ASSOCIATED ATTACHMENTS/ENCLOSURES:

Attachment 02.04.03-8AM: Subbasin 42 (Blue Ridge Dam) Unit Hydrograph Validation

(31 Pages including Cover Sheet)

NPG CALCULATION COVERSHEET/CCRIS UPDATE

REV 0 EDMS/RIMS NO.							EDMS TYPE:		EDMS ACCESSION NO (N/A for REV. 0)			
L58081030007							calculations(nuclear)		L58 091230 049			

Calc Title: Subbasin 42 (Blue Ridge Dam) Unit Hydrograph Validation

	CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT	CN	NUC	GEN	CEB	CDQ000020080091	1	2	Entire calc ☒ Selected pages ☐
NEW									

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

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

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

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

PREPARER ID	PREPARER PHONE NO	PREPARING ORG (BRANCH)	VERIFICATION METHOD	NEW METHOD OF ANALYSIS
clstokes	615-252-4343	CEB	See Page 6a	☐ Yes ☒ No

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
Carrie L. Stokes	12/11/09	Karl Stickley	12/11/09

VERIFIER SIGNATURE	DATE	APPROVAL SIGNATURE	DATE
Karl Stickley	12/11/09	K.R. Spates	12/23/09

STATEMENT OF PROBLEM/ABSTRACT

Validate existing unit hydrograph for Blue Ridge Dam (Subbasin 42) using two recent flood events.

*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. L58081030007		EDMS TYPE: calculations(nuclear)	EDMS ACCESSION NO (N/A for REV. 0) L58 090707 001		

Calc Title: Subbasin 42 (Blue Ridge Dam) Unit Hydrograph Validation

	CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT		CN	NUC	GEN	CEB	CDQ000020080091	0	1	Entire calc ☒ Selected pages ☐
NEW									

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

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

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

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

PREPARER ID PDMADDUX	PREPARER PHONE NO 423-751-8015	PREPARING ORG (BRANCH) CEB	VERIFICATION METHOD Design Review	NEW METHOD OF ANALYSIS ☐ Yes ☒ No

PREPARER SIGNATURE Perry D. Maddux	DATE 07/01/2009	CHECKER SIGNATURE Dennis L. Lundy	DATE 7-1-09
VERIFIER SIGNATURE Dennis L. Lundy	DATE 7-1-09	APPROVAL SIGNATURE K.R. Spates	DATE 7-2-09

SCB

STATEMENT OF PROBLEM/ABSTRACT

Validate existing unit hydrograph for Blue Ridge Dam (Subbasin 42) using two recent flood events.

Revision 1 Issued to address PER 171268, and lift UVA.

*EDCN Numbers:
WBN: 54018
SQN: 22404
BFN: (Later)

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

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CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	REV
	CN	NUC	GEN	CEB	CDQ000020080091	2

ALTERNATE CALCULATION IDENTIFICATION

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

CATEGORIES NA

KEY NOUNS (A-add, D-delete)

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

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

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

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

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE

PREPARER PHONE NO.	EDMS ACCESSION NO.

NPG CALCULATION RECORD OF REVISION

CALCULATION IDENTIFIER   CDQ000020080091

Title	Subbasin 42 (Blue Ridge Dam) Unit Hydrograph Validation

Revision No.	DESCRIPTION OF REVISION
0	Initial issue
1	Revision 1 lifts the UVA under Section 3.2, and addresses PER 171268, which identified an incorrect version of FLDHYDRO that was used in development of Revision 0 of this calculation. The UVA was lifted by issuance of the SPP 2.6 software documentation (Users Manual - Ref. 3) for FLDHYDRO, and Reference 2.3 was revised to reflect the EDMS number of the issued document. Two electronically attached FLDHYDRO output files were replaced with equivalent files generated using current QA Version 1.0 of FLDHYDRO, dated 11/04/2008. Results of FLDHYDRO and this calculation were unaffected by the version change. Revised page 9 to add the word "data" following the word "precipitation" in the ANSI/ANS-2.8-1992 quotation. Revised form headers from "TVAN" to "NPG". Significant changes in Revision 1 are noted with a right margin revision bar. Pages replaced: 1, 2, 3, 6, 8, 9 Pages Added / Deleted: None Attachments 2-2 and 2-4 (electronically attached FLDHYDRO output files) were replaced. See page 6 for the listing of file names and their associated attachment numbers. Total pages of calculation hardcopy for Revision 1 = 28 pages
2	This calculation was revised to address the following: • PER 203951- The verification of the original calculation was completed by personnel who had not completed the required NEDP-7 Job Performance Record (JPR). A verification JPR is now in place for all personnel engaged in verification tasks. Checking 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 204081- The verification of Rev 1 of the calculation was completed by a TVA Project Engineer with expired qualifications. • PER 203872- replace NEDP-2 forms on Pages 1 through 5 with the forms from the NEDP-2 Revision in effect at the time of calculations issuance. Significant changes in Revision 2 are noted with a right margin revision bar. Administrative changes and typos are excluded. Pages Added: 1a & 6a Pages Replaced: 1-5 & 8 Total pages of calculation hard copy for Revision 2= 30

NPG CALCULATION TABLE OF CONTENTS		
Calculation Identifier: CDQ000020080091	Revision: 2	

TABLE OF CONTENTS

SECTION	TITLE	PAGE

Attachments: see listing of electronic attachments on page 6

NPG COMPUTER INPUT FILE
STORAGE INFORMATION SHEET

Document CDQ000020080091	Rev. 2	Plant: GEN	

Subject: Subbasin 42 (Blue Ridge Dam) Unit Hydrograph Validation

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

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

See listing of electronically attached Input & Output files on the following page.

☐ Microfiche/eFiche

NPG COMPUTER INPUT FILE STORAGE INFORMATION SHEET		
Document CDQ000020080091	Rev. 1	Plant: GEN
Subject: Subbasin 42 (Blue Ridge Dam) Unit Hydrograph Validation		

Electronic Attachment	Name of File of Folder	File Location
Supporting Spreadsheets		
Attachment 1-1	Basin 42-FLDHYDRO I&O Prepwork.xls	Attached to PDF
Attachment 1-2	Basin 42 PPT Data Processing 2004.xls	Attached to PDF
Attachment 1-3	Basin 42 PPT Data Processing 2005.xls	Attached to PDF
Attachment 1-4	Basin 42- Base Flow Separation.xls	Attached to PDF
Attachment 1-5	Blue Ridge Hourly HW & Q.xls	Attached to PDF
Attachment 1-6	Blue Ridge Reverse Routing 2004.xls	Attached to PDF
Attachment 1-7	Blue Ridge Reverse Routing 2005.xls	Attached to PDF
Attachment 1-8	Ocoee Basin Dam data.xls	Attached to PDF
Attachment 1-9	GriddedPrecipatationDataAllSubbasins2004.xls	Attached to PDF
Attachment 1-10	GriddedPrecipatationDataAllSubbasins2005.xls	Attached to PDF
Attachment 1-11	Blue Ridge Reverse Reservoir Routing 2000.xls	Attached to PDF
Attachment 1-12	Blue Ridge Reverse Reservoir Routing 2001.xls	Attached to PDF
Attachment 1-13	Blue Ridge Reverse Reservoir Routing 2002.xls	Attached to PDF
Attachment 1-14	Blue Ridge Reverse Reservoir Routing 2003.xls	Attached to PDF
Attachment 1-15	Blue Ridge Reverse Reservoir Routing 2006.xls	Attached to PDF
Attachment 1-16	Blue Ridge Reverse Reservoir Routing 2007.xls	Attached to PDF
FLDHYDRO Files		
Attachment 2-1	Basin42ppt2004.dat	Attached to PDF
Attachment 2-2	Basin42ppt2004.out (Revised in Revision 1)	Attached to PDF
Attachment 2-3	Basin42ppt2005.dat	Attached to PDF
Attachment 2-4	Basin42ppt2005.out (Revised in Revision 1)	Attached to PDF
HEC-HMS File Folders		
Attachment 3	Basin_42-20080091.zip (HEC-HMS project files)	FILEKEEPER No. 310971

NPG CALCULATION VERIFICATION FORM

Calculation Identifier CDQ000020080091	Revision 2

Method of verification used:

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

Verifier _~K~/E~/4~/4~_ Date _12/11/09_

Karl E. Stickley ✓

Comments:

This calculation entitled, "Subbasin 42 (Blue Ridge Dam) Unit Hydrograph Validation" was verified by independent design review. The process involved a critical review of the calculation to ensure that it is correct and complete, uses appropriate methodologies, and achieves its intended purpose. The inputs were reviewed and determined to be appropriate inputs for this calculation. The results of the calculation were reviewed and were found to be reasonable and consistent with the inputs provided. Backup files and documents were consulted as necessary to verify data and analysis details found in the calculation.

Detailed comments and editorial suggestions for the changes made in this revision were transmitted to the author and reviewer by email along with a marked up copy of the calculation.

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.

