO value as a percentage.

** % Error is the observed time to peak less the simulated time to peak divided by the observed time to peak. The time to peak is measured from the onset of excess precipitation in the FLDHYDRO output.

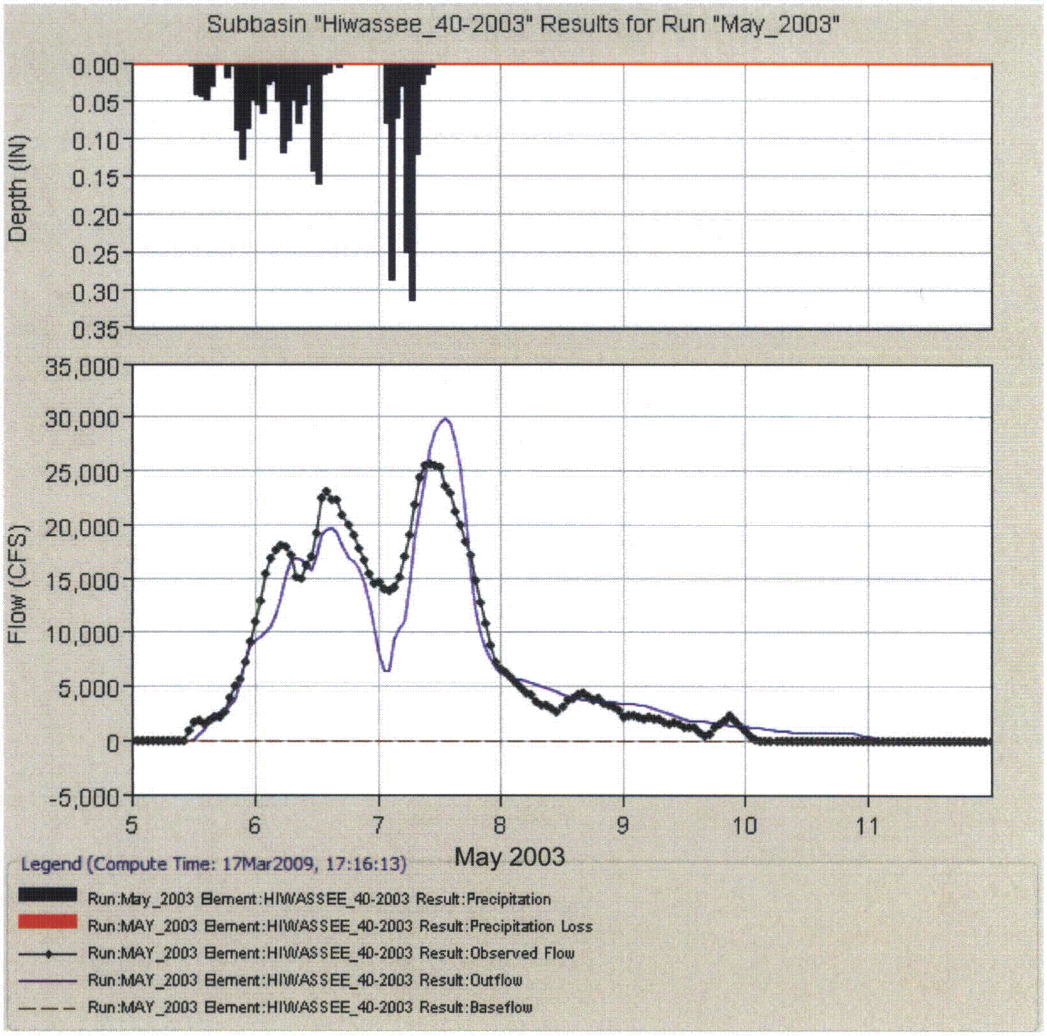

Figure 66: Hiwassee Dam HEC-HMS output for May 2003 storm

From the May 2003 simulation:

1. The simulated peak discharge occurred three hours after the observed peak discharge.
2. The magnitude of the simulated peak was 17 percent higher than the observed peak.

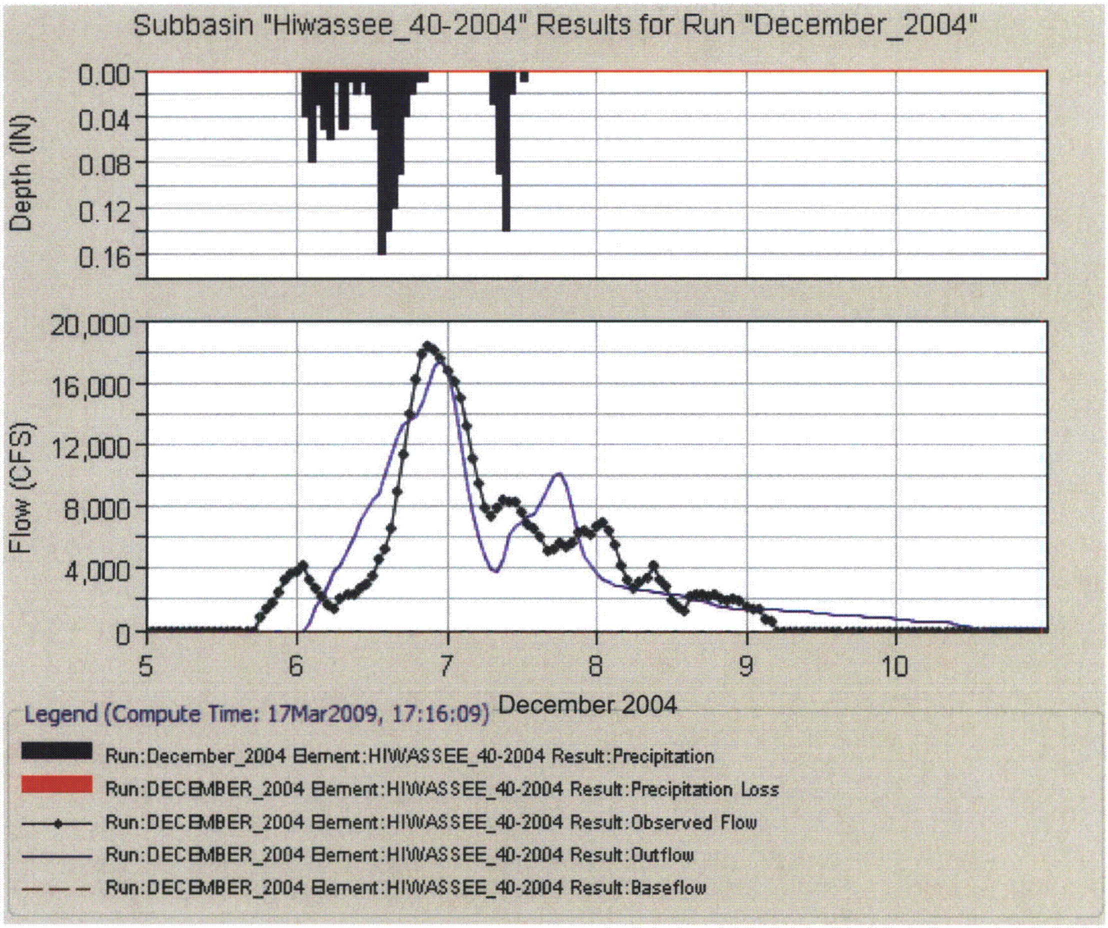

Figure 67: Hiwassee Dam HEC-HMS output for December 2004 storm

From the December 2004 simulation:

1. The simulated peak discharge occurred two hours after the observed peak discharge.
2. The magnitude of the simulated peak was 5 percent lower than the observed peak.

7.7.4 Apalachia Dam Subbasin 41

A HEC-HMS project file was developed for testing the Apalachia Dam revised unit hydrograph. The following basin models were developed:

- Apalachia-41_1994
- Apalachia-41_1998

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 "Effect_Apr1998" with hourly incremental depths of excess rainfall
- Precipitation Gage "Effect_Mar1994-1hr" with-hourly incremental depths of excess rainfall
- Discharge Gage "ObsDRO_ Apr1998" with hourly subbasin local direct runoff discharge in cfs
- Discharge Gage "ObsDRO_ Mar1994" with hourly subbasin local direct runoff discharge in cfs

The revised unit hydrograph for the Apalachia Dam subbasin was input to HEC-HMS with the Paired Data Manager as "TVAUH." HEC-HMS basin model component files are enclosed as Attachment 3- 4.

Simulated hydrograph is compared to the observed hydrograph for the March 1994 flood in Figure 68 using the one-hour unit hydrograph and one-hour excess precipitation. One-hour excess precipitation values were extracted from hourly FLDHYDRO output obtained using one-hour intervals of input rainfall which were calculated as 1/6 of the corresponding six-hour rainfall data. Calculations providing the conversion from one-hour to six-hour excess precipitation intervals are enclosed as Attachment 1- 46. Graphical HEC-HMS output for the April 1998 flood which was used to derive the revised UH is also provided in the Appendix, Section 9 (Figure 81). The results for the April 1998 flood provide confirmation of the revised UH using the estimated excess precipitation associated with this flood. An assessment of the results of the simulations is presented in Table 16.

Table 16: Apalachia Dam comparison of HEC-HMS results

Flood		Validation March 1994	Confirmation April 1998
Volume (in)	HMS	2.27	1.30
	Observed RO	2.24	1.29
	Residual	0.03	0.01
	% Error*	1.3	0.8
Peak Discharge (cfs)	HMS	5,158	2,792
	Observed RO	5,217	3,209
	Residual	-59.1	-416.3
	% Error*	1.1	-13.0
Time of Peak (hrs)	HMS	3/27/94 13:00	4/19/98 9:00
	Observed RO	3/27/94 11:00	4/19/98 9:00
	Residual (hrs)	2.00	0.00
	% Error**	-28.6	0.0

* % Error is the Residual divided by Observed RO value as a percentage.

** % Error is the observed time to peak less the simulated time to peak divided by the observed time to peak. The time to peak is measured from the onset of excess precipitation in the FLDHYDRO output.