Subbasin 42, Blue Ridge Dam: The inflow hydrographs, obtained by Reverse Reservoir Routing, were averaged. When compared to the original reservoir release and storage data, the inflow hydrographs are slightly different in volume. For the May 2003 storm, the inflow hydrograph, taken at 2-hour intervals is higher by 1.60%. For the September 2004 storm, the inflow hydrograph is lower by 0.32%.

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.

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

TVA

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Subject:	Subbasin 42 (Blue Ridge Dam) Unit Hydrograph Validation		Prepared	T.H.J.
			Checked	N.D.M.

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 of the Tennessee River upstream of the Guntersville Dam for use in the Probable Maximum Flood (PMF) and dam break analysis at the proposed Bellefonte Nuclear Power Plant site, presented in Calculation CDQ000020080054.

Inputs to the dynamic model include hydrographs for 46 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, utilizing observed rainfall and streamflow and reservoir headwater and discharge data, and are being validated by checking their performance in reproducing recent flood events.

This calculation presents the validation of the unit hydrograph developed by the TVA in 1982 for the Blue Ridge Dam, Subbasin 42, located within the Tennessee River watershed as shown in Figure 1.
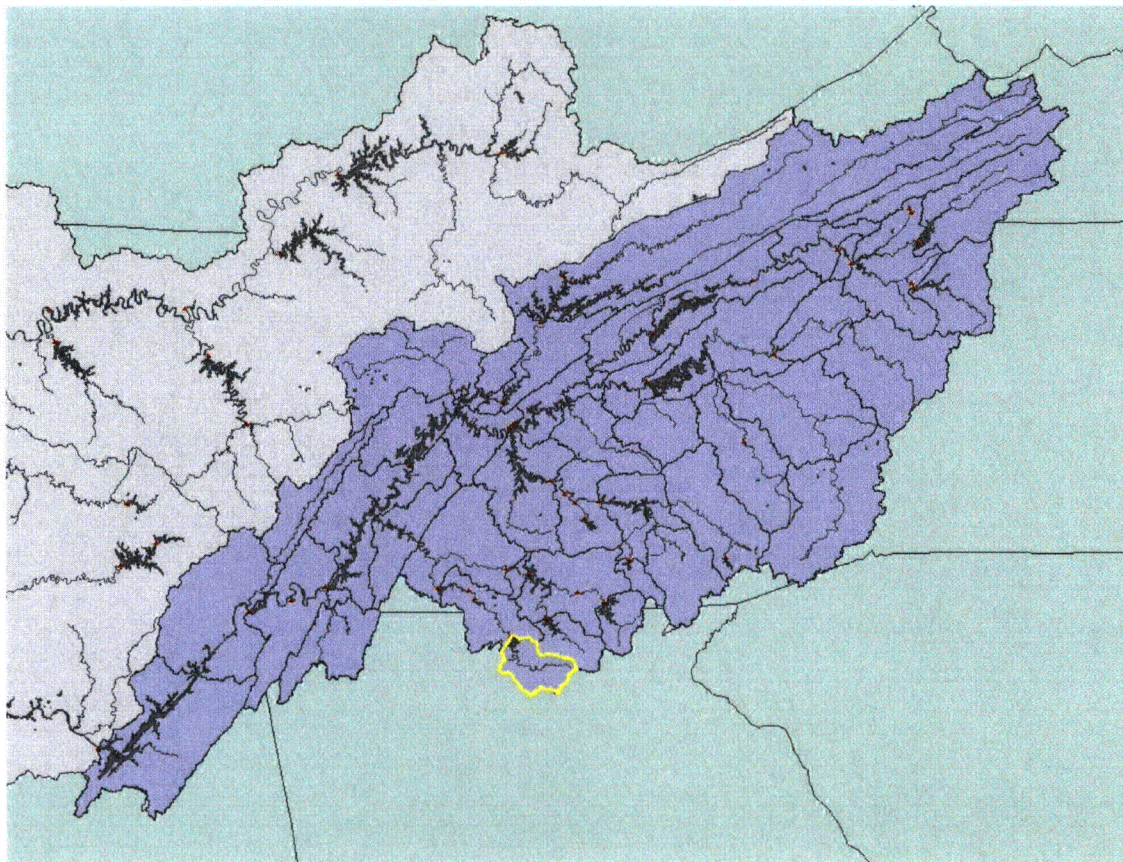
Figure 1: Location of Blue Ridge Dam Subbasin (No. 42) within the Tennessee River watershed

TVA

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		Checked	KS

2 References

1. Viessman, W., J.W. Knapp, G.L. Lewis,, and T.E. Harbaugh, *Introduction to Hydrology*, *Second Edition*, Harper & Row, Publishers, 1977.
2. Chow, V.T., D.R. Maidment, and L.W. Mays, *Applied Hydrology*, McGraw-Hill Book Company, 1988.
3. Tennessee Valley Authority, UNITGRPH-FLDHYRDO-TRBROUTE-CHANROUT User's Manual, Version 1.0, (L58090325001).
4. American Nuclear Society, American National Standard for Determining Design Basis Flooding at Power Reactor Sites, ANSI/ANS-2.8-1992, 1992.
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.
6. U.S. Army Corps of Engineers, Hydrologic Modeling System HEC-HMS User's Manual, Version 3.2, April 2008.
7. U.S. Army Corps of Engineers, Hydrologic Modeling System HEC-HMS Technical Reference Manual, March 2000.
8. Tennessee Valley Authority, Unit Area 42, Blue Ridge Dam, File Book Reference. (EDMS No. L58 080910 003)
9. 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.
10. Tennessee Valley Authority, Calculation No. CDQ000020080055, Processing and Validation of National Weather Service's NEXRAD Stage III Hourly Precipitation Data for Hydrologic Analysis of TVA Subbasins, Revision 3
11. Tennessee Valley Authority, Bellefonte Nuclear Plant - White Paper, Hydrologic Analysis, Revision 1, July 25, 2008. (EDMS No. L58 080725 006) FOR INFORMATION ONLY
12. 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)
13. Christopher Zoppou, "Reverse Reservoir Routing of Flood Hydrographs Using Level Pool Routing" ASCE Journal of Hydrologic Engineering, Vol. 4 No. 2, April 1999.
14. Linsley, R.K., Kohler, M.A., and J.L. Paulhus, Hydrology for Engineers, McGraw-Hill Book Company 1982.

3 Assumptions

3.1 General Assumptions

None.

3.2 Unverified Assumptions

None.

TVA

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			Checked	DLL

4 Background

The unit hydrograph is used to predict the runoff response at the outlet of a watershed, or subbasin, to the input of one inch of excess rainfall applied over a given duration of time. Runoff from other depths of excess rainfall can be obtained by scaling (References 1 and 2).

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_n at a given time n is obtained from the excess runoff P_m and the unit hydrograph ordinate U_{n-m+1} as follows (Reference 2):

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

The reverse process, called deconvolution is used to derive the ordinates of the unit hydrograph by reconstituting floods from precipitation and streamflow data.

Unit hydrograph theory is applicable under the following conditions (Reference 2):

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".

It should be noted that any given unit hydrograph is associated with an excess rainfall duration.

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 hydrograph for Subbasin 42, 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 for this period as is described in Section 6.4. Furthermore, since the original unit hydrograph for Subbasin 42 was developed

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		Checked	N.D.M.

from floods that occurred between 1951 and 1967 (see Section 6.1), it was necessary to use recent rainfall and stream flow data to evaluate the possibility that changes in watershed characteristics over the intervening 50 years might have altered the rainfall-runoff response of the watershed to such an extent as to invalidate the original TVA unit hydrograph.

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

1. Screen historical streamflow data from the 1997-2007 period to identify the two highest flood events. These flood events are used for unit hydrograph validation.
2. Obtain the observed hydrograph data for the two flood events and transfer the flow series to the subbasin outlet using established hydrologic procedures, as necessary, to develop the local basin hydrograph.
3. Separate baseflow from the local basin hydrograph to obtain the "observed" direct runoff hydrograph for the basin, and calculate the volume of the direct runoff based on the hydrograph ordinates.
4. Obtain observed rainfall data for the selected flood events and calculate the basin average precipitation for the adopted time step.
5. Convert the observed rainfall series to an effective rainfall series using the TVA's API-RI method as implemented in FLDHYDRO (Reference 3). This includes inputting the observed runoff volume obtained in Step 3 to ensure that the effective rainfall volume calculated by FLDHYDRO equals the observed runoff volume.
6. Run HEC-HMS (References 6 and 7) utilizing the TVA unit hydrograph and the effective rainfall 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.

Note that in selecting the flood events for unit hydrograph validation (Step 1), preference is given to storms that produce continuous excess rainfall over a relatively short period, as opposed to storms for which the excess rainfall is not continuous, because the former storms produce a well-defined flood hydrograph that is better suited for unit hydrograph validation. This preference may result in the selection of a flood event for unit hydrograph validation with a peak discharge that does not rank as one of the two highest peak discharges within the period considered.

6 Design Input Data

The input data necessary for validating the unit hydrograph for the Blue Ridge Dam, Subbasin 42, are summarized below.

- Unit hydrograph ordinates and duration
- Observed outflows from Blue Ridge Dam and corresponding headwater elevations
- The stage-volume relationship for the reservoir
- Observed rainfall data associated with the selected flood events

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

6.1 Unit Hydrograph Ordinates

The drainage area of the Blue Ridge Dam subbasin is given in the TVA File Book References as 232 mi^2 (Reference 8) and was calculated in GIS as 231.6 mi^2. The unit hydrograph for this subbasin is described in the TVA File Book Reference (Reference 8) and was developed using the methodology proposed by Newton and Vinyard (Reference 9). This methodology evaluates possible errors in the initial estimate of the time distribution of precipitation excess, and makes corrections to the precipitation excess in the development of the unit hydrograph. The data used to develop the unit hydrographs include streamflow and precipitation records from the following historical floods:

- March 29, 1951
- December 12, 1961
- October 4, 1964
- August 23, 1967

Runoff hydrographs from the subbasin (i.e., the inflow hydrographs to the reservoir) were computed by the TVA for each of these storms using reservoir stage and discharge records at Blue Ridge Dam by reverse reservoir routing (see Section 7.2). A unit hydrograph was obtained from the runoff hydrograph for each storm using the process of deconvolution, and a composite unit hydrograph was developed from the four runoff hydrographs.

The resulting composite two-hour unit hydrograph is plotted in Figure 2. The time base and ordinates for the derived unit hydrograph are provided in Table 1 along with a volume check demonstrating that volume of runoff is equivalent to one inch of excess rainfall over the entire basin.
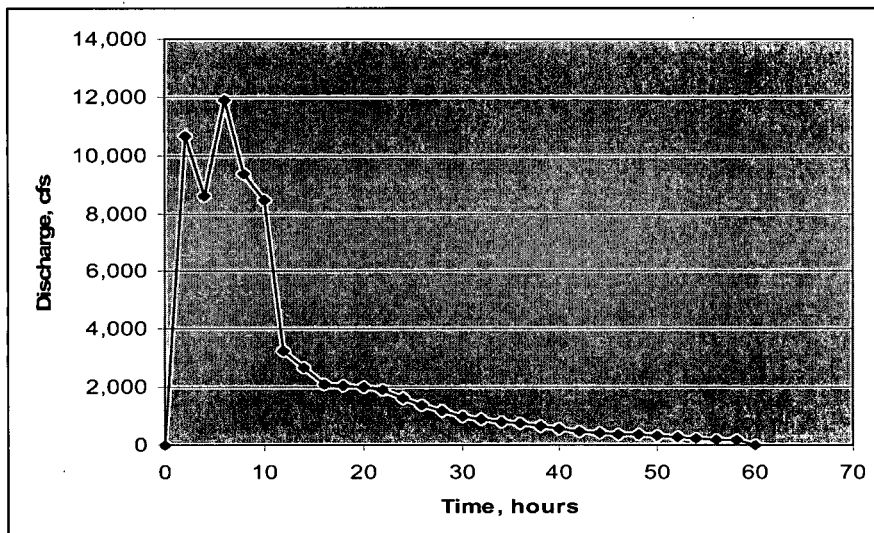

Figure 2: Two-hour unit hydrograph for Subbasin 42 (Blue Ridge Dam)

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			Checked	N.D.M.

Table 1: Two-hour unit hydrograph ordinates for the Blue Ridge Dam subbasin (Reference 8)

Hour	Q, cfs	Avg. Q (1)	Volume, acft (2)
0	0	5,333	881
2	10,665	9,634	1,592
4	8,603	10,253	1,695
6	11,902	10,637	1,758
8	9,372	8,918	1,474
10	8,463	5,848	967
12	3,233	2,953	488
14	2,672	2,391	395
16	2,110	2,079	344
18	2,047	2,016	333
20	1,984	1,953	323
22	1,921	1,785	295
24	1,648	1,512	250
26	1,375	1,284	212
28	1,193	1,102	182
30	1,011	967	160
32	923	879	145
34	834	790	131
36	746	702	116
38	657	613	101
40	569	525	87
42	480	461	76
44	441	422	70
46	403	384	63
48	364	345	57
50	325	306	50
52	286	267	44
54	247	228	38
56	208	189	31
58	169	85	14
60	0	0	0

Total Volume		12,372	acft
Basin area		231.6	mi^2
Runoff depth (3)		1.0016	inch

Notes:

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

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

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

6.2 Observed Outflows and Headwater Elevations

Hourly records of outflow from the Blue Ridge Dam (including spills and turbine discharges) and hourly headwater elevations were obtained from TVA in the spreadsheet "Blue Ridge Hourly HW & Q.xls" (Attachment 1-5) and are contained on the tabs "Total Q" and "HW" of the spreadsheet.

TVA

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			Checked	N.D.M.

6.3 Stage-Volume Relationship

The stage-volume relationship for the Blue Ridge reservoir, which is used for reverse reservoir routing, was obtained from TVA in the spreadsheet "Ocoee Basin Dam data.xls" (Attachment 1-8). This file includes stage-volume data of all dams in the upstream watershed. The stage-volume curve for Blue Ridge reservoir is plotted in Figure 3.
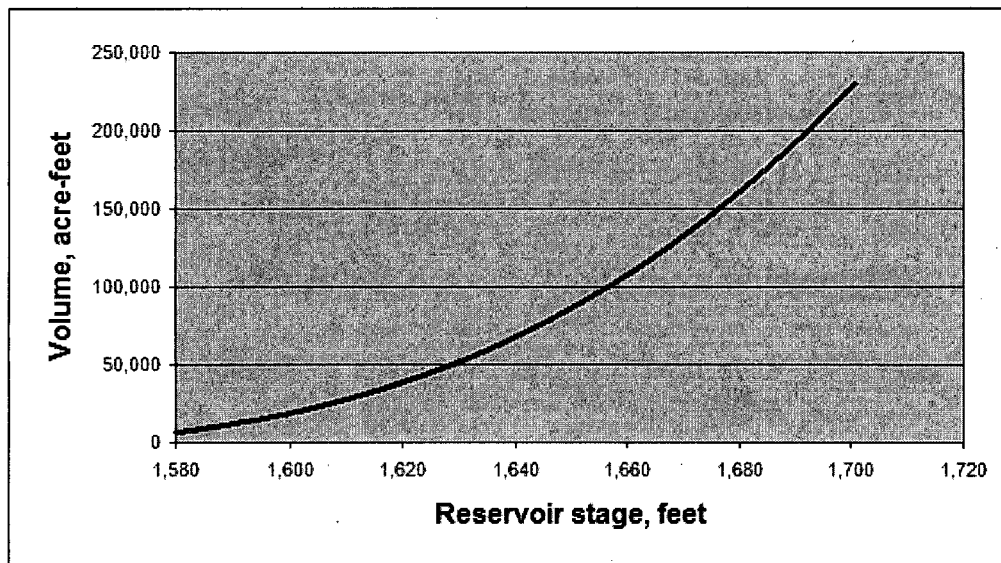
Figure 3: Stage-volume curve for Blue Ridge reservoir

6.4 Observed Rainfall

Radar-based, geospatially referenced precipitation data is extremely useful for hydrologic analysis because of its comprehensive spatial and temporal detail. Gridded daily precipitation data are available at http://water.weather.gov/ back to 2005. Hourly precipitation data are not generally available without special arrangements with the 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 10). 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 10 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.

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7 Computations and Analyses

7.1 Flood Events for Unit Hydrograph Validation

Two recent storms/floods were selected for the validation process based on the availability of rainfall and streamflow data. Gridded hourly rainfall data for the period from 1998 to 2007 are available from the U.S. National Weather Service (NWS) Lower Mississippi River Forecast Center (LMRFC). For the Blue Ridge Dam watershed, it was necessary to develop streamflow time series from reverse reservoir routing for that period using headwater and dam outflow data, as described below.

Reverse reservoir routing (RRR) could only be implemented for the years 2000 through 2007, as the data sets were incomplete for the years 1998 and 1999. The spreadsheets used for reverse reservoir routing are provided as Attachments 1-6 and 1-7 for the 2004 and 2005 year time series and as Attachments 1-11 through 1-16 for the remaining years.

Results of the review of the one-hour inflow RRR-determined flow series for the period from 2000 to 2007 are summarized in Table 2

Table 2: Annual Peak Discharges in Subbasin 42 from 1997 through 2007

Year	Peak Discharge* (ft³/s)	Date	Rank	Comment
1997	-	-	-	Not evaluated because of significant period of missing data
1998	-	-	-	Not evaluated because of significant period of missing data
1999	-	-	-	Not evaluated because of significant period of missing data
2000	4,644	Jul 8	7	
2001	5,042	Nov 26	5	
2002	4,865	Dec 26	6	
2003	9,534	May 7	2	Very "noisy" results from reverse reservoir routing and not reliable for unit hydrograph validation
2004	12,003	Sep 16	1	Use for unit hydrograph validation
2005	7,613	Nov 22	3	Possibly spurious peak (better-defined flood event with peak of 5,573 cfs on July 12 selected for use)
2006	5,478	Mar 23	4	
2007	2,861	Jan 1	8	

* Annual peak discharge as determined from three-point average hourly flow series developed from reverse reservoir routing.