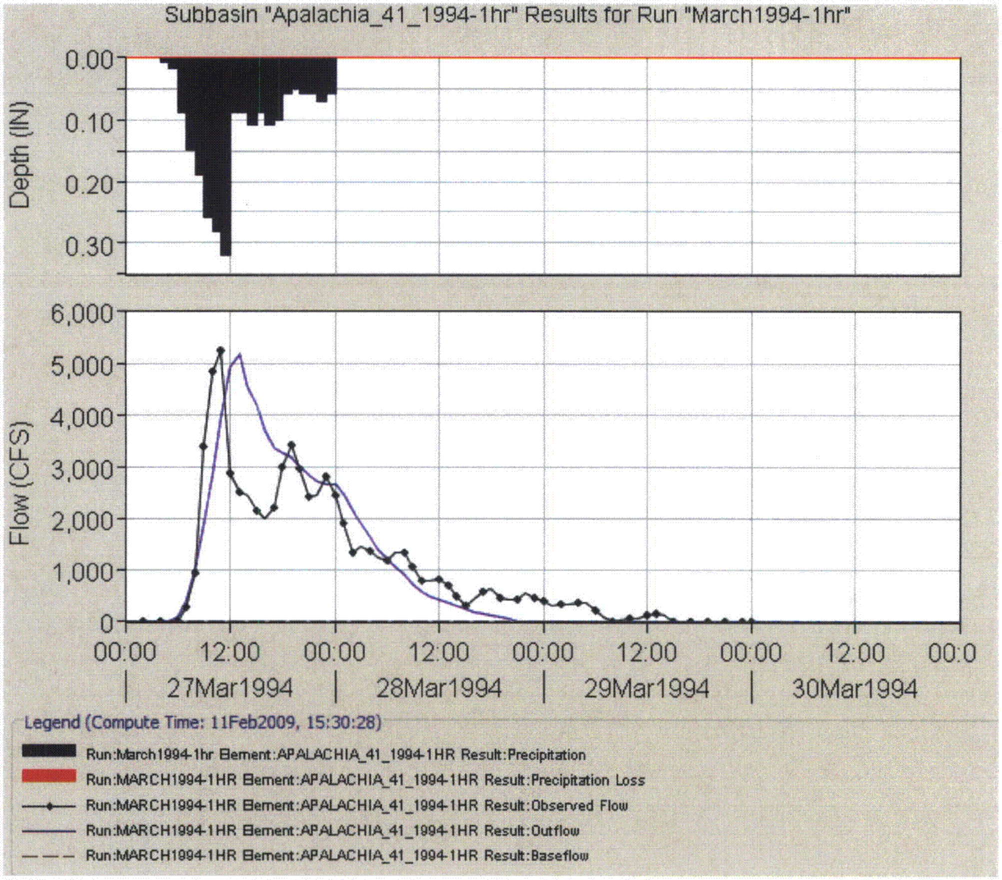

Figure 68: Appalachia Dam HEC-HMS output for March 1994 storm

From the March 1994 simulation:

1. The simulated peak discharge occurred two hours after the observed peak discharge.
2. The magnitude of the simulated peak was one percent lower than the observed peak.

7.7.5 Ocoee No. 1 Dam Subbasin 43

A HEC-HMS project file was developed for testing the unit hydrograph developed for the Ocoee No. 1 Dam Subbasin; this file is enclosed as Attachment 3- 5 and contains the following basin models:

- Ocoee-43_1998
- Ocoee-43_2003
- Ocoee-43_2004

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 "Effect_Apr1998" with hourly excess precipitation incremental depths
- Precipitation Gage "Effect_May2003" with hourly excess precipitation incremental depths
- Precipitation Gage "Effect_Sep04" with hourly excess precipitation incremental depths
- Discharge Gage "RRR_Local_Apr1998" with hourly subbasin local direct runoff discharge in cfs
- Discharge Gage "RRR_Local_May2003" with hourly subbasin local direct runoff discharge in cfs
- Discharge Gage "RRR_Local_Sep2004" with hourly subbasin local direct runoff discharge in cfs

The six-hour unit hydrograph for the Ocoee No. 1 Dam subbasin was input to HEC-HMS with the Paired Data Manager as "TVAUH."; HMS internally calculated a one-hour UH, which is shown in Figure 54. This one-hour UH was used to simulate the April 1998, May 2003, and September 2004 floods. The simulated hydrographs are compared to the observed hydrographs in Figure 69, Figure 70, and Figure 71. An assessment of the results of the simulations is presented in Table 17.

Table 17: Subbasin 43 comparison of HEC-HMS results

Flood		Validation (1-hour UH)		
		April 1998	May 2003	September 2004
Volume (in)	HMS	1.70	2.53	1.76
	Observed RO	1.66	2.52	1.73
	Residual	0.04	0.01	0.03
	% Error*	2.4	0.4	1.7
Peak Discharge (cfs)	HMS	23,726	24,750	26,959
	Observed RO	19,264	22,089	28,121
	Residual	4,462.4	2,661.2	-1,161.7
	% Error*	23.2	12.0	-4.1
Time of Peak (hrs)	HMS	4/19/98 8:00	5/7/03 8:00	9/17/04 0:00
	Observed RO	4/19/98 11:00	5/7/03 10:00	9/17/04 0:00
	Residual (hrs)	-3.00	-2.00	0.00
	% Error**	8.6	4.3	0.0

* % Error is the Residual divided by Observed RO value as a percentage.

** % Error is the observed time to peak less the simulated time to peak divided by the observed time to peak. The time to peak is measured from the onset of excess precipitation in the FLDHYDRO output.

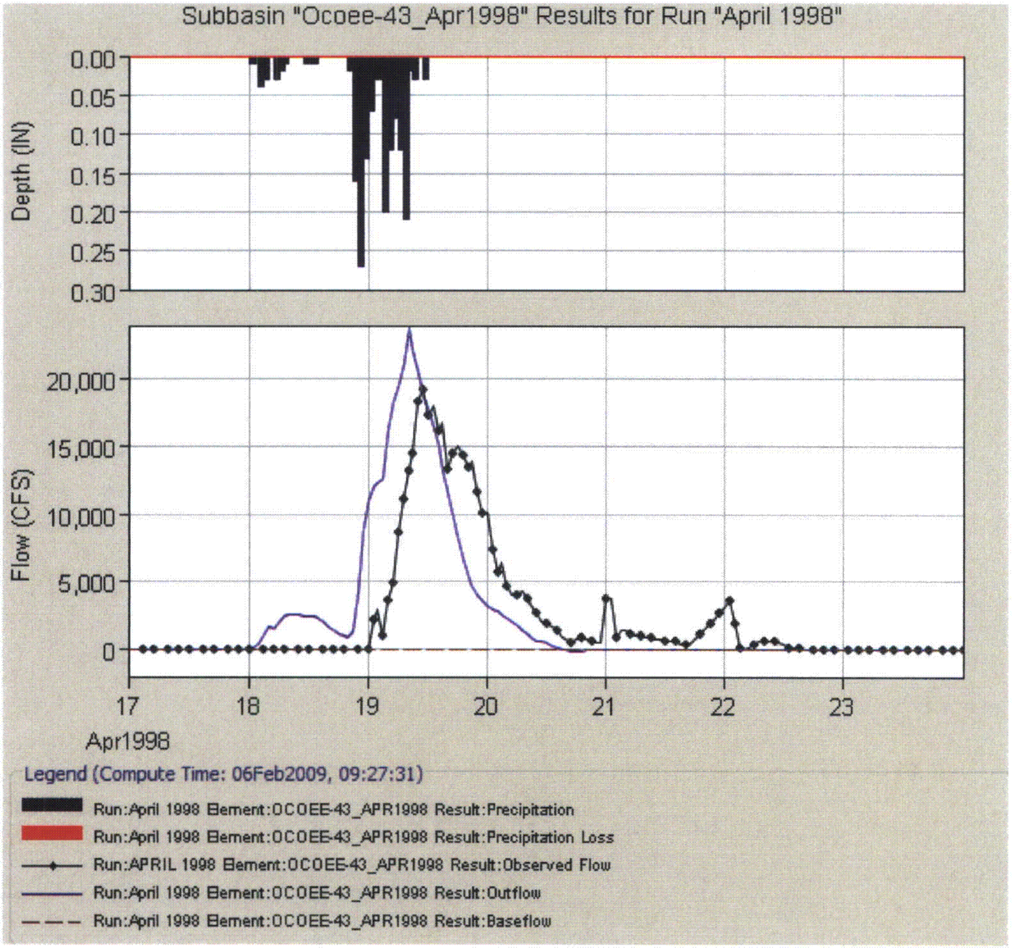

Figure 69: Ocoee No. 1 Dam HEC-HMS output for April 1998 storm

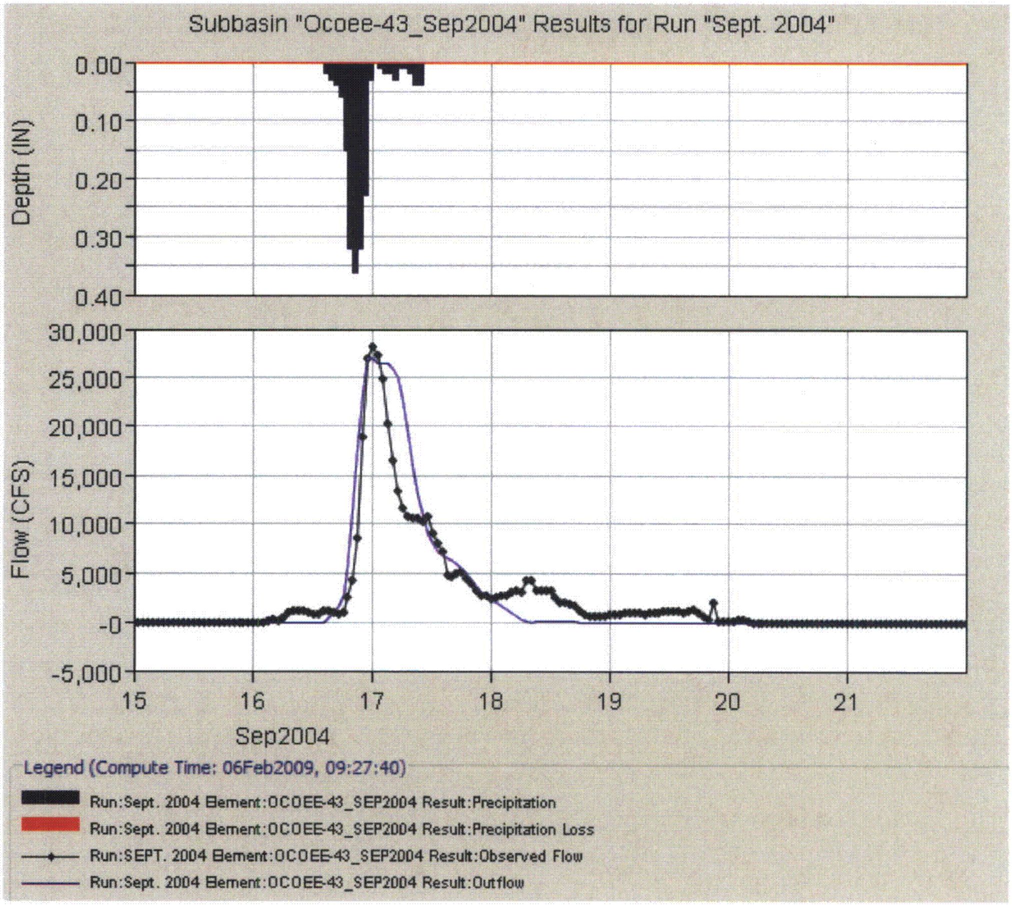

Figure 70: Ocoee No. 1 Dam HEC-HMS output for September 2004 storm

The September 2004 simulation provided a peak that occurred at the same time as the observed peak and that was four percent lower than the observed. The April 1998 simulation produced a hydrograph that provided a peak that led the observed peak significantly (three hours) and over-estimated the peak discharge by 23 percent. Given the divergence in the results of these two simulations relative to the observed conditions, a third flood, May 2003, was selected for simulation.