Based on the analysis of the flow series developed from reverse reservoir routing, the following two storm/flood events were selected for unit hydrograph validation:

- September 16, 2004, 00:00 hrs to September 22, 2004, 00:00 hrs, the "September 2004" storm
- July 10, 2005, 00:00 hrs to July 21, 2005, 00:00 hrs, the "July 2005" storm

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7.2 "Observed" Basin Hydrographs

The available streamflow data are the observed outflows from Blue Ridge Dam. For the purpose of unit hydrograph validation, it is necessary to use this reservoir outflow time series along with changes in reservoir storage to calculate reservoir inflows using reverse reservoir routing. The reservoir inflow series can then be used as the "observed" hydrograph for comparison with the flood hydrograph obtained from convolution of the TVA unit hydrograph with excess rainfall.

Reverse reservoir routing consists of solving the continuity equation for the reservoir, which can be stated as (Reference 13):

$$\frac{dS}{dt} = I(t) - Q(S(t)) \tag{2}$$

where I is the inflow rate, Q is the outflow rate, and S is storage at time t. Total outflow from the dam for each hour is provided by the TVA and results from the sum of measured turbine and spillway discharges; the observed headwater stage can be used to determine the associated storage, S, given the stage-volume curve for the reservoir.

Equation 2 can be written using a centered finite-difference scheme as follows, where the terms t+Δt and t-Δt refer to the following and preceding time steps, respectively (Reference 11):

$$I(t) = \frac{S(t + \Delta t) - S(t - \Delta t)}{2\Delta t} + Q(S(t)) \tag{3}$$

Using the records of outflow and headwater for Blue Ridge Dam developed by the TVA as recorded in the spreadsheet "Blue Ridge Hourly HW & Q.xls" (Attachment 1-5) and the stage-volume relationship for the reservoir provided by the TVA for the three dams within the Ocoee River watershed in the spreadsheet "Ocoee Basin Dam data.xls" (Attachment 1-8), reverse reservoir routing was performed for the September 2004 and July 2005 events, which are attached to this calculation as:

- Blue Ridge Reverse Reservoir Routing 2004.xls (Attachment 1-6)
- Blue Ridge Reverse Reservoir Routing 2005.xls (Attachment 1-7)

Fluctuations in the estimated inflow can 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). A three-point moving average technique was used to smooth the fluctuations in the hydrographs resulting from the reverse reservoir routing calculations.

The resultant inflow hydrographs are plotted in Figures 4 and 5

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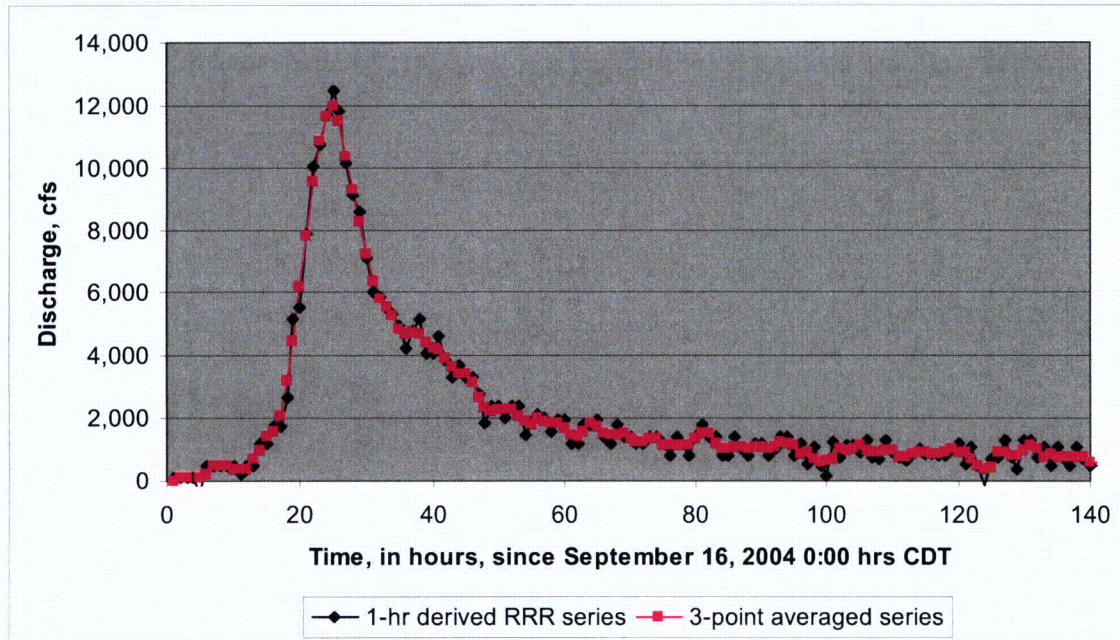
Figure 4: Blue Ridge Dam inflow hydrograph for September 2004 flood
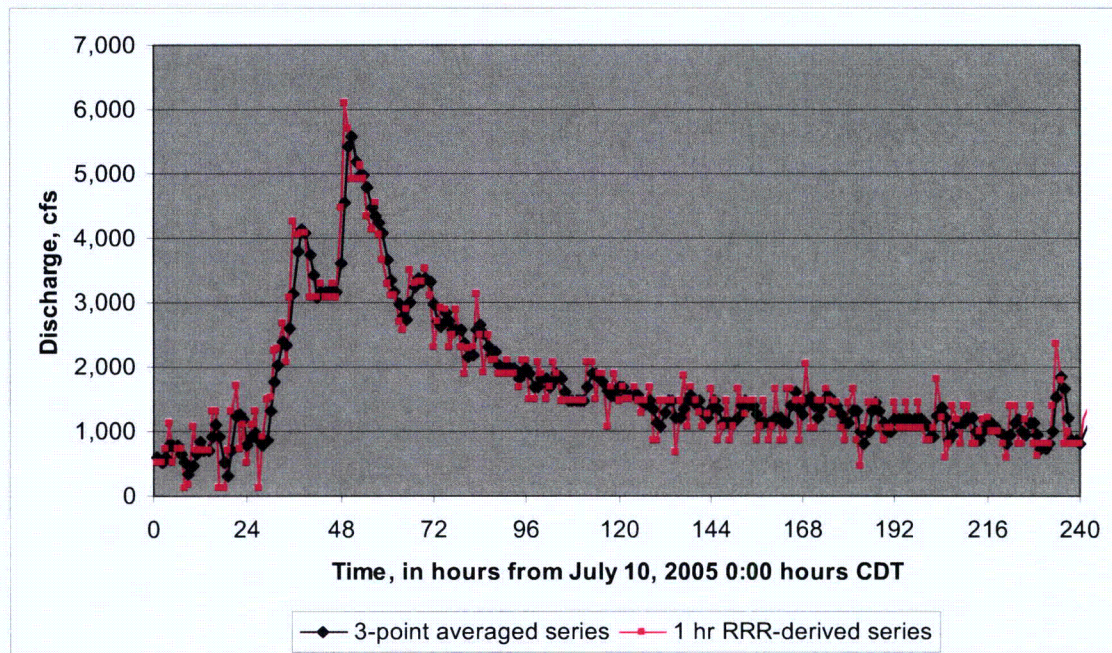
Figure 5: Blue Ridge Dam inflow hydrograph for July 2005 flood

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7.3 *Baseflow Separation*

Baseflow separation is required to determine an estimate of direct runoff associated with the rainfall event. The direct runoff volume is used in adjusting the effective rainfall volume in FLDHYDRO, as described in Section 7.5.

For this calculation, the baseflow is drawn from the starting point of runoff to a point on the receding limb of the hydrograph N hours after the time of peak discharge, where N is the area of the watershed in square miles, raised to the one-fifth power per the criterion proposed by Linsley et al (Reference 14). For the Blue Ridge Dam watershed, with a drainage area of 231.6 square miles, N is calculated as 2.97 days or 71 hours (see Table 3).