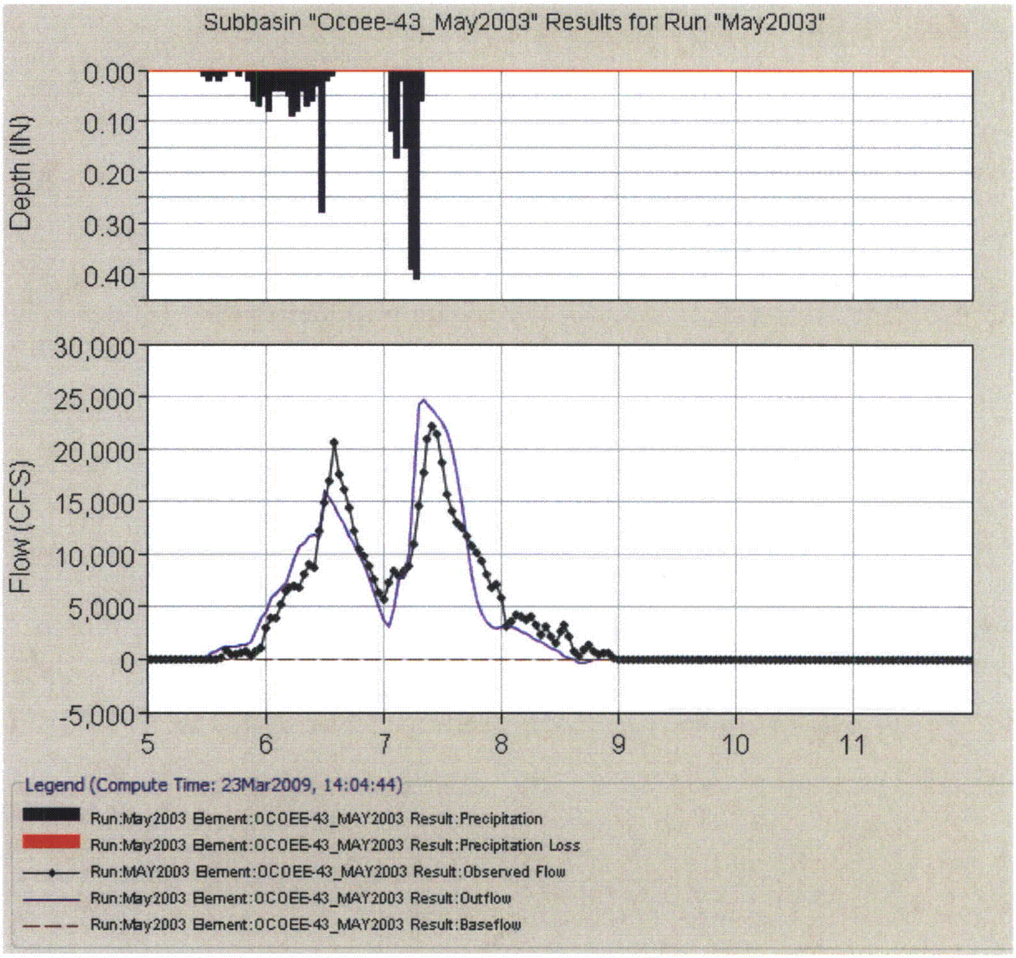

Figure 71: Ocoee No. 1 Dam HEC-HMS output for May 2003 storm

The May 2003 simulation peak discharge occurred two hours prior to the observed peak discharge. The magnitude of the simulated peak was twelve percent higher than the observed peak. The timing of the broad portions of the two peaks from the simulated hydrograph for May 2003 approximately matches the timing of the observed hydrograph.

8 Discussion and Conclusions

Unit hydrographs were regenerated for Subbasins 40 and 43 and were revised for Subbasins 38, 39, and 41 using the UNITGRPH program. The TVA provided stage, outflow, and storage-volume data for each reservoir. Using these reservoir data, "observed" subbasin local hydrographs were calculated for an 11-year period, 1997-2007. At least two large floods were identified for unit hydrograph validation for each subbasin from the "observed" subbasin local hydrographs, with the exception of Subbasin 41 as discussed in Sections 7.2.1 and 8.4. Baseflow was estimated and removed from hydrographs to obtain "observed" subbasin local direct runoff. Hourly, basin-average precipitation data were obtained for the 11-year period of analysis. FLDHYDRO and the RI methodology used within FLDHYDRO were used to estimate the excess rainfall from the precipitation data for each flood. The unit hydrograph for each subbasin and the estimated excess rainfall were then used in HEC-HMS to simulate the selected floods for each subbasin.

If the unit hydrograph was revised for a subbasin, the revised unit hydrograph was calculated using a flood occurring between 1997 and 2007. If historical data were available, a flood used in the original derivation of the unit hydrograph was also employed to create a composite, revised unit hydrograph. Revised unit hydrographs were validated using relatively large floods occurring between 1997 and 2007 along with earlier floods if the appropriate historical data were available.

A subjective, visual comparison of the HEC-HMS simulated hydrograph for each subbasin to the corresponding time series of "observed" subbasin local direct runoff was used to determine unit hydrograph validity. This comparison involved examination of: 1) overall flood hydrograph timing; 2) timing of flood hydrograph peak, 3) magnitude of flood hydrograph peak, and 4) degree of conservatism in flooding estimation. Subjectivity enters the validation process because the conditions underlying unit hydrograph theory (see Section 4) and the determination of excess precipitation (see Section 7.5).

In this calculation, the calculation of "observed" local runoff in lieu of gage measured discharge introduces additional subjectivity into the validation process. All of the observed hydrographs for these five subbasins were calculated using reverse reservoir routing. This procedure postulates a level reservoir surface (Section 7.1) and requires that changes in water surface elevation were accurately measured to the nearest 0.01 foot (Section 7.2). Derivation of hydrographs for Subbasins 40, 41, and 43 included additional stream reach routing calculations to remove inflows from upstream subbasins. These routing calculations employed either straight-lag or Muskingum routing. Straight lag routing requires that flow velocities be constant across the stream reach and that there be no change in storage in the river channel between the upstream and downstream ends of the reach (Section 7.1.1). Muskingum routing requires a linear relationship between stage and channel storage (Section 7.1.2). Actual flood flows usually do not fulfill the requirements underlying these calculation methods.

As a result, calculated hydrographs may not be as accurate as hydrographs measured at a stream gage. The expectation of some degree of inaccuracy in the "observed" direct runoff precludes an exact match between a discharge series calculated with a unit hydrograph for a particular rain storm and the observed discharge series. Unit hydrograph validation in this calculation package focused on reproduction of the basic hydrograph shape and on provision of a conservative estimate of flooding.

An emphasis on a conservative representation of flooding is included in the unit hydrograph validity assessment since the proposed use of these unit hydrographs will be to estimate the probable maximum flood at the TVA Nuclear Plant sites (see Section 1). For flooding concerns, a simulated peak discharge that is large relative to the observed peak discharge for a flood provides a conservative estimate since the simulation method is more likely to over-estimate flooding when in prediction mode. The desirability of erring on the conservative side, or of over-estimating flooding in this case, depends on the application.

8.1 Chatuge Dam, Subbasin 38

The unit hydrograph for Subbasin 38 was revised using the floods of February 1966 and September 2004. The revised unit hydrograph was validated using floods that occurred in May 2003, May 1973, and October 1964. The timing of the rising limbs, falling limbs, and peaks of the simulated hydrographs compared reasonably well with the observed hydrographs. In the simulation of the May 1973 flood, the instantaneous peak discharge was predicted to occur four hours prior to the observed peak; however, the timing of the main or broad portion of hydrograph was similar between the simulated and observed hydrographs.

The peaks of the hydrographs in the May 2003 and May 1973 simulations were over-estimated by 27 and 0.3 percent, respectively. The simulated peak discharge for the October 1964 flood was slightly lower, about three percent lower, than the observed peak discharge. On average, the three simulations provide a conservative representation of the peak since they provide a net over-estimation of the peak discharge.

Given that the overall timing match between simulation results and data is adequate and that the over-estimation of the peak discharge is conservative in this case, the revised unit hydrograph for the Chatuge Dam watershed (Subbasin 38) has been validated against a recent flood, which occurred in May 2003, and two historical floods, May 1973 and October 1964. The unit hydrograph is listed in tabular form in Table 9 and provided in graphical form in Figure 55.

8.2 Nottely Dam, Subbasin 39

The unit hydrograph for Subbasin 39 was revised using the floods of October 1964 and July 2005. The revised unit hydrograph was validated using floods that occurred in August 1967 and May 1973. The timing of the rising and falling limbs of the simulated hydrographs compared well with the observed hydrographs. In the May 1973 flood, the instantaneous peak discharge was predicted to occur two hours prior to the observed peak.

The peaks of both validation hydrographs were over-estimated. The August 1967 and May 1973 peaks were over-estimated by 26 and 40 percent, respectively. The August 1967 flood is the largest by peak magnitude of the two validation floods. The percent over-estimation decreases as peak flood magnitude increases. The revised unit hydrograph was also employed to simulate flood hydrographs for the two floods, July 2005 and October 1964, used to calculate the unit hydrograph. The peak discharge was under-estimated by ten percent for the July 2005 flood and over-estimated by 35 percent for the October 1964 flood as shown in Figure 77, Figure 78, and Figure 79 in the Appendix. In general, the revised unit hydrograph over-estimated peak discharge, which is conservative for this application. However, the degree of over-estimation varies among the simulated floods with the percent over-estimation decreasing as peak discharge increases. The peak discharge was under-estimated in the simulation of the July 2005 flood. Consequently, the revised unit hydrograph did not provide a systematic over-estimation of peak discharge in the four simulations.

Given that the overall timing match between simulation results and data is adequate and that over-estimation of the peak discharge is conservative in this case, the revised unit hydrograph for the Nottely Dam watershed (Subbasin 39) has been validated against the August 1967 flood and the May 1973 flood. A more recent flood, July 2005, was used in the derivation of the revised unit hydrograph. The validated unit hydrograph is listed in tabular form in Table 11 and provided in graphical form in Figure 58.

8.3 Hiwassee Dam, Subbasin 40

HEC-HMS was used to simulate the May 2003 and December 2004 floods in the Hiwassee Dam subbasin. The observed hydrographs for both floods had broad, relatively flat peaks. The hydrographs obtained from both simulations matched the broad portions of the peaks well even though the simulated peak discharge lagged the observed peak discharge. The unit hydrograph generated a peak for the 2003 simulation that exceeded the observed peak, which is conservative for this application. The simulated peak for the 2004 flood was lower than the observed peak so that the error in simulated peak relative to observed peak was not consistent. The simulated peak in the 2003 flood was about 17 percent higher than the observed while the simulated peak for the 2004 flood was about 5 percent lower than observed.

The results of the two simulations did not vary systematically relative to the observed hydrographs. The inconsistency in representation across the two floods suggests that the watershed runoff response may not be completely linear and/or estimated excess precipitation does not match actual excess precipitation for one or both of the floods. The original UH for Subbasin 40 replicated five historical floods well. Four of these historical floods had peak magnitudes above 30,000 cfs.