Results for the September 2004 and July 2005 flood events are plotted on Figures 6 and 7, respectively. Baseflow separation calculations are carried out in the spreadsheet "Basin42-Base Flow Separation.xls," provided as Attachment 1-4 to this calculation.
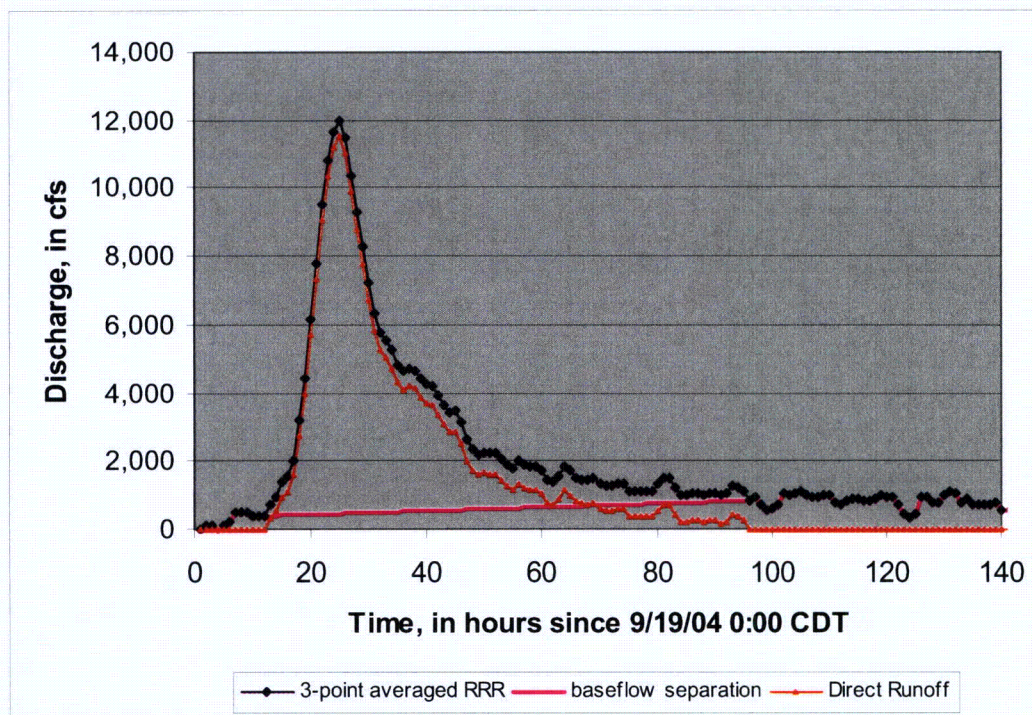
Figure 6: Blue Ridge Dam baseflow separation for the September 2004 flood

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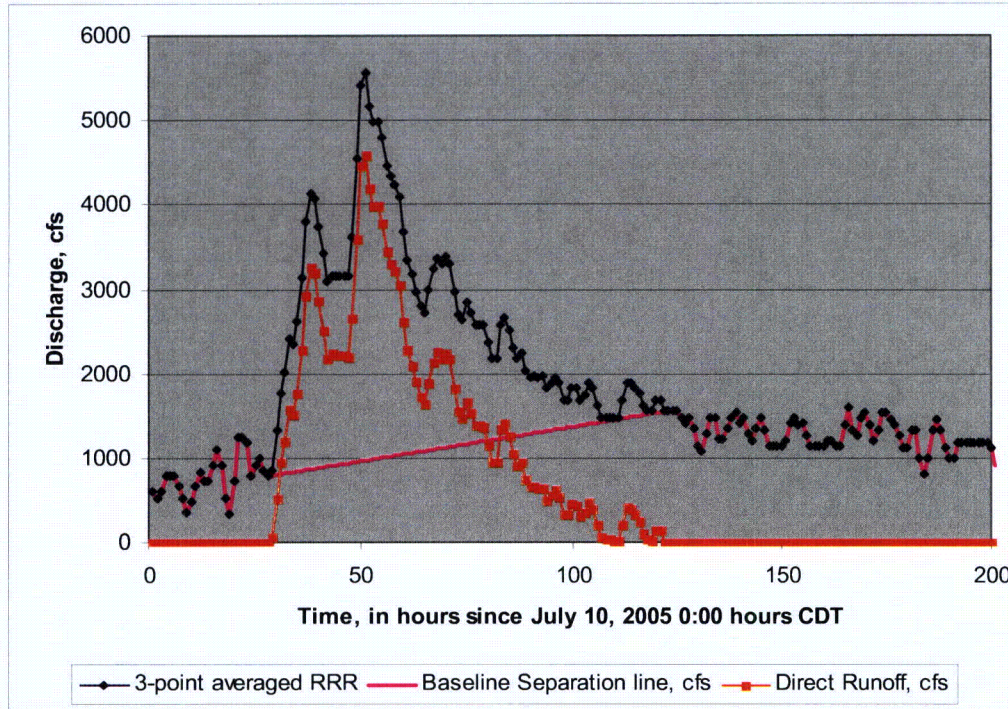
Figure 7: Blue Ridge Dam baseflow separation for the July 2005 flood

Baseflow was removed from the inflow hydrographs to calculate the direct runoff volume. This volume is used in adjusting the effective rainfall volume, as noted in Section 5. The direct runoff volume calculation is summarized in Table 3. Direct runoff volume, V, per period, Δt, is calculated from period average flow rate, Q, as:

$$V \text{ [ac-ft]} = Q \text{ [cfs]} * \Delta t \text{ [hours]} * 3{,}600 \text{ sec/hour} / 43{,}560 \text{ ft}^3\text{/ac-ft}$$

Table 3: Direct runoff volume calculations for the September 2004 and July 2005 events

Storm/Flood Event	Starting Hour of direct RO (1)	Peak Hour of direct RO (1)	End Hour of Direct Runoff (2)	Total Runoff Volume, acft (3)	Runoff Depth, inches (4)
September 2004	10	25	96	17,587	1.42
July 2005	28	51	122	11,627	0.94

1) by observation of hydrograph, arbitrary zero hour for storm isolation (see Attachment 1-4)

2) End hour = Peak hour + N expressed in hours (see text)

3) By integration of hydrograph after base flow separation

4) Depth = 12 "/ft x Volume in acft/640 acres/mi2/231.6 mi2

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7.4 Observed Basin Average Rainfall

Observed average basin rainfall for the September 2004 and July 2005 storms were obtained from Reference 10 (see spreadsheets "GriddedPrecipitationDataAllSubbasins2004.xls" and "Gridded-PrecipitationDataAllSubbasins2005.xls", provided as Attachments 1-9 and 1-10). The hourly and daily precipitation series developed from NWS gridded data for 2004 and 2005 for use in FLDHYDRO are provided in the spreadsheets "Basin 42 PPT data Processing 2004.xls" and "Basin 42 PPT data Processing 2005.xls" (Attachments 1-2 and 1-3, respectively) along with adjustments from Greenwich Mean Time to Central Time and conversion from millimeters to inches.

7.5 Effective Basin Average Rainfall

The effective rainfall hyetograph is the input to the basin model that is converted into direct runoff at the basin outlet. This is developed from the observed rainfall hyetograph by the application of a loss rate function which accounts for the hydrologic abstractions of evaporation and transpiration, interception, depression storage, and infiltration (Reference 1). Excess precipitation is often referred to as "runoff" in TVA documents because the two terms are identical.

Effective rainfall is obtained from observed rainfall data with the FLDHYDRO program (Reference 3). The FLDHYDRO program was developed by the TVA to implement the API/RI methodology developed by the NWS, as described in Reference 3. In brief, the method 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 1, page 101). A recession constant of 0.9 is used for this calculation.

The API is used to obtain a Rainfall 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 use of the loss function is discussed in the TVA White Paper (Reference 11) and the methodology is described in detail in NWS publications (Reference 12).

Input to FLDHYDRO is via a column delimited batch file. Input includes:

- Hourly precipitation gage readings for a maximum of 30 recording gages and daily precipitation readings for a maximum of 100 non-recording gages
- Flags and indices to relate each non-recording gage record to a recording gage record for interpolation
- Thiessen coefficients to weight gage records for the calculation of basin average precipitation depths (not used for gridded precipitation data)
- Depth of Runoff for the period of rainfall

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Using the gridded precipitation data simplifies the setup of input to the FLDHYDRO model because only one "gage reading" is needed for each hour. When using gridded precipitation data, input for each run includes the following data and "flags":

- NARFE = 1 to obtain a printout of flood hydrographs only
- NRI = 1 for the number of Rainfall Indices to be used per basin
- NCPTS = 1 for the number of sites for surface runoff volume check (set to zero for the NORO runs)
- NSUBW = 1 for the number of sub-watersheds (each subbasin is run separately)
- NREC = 1 for the number of recorders (run using only gridded precipitation data as one "recorder")
- NSTNS = 1 for total number of stations (i.e. no non-recording stations used)
- STAB = 1 for all stations are in the same API area
- ITDGR = 0 for the hour at which each gage is read
- BEGDR = the starting date (September 15, 2004 or July 10, 2005, depending on the run, given as MMDDYY)
- BEGTR = time at which the first hour of rainfall has been recorded (a two digit number ranging from 01 to 24)
- NHR = the number of hourly readings for the storm
- SHRAIN = the time series of hourly rainfall readings (in 10F8.0 format) obtained from processing of NWS gridded rainfall
- NDRAPI = the number of days of antecedent rainfall listed before the storm
- API = the initial API at the beginning of the antecedent daily rainfall series (setting this value to 1.0 is sufficient when a month of data is used because the initial condition has negligible impact on the final API for a sufficiently long series)
- APRAIN = the time series of daily rainfall readings (in 10F8.0 format) obtained from the sum of hourly rainfall data for approximately one month prior to the start of the hourly rainfall
- BAREA = the subbasin area in square miles
- APITYPE = the API zone (with SE = 1, E = 2, NE = 3, N = 4, W = 5, and S = 6). The Blue Ridge Dam subbasin is within the SE zone, (see Fig. 8).
- NSPW = 1 for number of rainfall stations for each subwatershed (for gridded data there are no Thiessen weighting factors)
- NUMVOL = number of watersheds above surface runoff volume check point
- CHKVOL = the volume of surface runoff in inches, which is calculated from outflow hydrographs after baseflow separation; when CHKVOL is greater than zero, the final runoff index is adjusted if necessary to provide a volume equal to CHKVOL.

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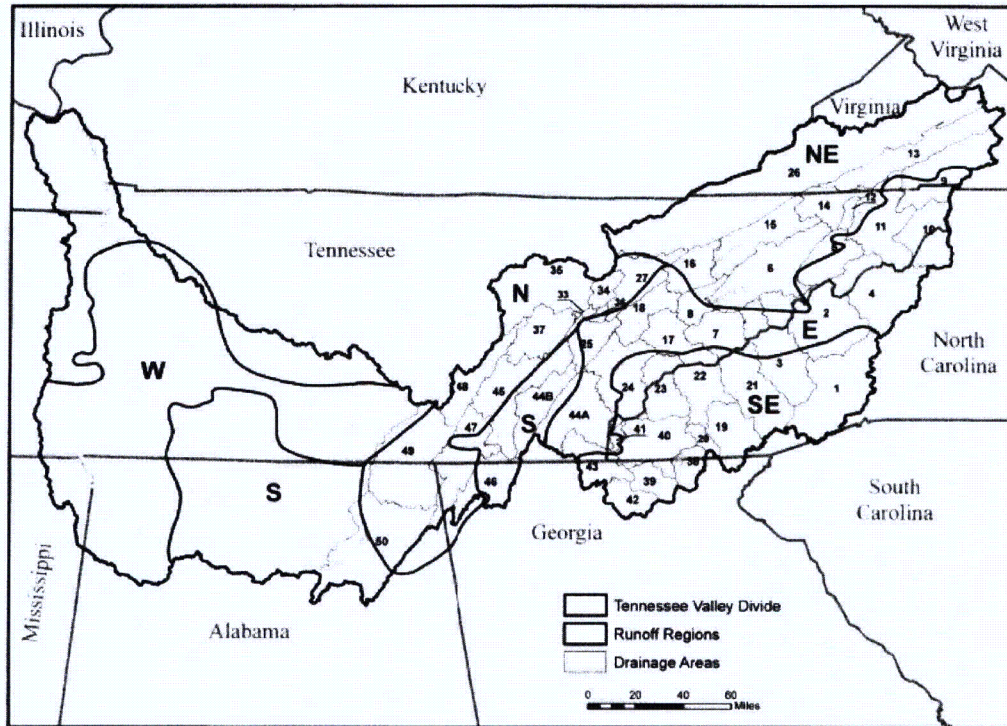
Figure 8: Runoff regions for application of TVA FLDHYDRO program

Data processing to obtain daily antecedent rainfall depths and hourly storm depths and convert the gridded precipitation data to the format required for use in FLDHYDRO was carried out in "Basin 42 PPT Data Processing 2004.xls" and "Basin 42 PPT Data Processing 2005.xls" (Attachments 1-2 and 1-3). The antecedent rainfall days used for the September 2004 and July 2005 simulations are presented in Table 4. The hourly basin average rainfall depths are reproduced in Table 5 in the 10F8.0 FORTRAN format used by the FLDHYDRO program.

Input data and parameters for running FLDHYDRO to get effective basin average rainfall for the Blue Ridge Dam model were written to the following files:

- Basin42ppt2004.dat (Attachment 2-1)
- Basin42ppt2005.dat (Attachment 2-3)

Output (echoing input) is provided in the following files:

- Basin42ppt2004.out (Attachment 2-2)
- Basin42ppt2005.out (Attachment 2-4)

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Figures 9 and 10 provide a plot of the output for the 2004 and 2005 events. The incremental effective basin average rainfall time series in the last column of each table were developed on tabs "FLDHYDRO 2004" and "FLDHYDRO 2005" of spreadsheet "Basin 42-FLDHYDRO I&O Prepwork.xls" (Attachment 1-1) for input to HEC-HMS (Reference 6).

Table 4: Daily basin average rainfall depths used in API calculations for September 2004 and July 2005 events

Date	Daily rainfall depth, inches		Date	Daily rainfall depth, inches
8/16/2004	0.000		6/10/2005	0.553
8/17/2004	0.140		6/11/2005	0.230
8/18/2004	0.000		6/12/2005	1.204
8/19/2004	0.000		6/13/2005	0.099
8/20/2004	1.193		6/14/2005	0.000
8/21/2004	0.125		6/15/2005	0.001
8/22/2004	0.000		6/16/2005	0.000
8/23/2004	0.000		6/17/2005	0.000
8/24/2004	0.413		6/18/2005	0.307
8/25/2004	0.001		6/19/2005	0.001
8/26/2004	0.000		6/20/2005	0.337
8/27/2004	0.182		6/21/2005	0.037
8/28/2004	0.219		6/22/2005	0.000
8/29/2004	0.065		6/23/2005	0.000
8/30/2004	0.013		6/24/2005	0.000
8/31/2004	0.000		6/25/2005	0.028
9/1/2004	0.619		6/26/2005	0.255
9/2/2004	0.077		6/27/2005	0.342
9/3/2004	0.000		6/28/2005	1.844
9/4/2004	0.000		6/29/2005	0.312
9/5/2004	0.000		6/30/2005	0.307
9/6/2004	0.001		7/1/2005	0.501
9/7/2004	2.186		7/2/2005	0.004
9/8/2004	0.109		7/3/2005	1.010
9/9/2004	0.000		7/4/2005	0.288
9/10/2004	0.051		7/5/2005	0.083
9/11/2004	0.000		7/6/2005	0.680
9/12/2004	0.000		7/7/2005	1.211
9/13/2004	0.000		7/8/2005	0.000
9/14/2004	0.000		7/9/2005	0.000
9/15/2004	0.004			

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Table 5: Hourly basin average rainfall depths used for modeling excess precipitation (runoff) in FLDHYDRO

Hourly rainfall depths, in inches starting September 16, 2004									
0.008	0.002	0.001	0.002	0.002	0.000	0.009	0.062	0.029	0.113
0.005	0.012	0.053	0.213	0.351	0.162	0.217	0.289	0.894	0.865
0.409	0.277	0.239	0.007	0.015	0.005	0.018	0.060	0.046	0.050
0.032	0.030	0.033	0.026	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Hourly rainfall depths, in inches starting July 10, 2005									
0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.030
0.179	0.073	0.051	0.030	0.020	0.076	0.180	0.260	0.215	0.374
0.193	0.204	0.313	0.173	0.084	0.027	0.014	0.006	0.008	0.000
0.000	0.011	0.029	0.006	0.165	0.628	0.098	0.013	0.000	0.000
0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.003	0.016	0.213
0.092	0.066	0.139	0.007	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.001	0.000	0.063	0.028	0.011	0.000	0.030	0.027
0.001	0.000	0.004	0.073	0.077	0.030	0.001	0.000	0.000	0.000
0.000	0.002	0.010	0.016	0.020	0.002				

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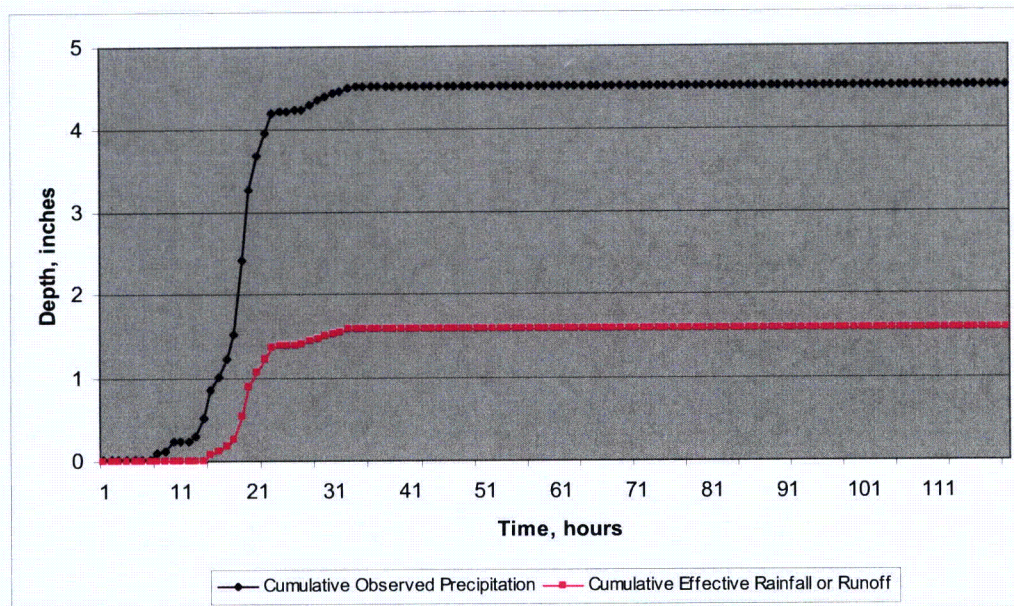
Figure 9: Cumulative observed and effective basin average precipitation for the September 2004 event
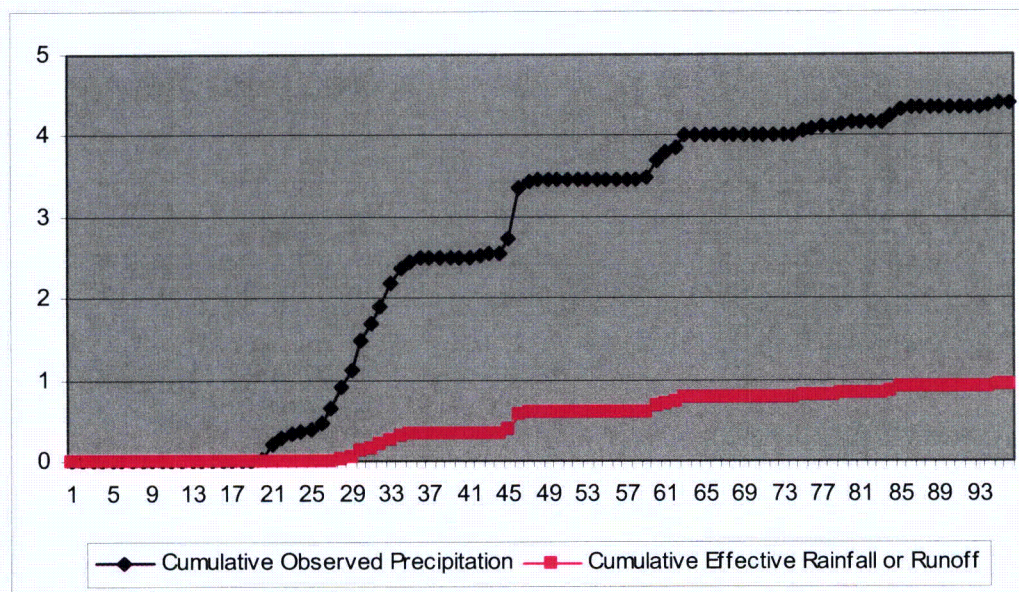
Figure 10: Cumulative observed and effective basin average precipitation for the July 2005 event