Since the unit hydrograph developed by the TVA provided storm runoff hydrographs that generally replicated the timing of the observed hydrographs and generated flood hydrographs that were conservative on average, it is concluded that the unit hydrograph developed for the Hiwassee Dam watershed (Subbasin 40) has been validated against more recent floods that occurred in May 2003 and December 2004. The validated unit hydrograph is listed in tabular form in Table 7 and provided in graphical form in Figure 53.

8.4 Apalachia Dam Subbasin 41

The unit hydrograph for Subbasin 41 was revised. Only two floods were conclusively identified in this subbasin between 1985 and 2007 as discussed in Sections 7.2.1 and 7.6.4.3. Consequently, one flood was used to calculate the revised unit hydrograph, and one was employed to validate the unit hydrograph.

The revised unit hydrograph was validated against a flood that occurred in March 1994. The timing of the rising limbs, falling limbs, and peaks of the simulated hydrograph compared reasonably well with the observed hydrograph as shown in Figure 68. The peak of the hydrograph in the March 1994 simulation was under-estimated by roughly one percent. The peak discharge in the simulated hydrograph occurred two hours after the peak discharge in the observed hydrograph. The March 1994 flood was simulated using excess precipitation interpolated to one-hour intervals. A HEC-HMS simulation using excess precipitation at six-hour intervals is provided in Figure 80 in the Appendix for reference. The flood hydrograph for the April 1998 flood, which was used to calculate the unit hydrograph, was simulated in HEC-HMS with the revised unit hydrograph. The simulated peak discharge for the April 1998 flood was about 13 percent lower than the observed peak discharge.

Subbasin 41 is relatively small, less than 50 mi^2 in area. Given that the timing of the simulated hydrograph adequately matches the observed hydrograph timing and that this subbasin is relatively small, the revised unit hydrograph for the Apalachia Dam watershed (Subbasin 41) has been validated for flood estimation purposes against a flood that occurred in March 1994. The validated unit hydrograph is listed in tabular form in Table 12 and provided in graphical form in Figure 60.

8.5 Ocoee No. 1 Dam Subbasin 43

Floods in Subbasin 43 during April 1998, May 2003, and September 2004 were simulated in HEC-HMS. The unit hydrograph provided a peak for the 2003 flood that exceeded the observed peak by twelve percent, which is conservative for this application. The simulated peak for the 1998 flood also exceeded the observed peak. The simulated peak for the 2004 flood was four percent lower than the observed peak so that the error in simulated peak relative to observed peak was not consistent.

The timing of the simulated hydrograph matched the timing of the observed hydrograph reasonably well for the 2003 and 2004 floods; however, the timing of the simulated hydrograph in the 1998 flood did not match the timing of the observed hydrograph as well. The rising limb of the hydrographs from the 1998 and 2003 simulations led the rising limb of the observed flood hydrograph. The peak discharge in these two simulations also occurred before the observed peak discharge. The peak discharge in the 2004 simulation occurred simultaneously to the observed peak, and the timing of the rising limb in this simulation was similar to the timing of the rising limb in the observed hydrograph.

Given that the unit hydrograph for Subbasin 43 provided storm runoff hydrographs that generally matched the timing of the observed hydrographs and the magnitude of the observed peak discharge, the Ocoee No. 1 Dam Subbasin unit hydrograph has been validated against more recent floods that occurred in April 1998, September 2004, and May 2003. The validated unit hydrograph is listed in tabular form in Table 8 and provided in graphical form in Figure 54.

8.6 Routing Methods and Tabulation of Adopted Unit Hydrographs

The routing methods used to determine local flow for the subbasins in this calculation include lag routing and Muskingum routing. These methods have been indirectly validated by this study for joint-use with the corresponding subbasin unit hydrograph. The routing method and routing parameters for each subbasin in this calculation, for which routing was used to determine local flows, are listed in Table 18.

Table 18: Routing methods and parameters for Subbasins 40, 41, and 43

Subbasin	Routing Reach	Routing Method	Lag Time (hrs)	Muskingum Coefficients	Routing Period Δt (hrs)
40	Chatuge Dam to Hiwassee Dam	Straight-Lag	6	N/A	N/A
	Nottely Dam to Hiwassee Dam	Straight-Lag	6	N/A	N/A
41	Hiwassee Dam to Apalachia Dam	Straight-Lag	0	N/A	N/A
43	Blue Ridge Dam to Copperhill gage	Muskingum Routing	N/A	$C_0 = 0.20$ $C_1 = 0.60$ $C_2 = 0.20$	3
	Copperhill gage to Ocoee No. 3 Dam	Muskingum Routing	N/A	$C_0 = 0.29$ $C_1 = 0.43$ $C_2 = 0.28$	1
	Ocoee No. 3 Dam to EMF gage	Muskingum Routing	N/A	$C_0 = 0.09$ $C_1 = 0.82$ $C_2 = 0.09$	2
	EMF gage to Ocoee No. 1 Dam	Muskingum Routing	N/A	$C_0 = 0.29$ $C_1 = 0.43$ $C_2 = 0.28$	1

The validated unit hydrographs for the five subbasins in this calculation are listed in Table 19. These unit hydrographs will be used in PMF determination as discussed in Section 1. The adopted unit hydrographs and routing parameters are compiled in a spreadsheet which is enclosed as Attachment 1- 47.

Table 19: Adopted unit hydrographs for Subbasins 38, 39, 40, 41, and 43

One-Hour Duration				Six-Hour Duration		
Time (hours)	Subbasin 38 Chatuge Dam	Subbasin 39 Nottely Dam	Subbasin 41 Apalachia Dam	Time (hours)	Subbasin 40 Hiwassee Dam	Subbasin 43 Ocoee No. 1 Dam
	Discharge (cfs)				Discharge (cfs)	
0	0	0	0	0	0	0
1	18,360	44,477	2,952	6	15,095	17,517
2	19,062	14,517	5,563	12	23,349	14,516
3	17,135	13,372	4,047	18	5,388	3,407
4	6,460	12,226	3,949	24	2,825	2,336
5	5,873	11,081	2,933	30	2,450	1,266
6	5,286	9,935	1,918	36	2,075	0
7	4,699	8,790	902	42	1,992	
8	4,112	7,644	873	48	1,910	
9	3,525	6,499	843	54	1,362	
10	2,938	5,353	814	60	813	
11	2,760	4,208	785	66	772	
12	2,582	0	755	72	731	
13	2,404		726	78	689	
14	2,226		696	84	669	
15	2,048		667	90	650	
16	1,870		637	96	0	
17	1,692		608			
18	1,515		579			
19	1,437		549			
20	1,360		520			
21	1,283		490			
22	1,205		461			
23	1,128		0			
24	1,051					
25	973					
26	947					
27	921					
28	895					
29	869					
30	843					
31	817					
32	791					
33	765					
34	738					
35	712					
36	686					
37	0					

9 Appendix

Table 20: 10 largest "observed", seven-hour, central moving average Subbasin 38 discharge values for each year from 1998-2007

Rank	Description	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	Discharge (cfs)	5,585	11,009	2,712	3,666	2,350	2,626	6,708	17,285	6,445	4,060	2,010
	Date	7/15/97 20:00	1/7/98 22:00	6/3/99 1:00	4/4/00 4:00	1/19/01 18:00	1/25/02 8:00	5/7/03 9:00	9/16/04 23:00	6/12/05 14:00	1/17/06 19:00	1/7/07 21:00
2	Discharge (cfs)	4,413	10,932	2,656	3,591	2,307	2,595	6,572	16,619	6,332	4,019	1,969
	Date	4/28/97 9:00	1/7/98 23:00	6/3/99 0:00	4/4/00 1:00	1/19/01 17:00	12/24/02 7:00	5/7/03 8:00	9/17/04 0:00	6/12/05 15:00	1/17/06 20:00	1/7/07 22:00
3	Discharge (cfs)	4,364	10,876	2,607	3,528	2,301	2,554	6,393	16,433	6,100	3,919	1,827
	Date	4/28/97 8:00	1/7/98 21:00	5/7/99 20:00	4/4/00 5:00	1/19/01 16:00	12/24/02 8:00	5/7/03 7:00	9/16/04 22:00	6/12/05 16:00	1/17/06 21:00	1/7/07 23:00
4	Discharge (cfs)	4,293	10,556	2,556	3,505	2,275	2,543	6,151	15,549	6,096	3,760	1,819
	Date	4/28/97 10:00	1/8/98 0:00	5/7/99 21:00	4/4/00 3:00	1/19/01 21:00	1/25/02 9:00	5/7/03 6:00	9/17/04 1:00	6/12/05 13:00	1/17/06 18:00	1/7/07 20:00
5	Discharge (cfs)	4,202	10,501	2,547	3,445	2,236	2,531	5,567	15,152	5,997	3,624	1,777
	Date	4/28/97 7:00	1/7/98 20:00	1/23/99 20:00	4/4/00 0:00	1/19/01 22:00	1/25/02 7:00	5/7/03 5:00	9/16/04 21:00	6/12/05 17:00	1/17/06 22:00	1/1/07 5:00
6	Discharge (cfs)	4,040	10,300	2,454	3,437	2,230	2,464	5,562	14,899	5,664	3,461	1,733
	Date	4/28/97 6:00	1/8/98 1:00	5/7/99 22:00	4/4/00 6:00	1/19/01 19:00	12/24/02 6:00	5/7/03 4:00	9/17/04 2:00	6/12/05 12:00	1/17/06 17:00	1/8/07 0:00
7	Discharge (cfs)	4,012	9,668	2,449	3,406	2,152	2,416	5,449	13,914	5,604	3,383	1,711
	Date	4/28/97 11:00	1/7/98 19:00	5/7/99 19:00	4/4/00 2:00	1/19/01 20:00	1/25/02 10:00	5/7/03 10:00	9/17/04 3:00	6/12/05 18:00	11/15/06 19:00	1/7/07 19:00
8	Discharge (cfs)	3,926	9,524	2,404	3,110	2,048	2,410	4,715	13,397	5,600	3,337	1,687
	Date	2/28/97 10:00	1/8/98 2:00	2/1/99 10:00	4/3/00 23:00	1/19/01 15:00	9/27/02 9:00	5/7/03 12:00	9/16/04 20:00	7/12/05 1:00	11/15/06 20:00	1/8/07 1:00
9	Discharge (cfs)	3,913	8,904	2,403	3,061	1,986	2,409	4,698	12,696	5,462	3,188	1,650
	Date	5/3/97 5:00	1/8/98 3:00	2/1/99 9:00	4/4/00 7:00	1/19/01 23:00	9/27/02 8:00	11/19/03 4:00	9/17/04 4:00	7/12/05 0:00	11/15/06 18:00	1/1/07 6:00
10	Discharge (cfs)	3,886	8,884	2,364	2,991	1,966	2,404	4,648	11,738	5,215	3,185	1,592
	Date	2/28/97 12:00	1/7/98 18:00	2/1/99 11:00	4/3/00 6:00	1/19/01 14:00	12/24/02 9:00	11/19/03 3:00	9/17/04 5:00	7/12/05 2:00	1/17/06 23:00	1/8/07 2:00

Largest storm by peak magnitude from 7-hour moving average hydrograph
Second largest storm, with available NWS precipitation data, by peak magnitude from 7-hour moving average hydrograph

Missing precipitation data from NWS gridded data set for this time period.