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7.6 HEC-HMS Simulations of Flood Events

A HEC-HMS project file was developed for testing the unit hydrograph developed by the TVA for the Blue Ridge Dam subbasin for the September 2004 and July 2005 storm events. This project file has been compressed into a zip file to preserve the folder structure and has been stored in FILEKEEPER (Attachment 3). The output associated with the HEC-HMS program, while stored within the zip file for convenience and preservation, is provided in the calculation as Figures 11 and 12.

The following basin models were developed:

- Blue Ridge 2004
- Blue Ridge 2005

The following input files were developed for the project and input to HEC-HMS (Reference 6) via the Time Series Data Manager (all time series are adjusted to Central Standard Time for this calculation):

- Precipitation Gage "Effective Sep2004" with hourly data incremental depths
- Precipitation Gage "EffectiveJul2005" with hourly data incremental depths
- Discharge Gage "RRRSept2004" with bi-hourly direct runoff discharge in cfs
- Discharge Gage "RRRJuly2005" with hourly direct runoff discharge in cfs

Note that instead of inputting observed basin average precipitation and utilizing a loss function for the subbasin, the effective basin average rainfall (or runoff) output from FLDHYDRO was utilized as "precipitation data." The unit hydrograph for the Blue Ridge Dam subbasin was input to HEC-HMS with the Paired Data Manager as TVAUH.

The TVA unit hydrograph was used to simulate the September 2004 and July 2005 floods in HEC-HMS using effective basin average rainfall determined with FLDHYDRO. The simulated hydrographs are compared to the observed hydrograph for each run in Figures 11 and 12, which were obtained from the HEC-HMS Graphical User Interface. Table 6 provides a qualitative assessment of the results of the simulations.

Table 6: Qualitative assessment of the observed versus simulated flood hydrographs

storm event	Summary results
September 2004	Excellent duplication of hydrograph shape and timing of peak discharge and length of rising and falling limbs of hydrograph
	Magnitude of peak discharge overestimated by about 11%
July 2005	Fair to good duplication of hydrograph shape, with good timing of peak discharge and length of rising and falling limbs of hydropgraph
	Exact duplication of first peak discharge with 22% underestimate of second peak

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Subbasin "Blue Ridge" Results for Run "Sep2004"

Legend (Compute Time: 15Oct2008, 12:16:54)

Run:Sep2004 Element:BLUE RIDGE Result:Precipitation
Run:SEP2004 Element:BLUE RIDGE Result:Observed Flow
Run:Sep2004 Element:BLUE RIDGE Result:Baseflow
Run:Sep2004 Element:BLUE RIDGE Result:Precipitation Loss
Run:Sep2004 Element:BLUE RIDGE Result:Outflow

Project: Basin 42
Simulation Run: Sep2004   Subbasin: Blue Ridge

Start of Run: 16Sep2004, 00:00   Basin Model: Blue Ridge 2004
End of Run: 22Sep2004, 00:00   Meteorologic Model: ExcessSep2004
Compute Time: 15Oct2008, 12:16:54   Control Specifications: Sept2004

Volume Units: ⦿ IN ◯ AC-FT

Computed Results

Peak Discharge :   12839.6 (CFS)   Date/Time of Peak Discharge : 17Sep2004, 00:00
Total Precipitation : 1.41 (IN)   Total Direct Runoff :   1.41 (IN)
Total Loss :   0.00 (IN)   Total Baseflow :   0.00 (IN)
Total Excess :   1.41 (IN)   Discharge :   1.41 (IN)

Observed Hydrograph at Gage RRRSept2004

Peak Discharge :   11528.00 (CFS)   Date/Time of Peak Discharge : 17Sep2004, 00:00
Avg Abs Residual : 273.86 (CFS)
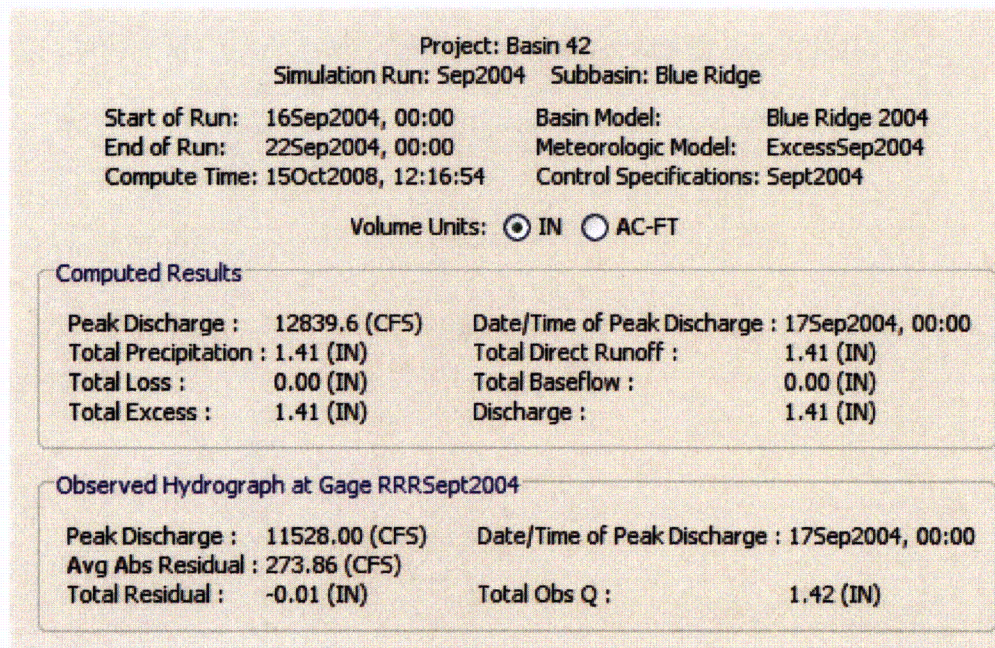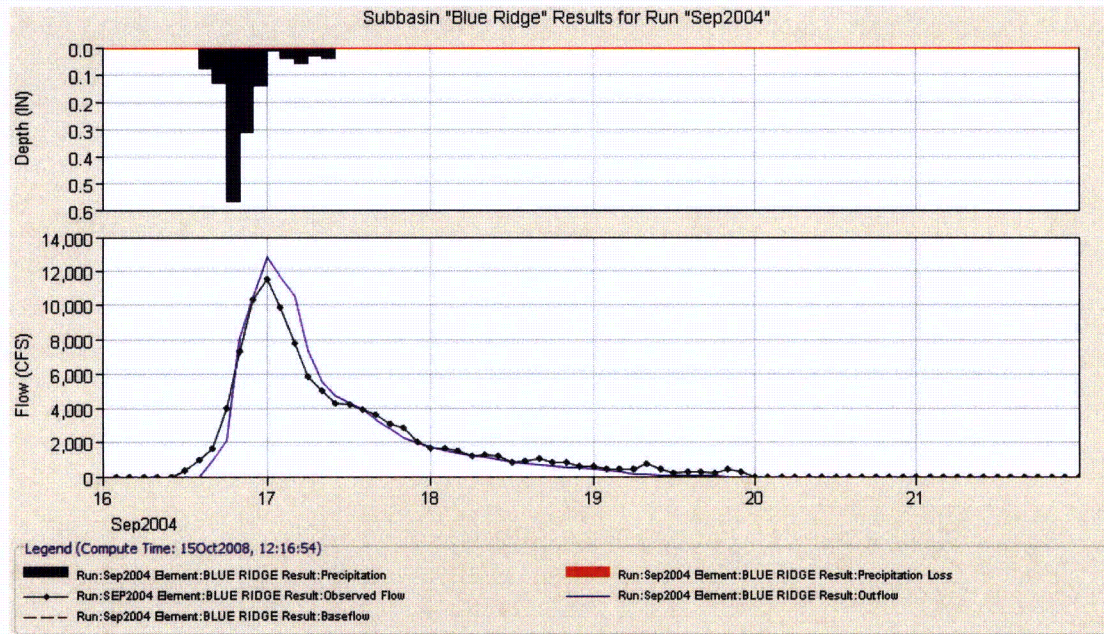Total Residual :   -0.01 (IN)   Total Obs Q :   1.42 (IN)

Figure 11: HEC-HMS results for Subbasin 42 for the September 2004 event

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			Checked	N.D.M.