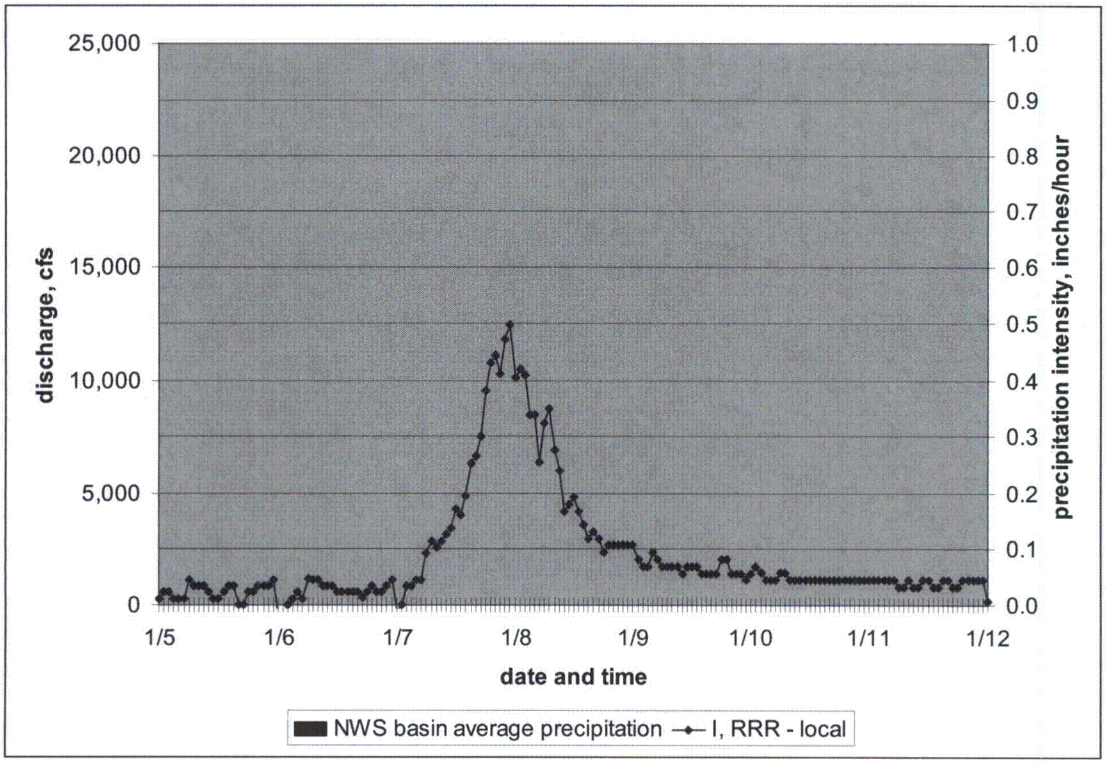

Figure 72: Chatuge Dam "observed" subbasin, local hydrograph for January 1998 flood showing lack of NWS precipitation data

Table 21: 10 largest "observed", 11-hour central moving average Subbasin 39 discharge values for each year from 1998-2007

Rank	Description	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	Discharge (cfs)	5,687	6,634	2,405	4,403	3,800	3,874	6,390	9,400	8,384	3,739	1,693
	Date	5/3/97 4:00	1/7/98 21:00	5/7/99 23:00	4/4/00 0:00	6/30/01 1:00	5/4/02 9:00	5/7/03 10:00	9/17/04 1:00	7/29/05 10:00	1/17/06 21:00	11/16/07 4:00
2	Discharge (cfs)	5,686	6,631	2,372	4,326	3,764	3,801	6,340	9,354	8,364	3,697	1,686
	Date	5/3/97 6:00	1/7/98 22:00	5/7/99 22:00	4/3/00 23:00	6/30/01 2:00	5/4/02 8:00	5/7/03 9:00	9/17/04 2:00	7/29/05 11:00	1/17/06 22:00	1/8/07 0:00
3	Discharge (cfs)	5,637	6,514	2,321	4,302	3,702	3,794	6,285	9,174	8,280	3,655	1,685
	Date	5/3/97 5:00	1/7/98 23:00	1/23/99 14:00	4/4/00 1:00	6/30/01 0:00	5/4/02 10:00	5/7/03 11:00	9/17/04 0:00	7/29/05 12:00	1/17/06 20:00	1/7/07 23:00
4	Discharge (cfs)	5,556	6,463	2,304	4,207	3,616	3,660	6,269	8,962	8,092	3,554	1,681
	Date	5/3/97 7:00	1/7/98 20:00	1/23/99 12:00	4/3/00 22:00	6/30/01 3:00	5/4/02 7:00	5/7/03 8:00	9/17/04 3:00	7/29/05 9:00	1/17/06 23:00	11/16/07 5:00
5	Discharge (cfs)	5,415	6,215	2,300	4,129	3,508	3,595	6,123	8,743	8,033	3,428	1,681
	Date	5/3/97 3:00	1/8/98 0:00	1/23/99 11:00	4/3/00 21:00	6/29/01 23:00	5/4/02 11:00	5/7/03 7:00	9/16/04 23:00	7/29/05 13:00	1/17/06 19:00	11/16/07 6:00
6	Discharge (cfs)	5,186	6,189	2,292	4,092	3,333	3,433	5,909	8,436	7,598	3,387	1,681
	Date	5/3/97 8:00	1/7/98 19:00	5/7/99 21:00	4/4/00 2:00	6/30/01 4:00	5/4/02 6:00	5/7/03 12:00	9/17/04 4:00	7/29/05 14:00	1/18/06 0:00	11/16/07 7:00
7	Discharge (cfs)	4,941	5,886	2,276	3,997	3,219	3,361	5,725	8,144	7,566	3,173	1,681
	Date	5/3/97 2:00	1/8/98 1:00	1/23/99 13:00	4/3/00 20:00	6/29/01 22:00	5/4/02 12:00	5/7/03 6:00	9/16/04 22:00	7/29/05 8:00	11/15/06 23:00	11/16/07 8:00
8	Discharge (cfs)	4,913	5,766	2,274	3,824	2,877	3,138	5,377	7,867	6,850	3,168	1,681
	Date	5/3/97 9:00	1/7/98 18:00	5/7/99 20:00	4/4/00 3:00	6/30/01 5:00	5/4/02 5:00	5/7/03 13:00	9/17/04 5:00	7/29/05 7:00	11/15/06 22:00	11/16/07 9:00
9	Discharge (cfs)	4,699	5,546	2,268	3,755	2,834	3,039	5,131	7,455	6,741	3,163	1,681
	Date	2/28/97 12:00	1/8/98 2:00	5/8/99 0:00	4/3/00 19:00	6/29/01 21:00	5/4/02 13:00	5/7/03 5:00	9/16/04 21:00	7/29/05 15:00	11/15/06 21:00	11/16/07 10:00
10	Discharge (cfs)	4,615	5,244	2,252	3,499	2,809	2,885	4,802	7,310	5,995	3,139	1,669
	Date	2/28/97 11:00	1/7/98 17:00	1/23/99 15:00	4/4/00 4:00	1/19/01 15:00	1/25/02 0:00	5/7/03 14:00	9/17/04 6:00	7/29/05 6:00	1/17/06 18:00	11/16/07 13:00

Largest storm by peak magnitude from 11-hour central moving average hydrograph
Second largest storm by peak magnitude from 11-hour central moving average hydrograph

Missing precipitation data from NWS gridded data set for this time period.

Third largest storm, with NWS precipitation data available, by peak magnitude from 11-hour central moving average hydrograph

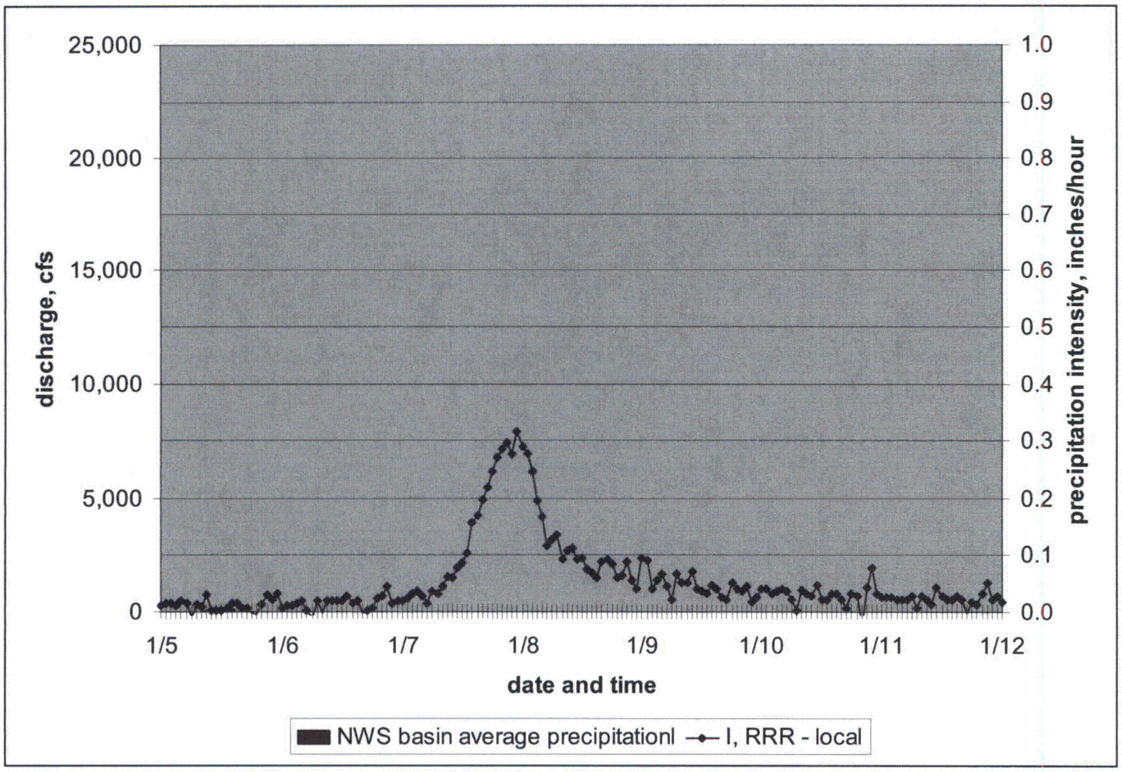

Figure 73: Nottely Dam "observed" subbasin, local hydrograph for January 1998 flood showing local runoff and the lack of NWS precipitation data

Table 22: 10 largest "observed", 25-hour central moving average discharge values for Subbasin 40 for each year from 1998-2007

Rank	Description	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	Discharge (cfs)	15,428	8,736	7,076	10,081	7,786	8,608	21,726	12,140	8,817	5,964	3,206
	Date*	2/28/97 19:00	1/8/98 6:00	1/15/99 8:00	4/4/00 6:00	1/19/01 20:00	1/25/02 5:00	5/7/03 2:00	12/7/04 4:00	2/21/05 19:00	1/18/06 5:00	3/2/07 19:00
2	Discharge (cfs)	15,347	8,721	7,070	10,069	7,784	8,552	21,585	12,124	8,773	5,937	3,176
	Date*	2/28/97 20:00	1/8/98 5:00	1/15/99 9:00	4/4/00 7:00	1/19/01 18:00	1/25/02 6:00	5/7/03 0:00	12/7/04 2:00	2/21/05 20:00	1/18/06 4:00	3/2/07 17:00
3	Discharge (cfs)	15,296	8,699	7,056	9,966	7,776	8,545	21,508	12,093	8,624	5,908	3,166
	Date*	2/28/97 18:00	1/8/98 7:00	1/15/99 10:00	4/4/00 4:00	1/19/01 19:00	1/25/02 0:00	5/7/03 1:00	12/7/04 3:00	2/21/05 23:00	1/18/06 3:00	3/2/07 18:00
4	Discharge (cfs)	15,275	8,695	7,045	9,961	7,724	8,541	21,407	12,000	8,611	5,803	3,126
	Date*	2/28/97 16:00	1/8/98 4:00	1/15/99 7:00	4/4/00 5:00	1/19/01 22:00	1/25/02 4:00	5/7/03 3:00	12/7/04 5:00	2/21/05 18:00	1/18/06 6:00	3/2/07 16:00
5	Discharge (cfs)	15,268	8,685	6,936	9,892	7,709	8,500	21,343	11,928	8,601	5,681	3,078
	Date*	2/28/97 15:00	1/8/98 3:00	1/15/99 6:00	4/4/00 9:00	1/19/01 21:00	1/25/02 3:00	5/7/03 4:00	12/7/04 1:00	2/21/05 22:00	1/18/06 2:00	1/8/07 10:00
6	Discharge (cfs)	15,194	8,610	6,898	9,885	7,629	8,441	21,246	11,755	8,580	5,656	3,057
	Date*	2/28/97 14:00	1/8/98 8:00	1/15/99 11:00	4/4/00 8:00	1/19/01 23:00	1/25/02 7:00	5/6/03 23:00	12/7/04 0:00	2/21/05 21:00	1/18/06 7:00	3/2/07 15:00
7	Discharge (cfs)	15,194	8,598	6,807	9,866	7,588	8,437	21,200	11,737	8,552	5,621	2,998
	Date*	2/28/97 17:00	1/8/98 2:00	1/15/99 5:00	4/4/00 3:00	1/19/01 17:00	1/25/02 1:00	5/7/03 5:00	12/7/04 6:00	2/21/05 17:00	1/18/06 8:00	3/2/07 20:00
8	Discharge (cfs)	15,121	8,591	6,740	9,850	7,547	8,427	21,015	11,672	8,443	5,587	2,979
	Date*	2/28/97 21:00	1/8/98 9:00	1/15/99 12:00	4/4/00 2:00	1/20/01 0:00	1/25/02 2:00	5/7/03 6:00	12/6/04 23:00	2/21/05 16:00	1/18/06 9:00	3/1/07 23:00
9	Discharge (cfs)	15,098	8,453	6,731	9,809	7,465	8,384	20,942	11,481	8,377	5,543	2,977
	Date*	2/28/97 13:00	1/8/98 1:00	1/15/99 3:00	4/4/00 1:00	1/20/01 1:00	1/24/02 23:00	5/7/03 7:00	12/7/04 7:00	2/22/05 0:00	1/18/06 1:00	3/2/07 14:00
10	Discharge (cfs)	14,918	8,435	6,721	9,777	7,369	8,329	20,683	11,454	8,310	5,531	2,949
	Date*	2/28/97 12:00	1/8/98 10:00	1/15/99 4:00	4/4/00 0:00	1/20/01 2:00	1/25/02 8:00	5/7/03 8:00	11/24/04 16:00	2/21/05 15:00	1/18/06 10:00	3/2/07 0:00

* Central Time

Largest storm by peak magnitude from 25-hour central moving average hydrograph

Second largest storm, with consistent NWS gridded data, by peak magnitude from 25-hour central moving average hydrograph

Volume of NWS gridded precipitation for this event << volume of storm runoff from observed, local hydrograph

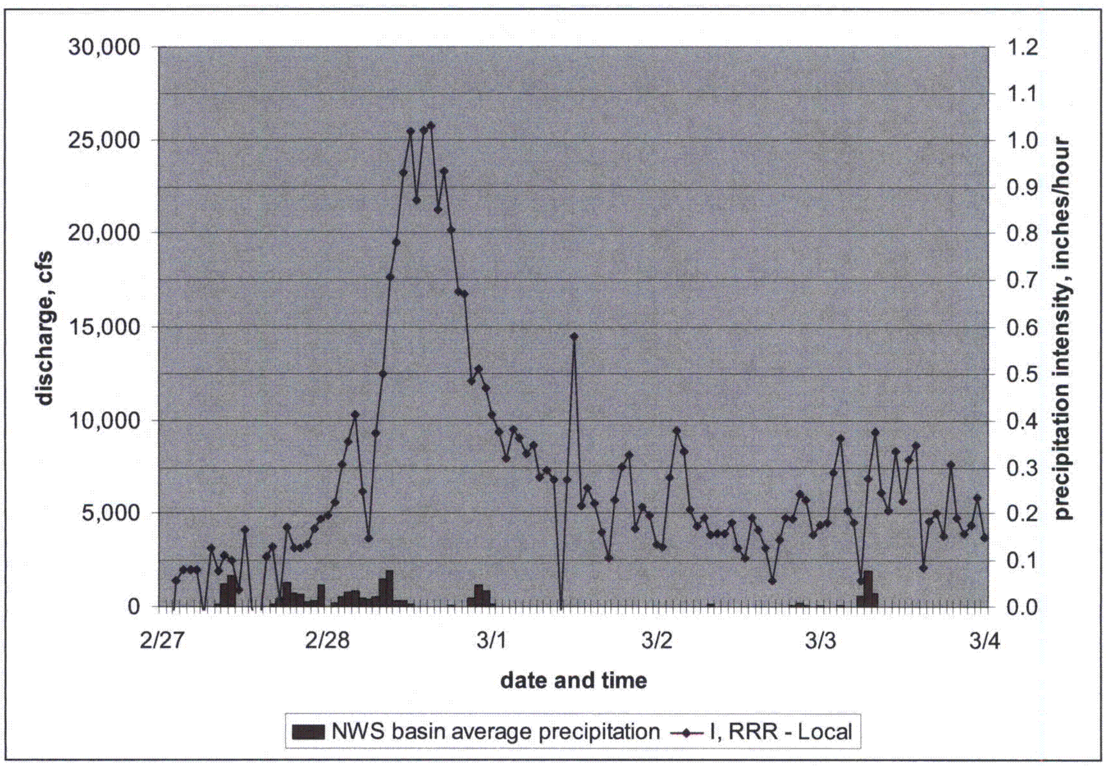

Figure 74: Hiwassee Dam, Subbasin 40, February 1997 flood showing poor correlation between NWS precipitation data magnitude and "observed" subbasin, local hydrograph

Table 23: Ocoee No. 1 Dam, Subbasin 43, ranking of largest floods for each year of 11-yr. period

Rank	Description	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	Discharge (cfs)	8,209	15,115	5,737	8,835	4,774	7,115	14,003	14,686	8,303	3,350	2,259
	Date*	2/28/97 20:00	4/19/98 15:00	5/6/99 13:00	4/4/00 3:00	1/19/01 19:00	1/25/02 3:00	5/7/03 12:00	9/17/04 6:00	2/21/05 21:00	1/18/06 5:00	3/2/07 16:00
2	Discharge (cfs)	8,204	15,057	5,649	8,826	4,770	7,095	13,993	14,657	8,241	3,339	2,235
	Date*	2/28/97 21:00	4/19/98 16:00	5/6/99 14:00	4/4/00 4:00	1/19/01 20:00	1/25/02 2:00	5/7/03 11:00	9/17/04 5:00	2/21/05 20:00	1/18/06 4:00	3/2/07 17:00
3	Discharge (cfs)	8,187	14,840	5,595	8,761	4,736	7,029	13,981	14,477	8,183	3,306	2,212
	Date*	2/28/97 19:00	4/19/98 14:00	5/6/99 12:00	4/4/00 5:00	1/19/01 21:00	1/25/02 4:00	5/7/03 13:00	9/17/04 7:00	2/21/05 22:00	1/18/06 6:00	3/2/07 15:00
4	Discharge (cfs)	8,174	14,788	5,585	8,669	4,724	6,999	13,954	14,415	8,146	3,280	2,210
	Date*	2/28/97 18:00	4/19/98 17:00	5/6/99 15:00	4/4/00 2:00	1/19/01 18:00	1/25/02 5:00	5/7/03 14:00	9/17/04 4:00	2/21/05 19:00	1/18/06 3:00	3/2/07 14:00
5	Discharge (cfs)	8,150	14,496	5,502	8,637	4,674	6,971	13,864	14,036	7,964	3,273	2,206
	Date*	2/28/97 17:00	4/19/98 13:00	5/6/99 16:00	4/4/00 6:00	1/19/01 22:00	1/25/02 6:00	5/7/03 10:00	9/17/04 3:00	2/21/05 18:00	1/18/06 7:00	3/2/07 13:00
6	Discharge (cfs)	8,118	14,448	5,391	8,502	4,674	6,947	13,841	13,742	7,949	3,121	2,195
	Date*	2/28/97 16:00	4/19/98 18:00	5/6/99 11:00	4/4/00 1:00	1/19/01 17:00	1/25/02 1:00	5/7/03 15:00	9/17/04 8:00	2/21/05 23:00	1/18/06 2:00	3/2/07 12:00
7	Discharge (cfs)	8,056	13,949	5,368	8,396	4,618	6,903	13,611	13,600	7,781	3,074	2,150
	Date*	2/28/97 22:00	4/19/98 19:00	5/6/99 17:00	4/4/00 0:00	1/19/01 16:00	1/25/02 7:00	5/7/03 9:00	9/17/04 2:00	2/21/05 17:00	1/18/06 8:00	3/2/07 18:00
8	Discharge (cfs)	8,016	13,939	5,290	8,276	4,543	6,840	13,481	13,088	7,601	3,039	2,133
	Date*	2/28/97 15:00	4/19/98 12:00	5/6/99 18:00	4/4/00 7:00	1/19/01 23:00	1/25/02 8:00	5/7/03 16:00	9/17/04 1:00	2/22/05 0:00	1/18/06 1:00	3/2/07 11:00
9	Discharge (cfs)	7,981	13,366	5,183	8,238	4,465	6,748	13,362	12,601	7,496	2,947	2,083
	Date*	5/3/97 13:00	4/19/98 11:00	5/6/99 10:00	4/3/00 23:00	1/20/01 0:00	1/25/02 0:00	5/7/03 8:00	9/17/04 0:00	2/21/05 16:00	1/18/06 9:00	3/2/07 10:00
10	Discharge (cfs)	7,953	13,215	5,105	8,024	4,449	6,727	13,133	12,596	7,186	2,937	2,030
	Date*	5/3/97 14:00	4/19/98 20:00	5/6/99 19:00	4/3/00 22:00	1/19/01 15:00	1/25/02 9:00	5/7/03 7:00	9/17/04 9:00	2/22/05 1:00	1/18/06 0:00	3/2/07 9:00