Subbasin "Blue Ridge" Results for Run "July2005"

Project: Basin 42
Simulation Run: July2005   Subbasin: Blue Ridge

Start of Run: 10Jul2005, 00:00   Basin Model: Blue Ridge 2005
End of Run: 21Jul2005, 00:00   Meteorologic Model: ExcessJul2005
Compute Time: 11Oct2008, 17:12:18   Control Specifications: July2005

Volume Units: ⊙ IN ○ AC-FT

Computed Results

Peak Discharge :	3615.1 (CFS)	Date/Time of Peak Discharge :	12Jul2005, 02:00
Total Precipitation :	0.93 (IN)	Total Direct Runoff :	0.93 (IN)
Total Loss :	0.00 (IN)	Total Baseflow :	0.00 (IN)
Total Excess :	0.93 (IN)	Discharge :	0.93 (IN)

Observed Hydrograph at Gage RRRJuly2005

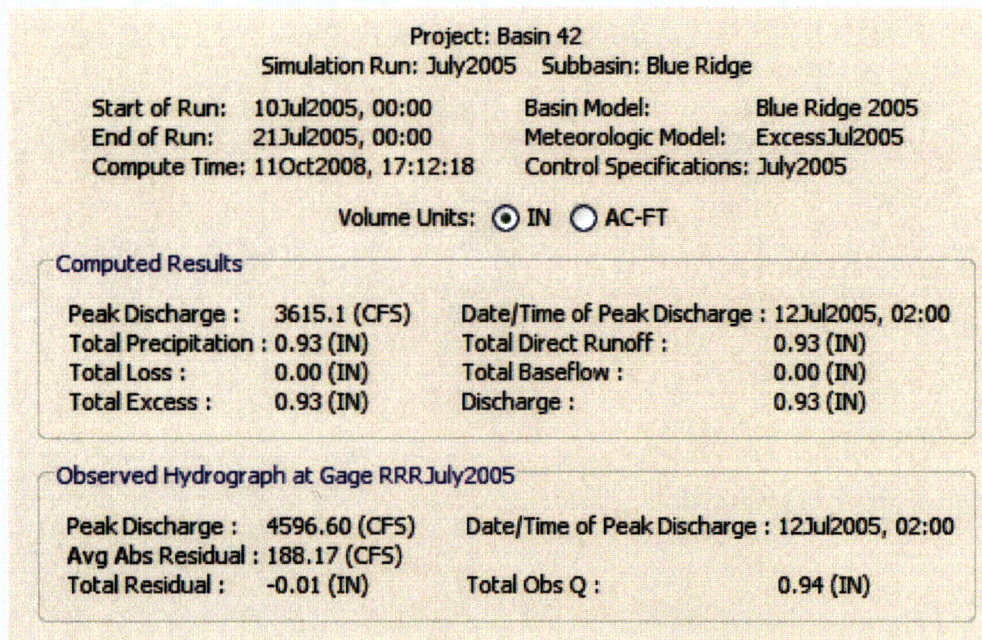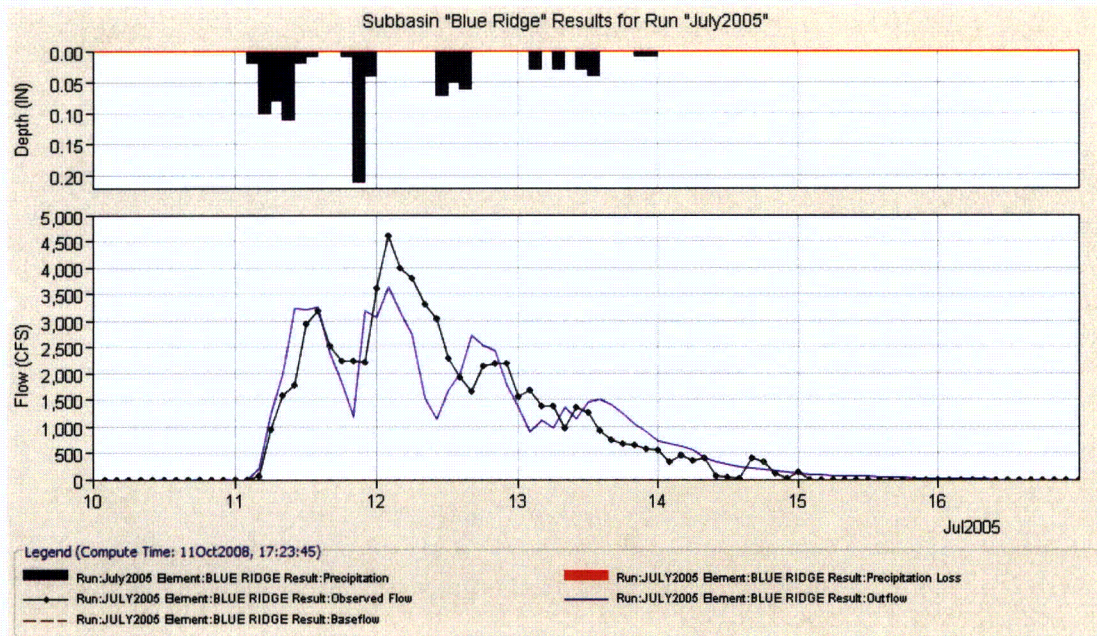|			
Peak Discharge :	4596.60 (CFS)	Date/Time of Peak Discharge :	12Jul2005, 02:00
Avg Abs Residual :	188.17 (CFS)		
Total Residual :	-0.01 (IN)	Total Obs Q :	0.94 (IN)

Figure 12: HEC-HMS results for Subbasin 42 for the July 2005 event

TVA

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Subject: Subbasin 42 (Blue Ridge Dam) Unit Hydrograph Validation		Prepared	T.H.J.
		Checked	N.D.M.

8 Conclusions

FLDHYDRO was used to estimate the excess rainfall for Subbasin 42. This program uses previously established loss functions based on initial moisture conditions (API), the week of the year, and the region. For this calculation, the program option for adjusting the effective basin average rainfall hyetograph to match the observed direct runoff volume was used. The unit hydrograph for Subbasin 42 and the estimated excess rainfalls were then used in HEC-HMS to simulate the September 2004 and July 2005 floods within Subbasin 42. The resulting hydrographs at the subbasin outlet were compared to the hydrographs obtained from reverse reservoir routing, with baseflow removed from each flow series.

The September 2004 simulation resulted in a storm hydrograph that compares extremely well with the observed hydrograph obtained from reverse reservoir routing in terms of the timing, peak discharge, and overall shape, including the timing of the rising and falling limbs. The simulated peak discharge for the flood event was 11 percent higher than the observed peak obtained by reverse reservoir routing.

The July 2005 simulation resulted in a basin outflow hydrograph that compares reasonably well with the observed hydrograph obtained from reverse reservoir routing in terms of the overall shape of the hydrograph and the timing of the multiple peak discharges. There was an essentially exact duplication of the first peak with a 22 percent underestimation of the second, maximum peak for the storm event.

The unit hydrograph was less successful in replicating the July 2005 event than in replicating the September 2004 event. There is greater uncertainty in simulating rainfall losses in storm events consisting of a complex rainfall pattern with several rainfall bursts separated by several hours than for shorter more intense storms. Even so, a reasonable simulation of the 2005 event was achieved in terms of qualitative comparisons with the observed flow series.

Based on the preceding discussion, it is concluded that the unit hydrograph developed by the TVA for the Blue Ridge Dam watershed (Subbasin 42) has been validated against a more recent storm event that occurred in September 2004, and gives reasonable results for the 2005 flood. Considering that the unit hydrograph developed from historical flood events (1951, 1961, 1964 and 1967) with good results (Reference 8), and demonstrated in this calculation to be valid for an event that occurred in 2004, it may be concluded that the unique physical characteristics and runoff processes of the drainage basin remain the same as at the time of unit hydrograph development. Therefore, the unit hydrograph for Subbasin 42, tabulated in Table 1 and plotted in Figure 2, accurately describes the response of the watershed and is adequate for application to design storm events.