* Central Time

Largest storm by peak magnitude from 19-hour central moving average hydrograph
Second largest storm by peak magnitude from 19-hour central moving average hydrograph
Third largest storm by peak magnitude from 19-hour central moving average hydrograph

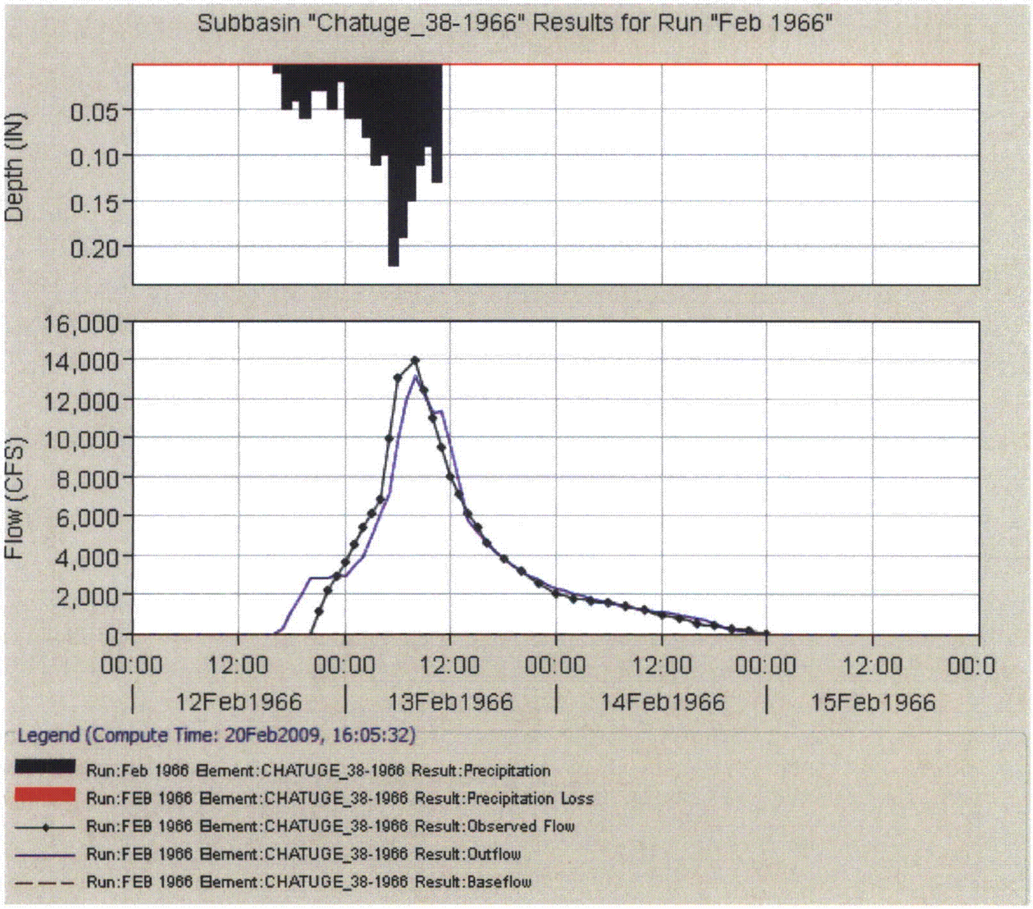

Figure 75: Chatuge Dam HEC-HMS output for February 1966 storm

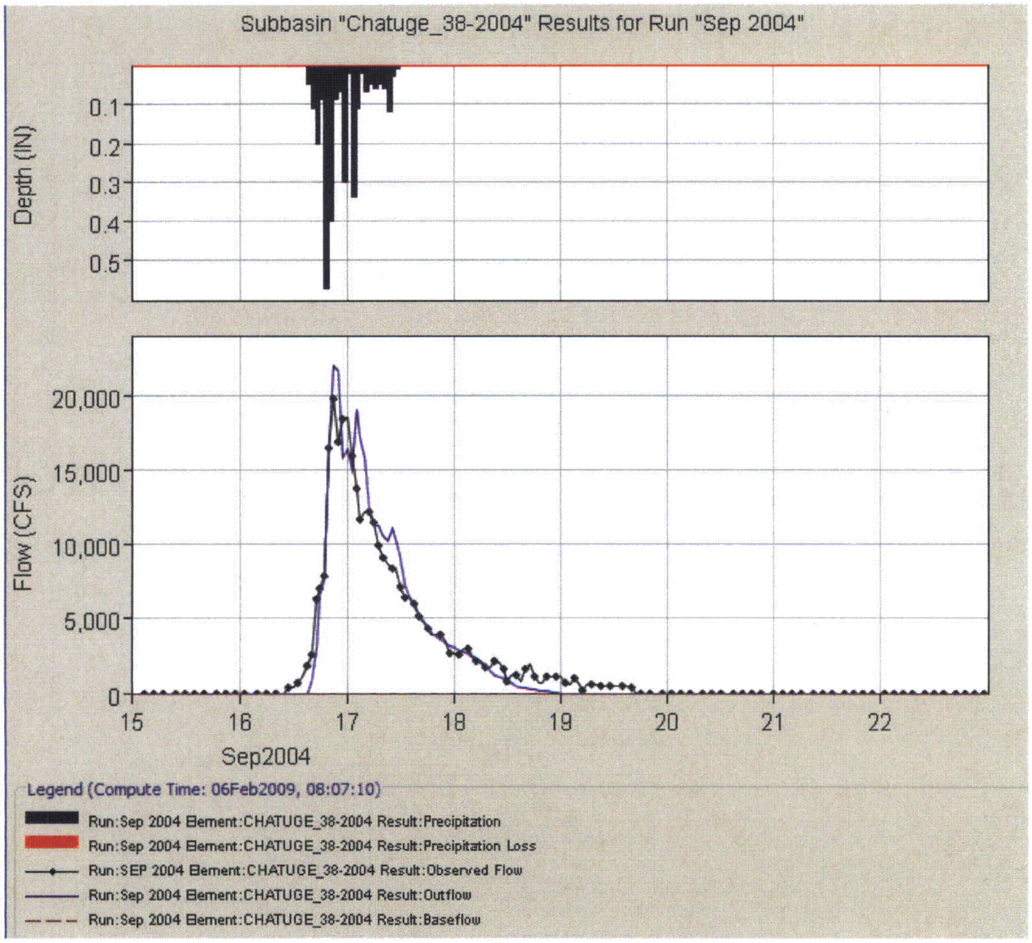

Figure 76: Chatuge Dam HEC-HMS output for September 2004 storm

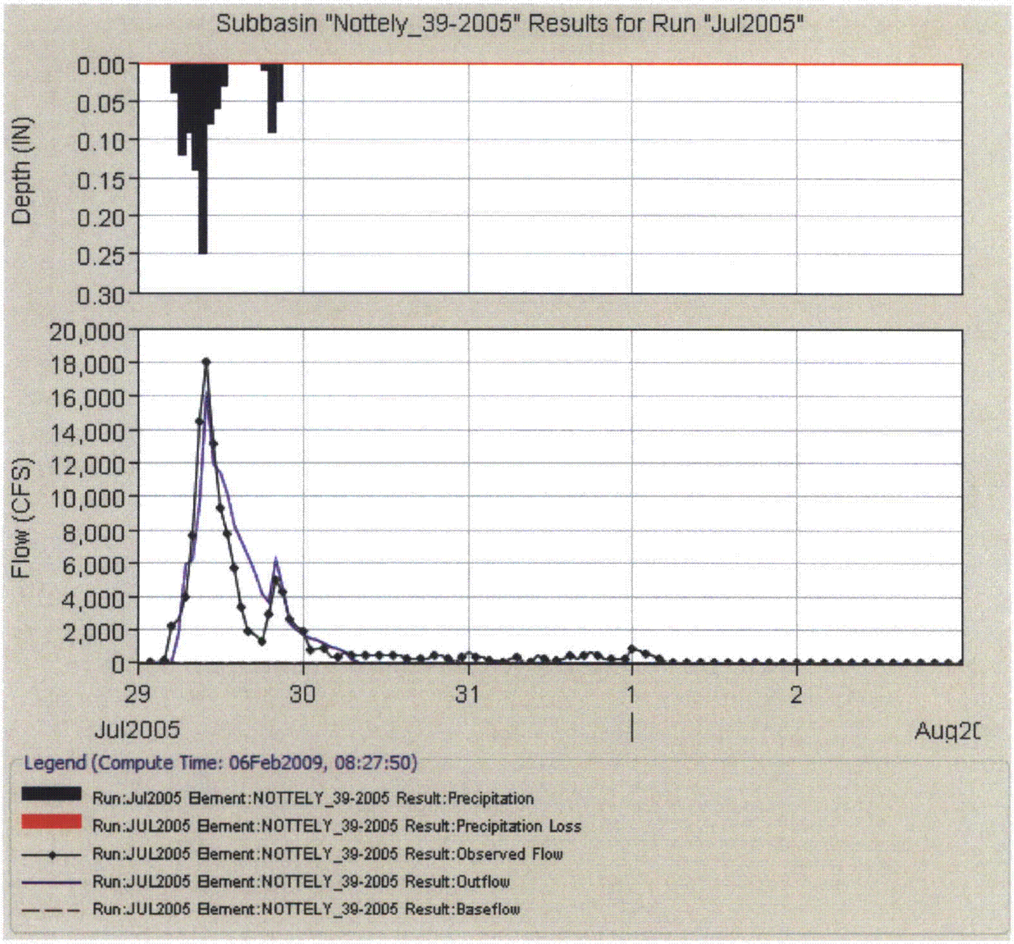

Figure 77: Nottely Dam HEC-HMS output for July 2005 storm

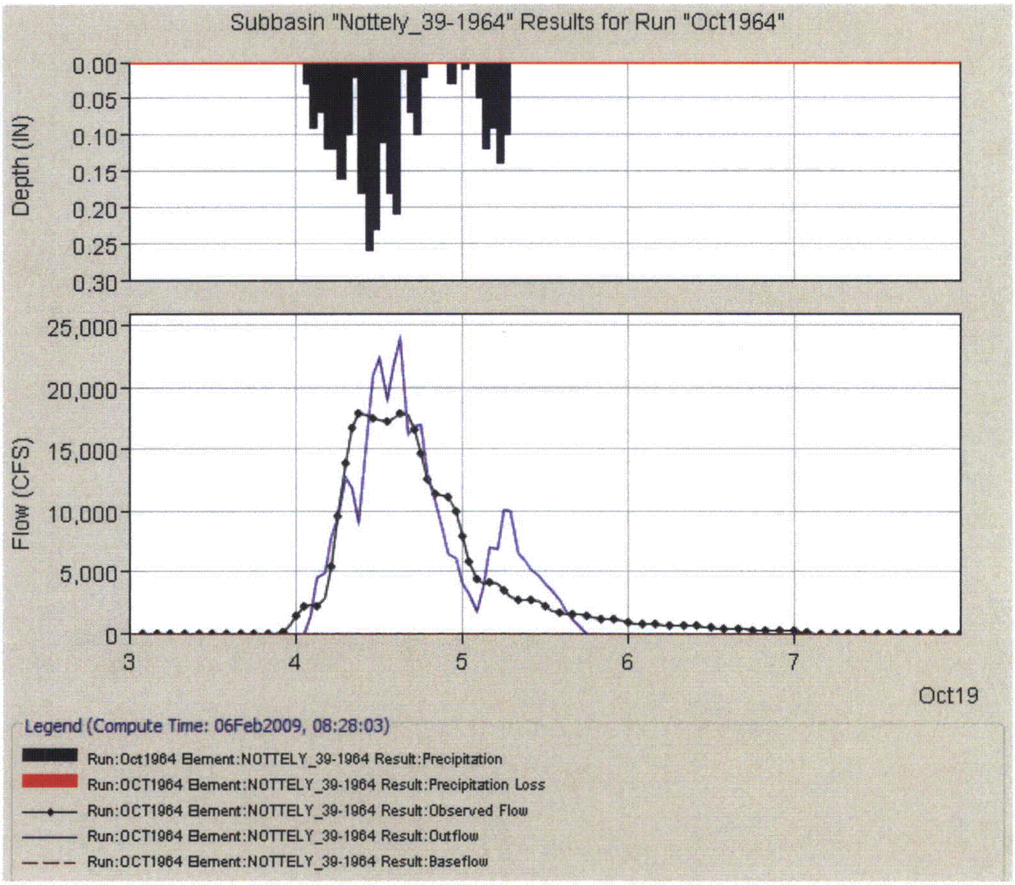

Figure 78: Nottely Dam HEC-HMS output for October 1964 storm compared to direct runoff calculated from Reference 34

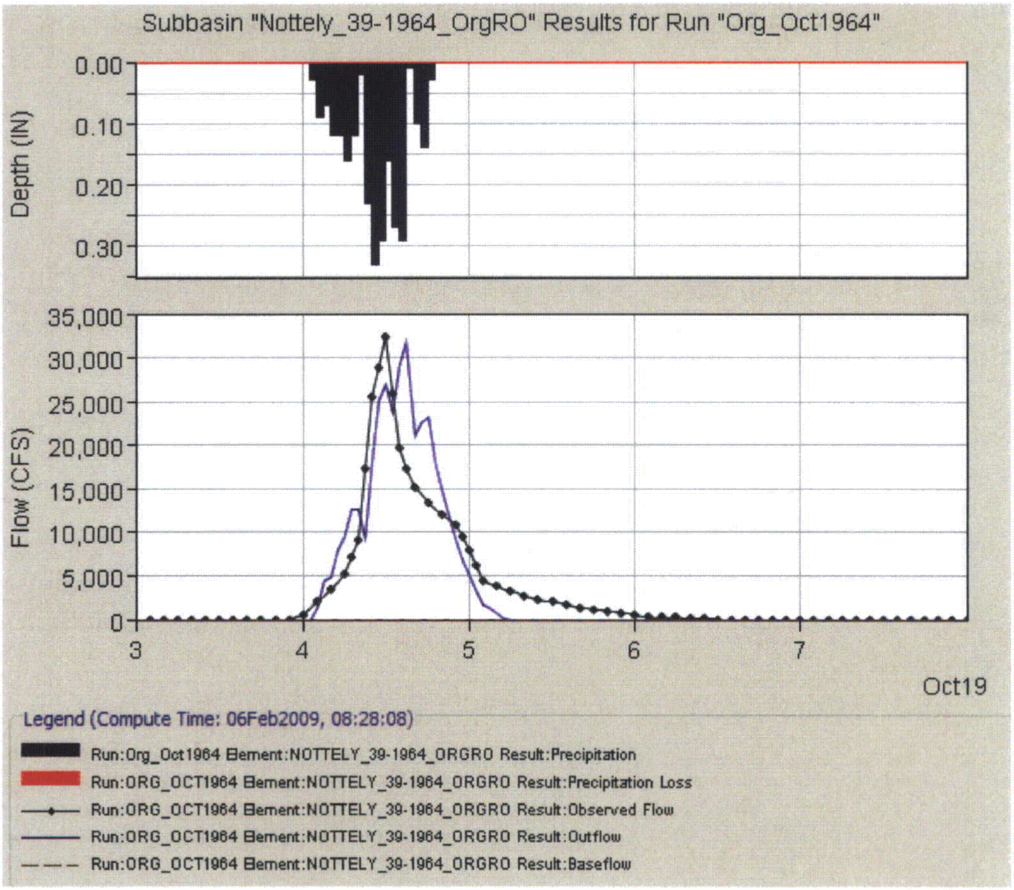

Figure 79: Nottely Dam HEC-HMS output for October 1964 storm compared to direct runoff obtained from Reference 11

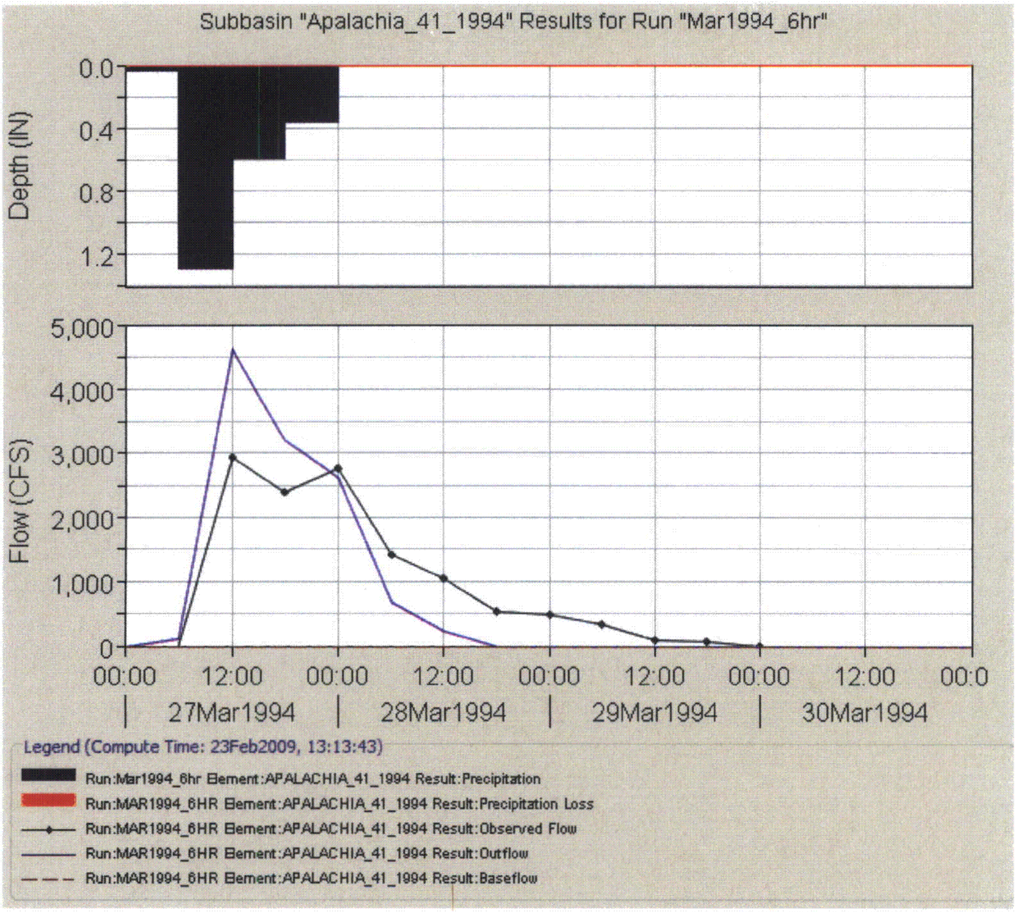

Figure 80: Apalachia Dam HEC-HMS output for March 1994 flood using six-hour excess precipitation values

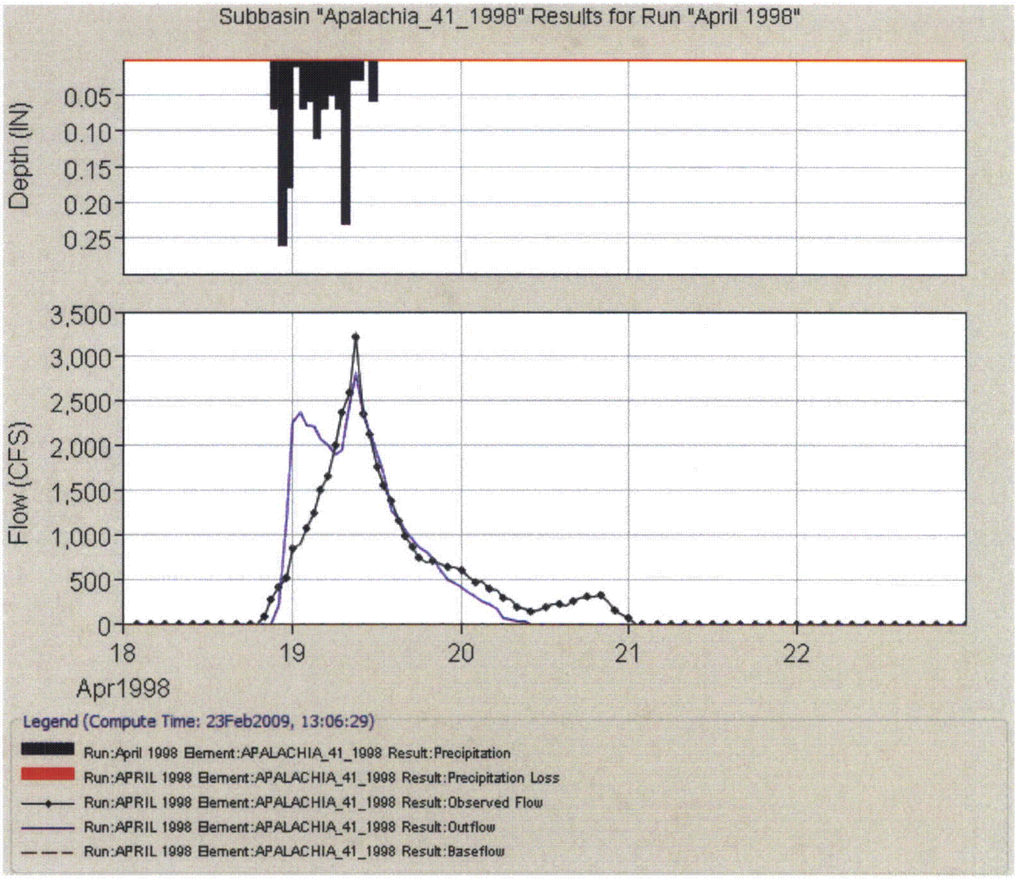

Figure 81: Apalachia Dam HEC-HMS output for April 1998 flood