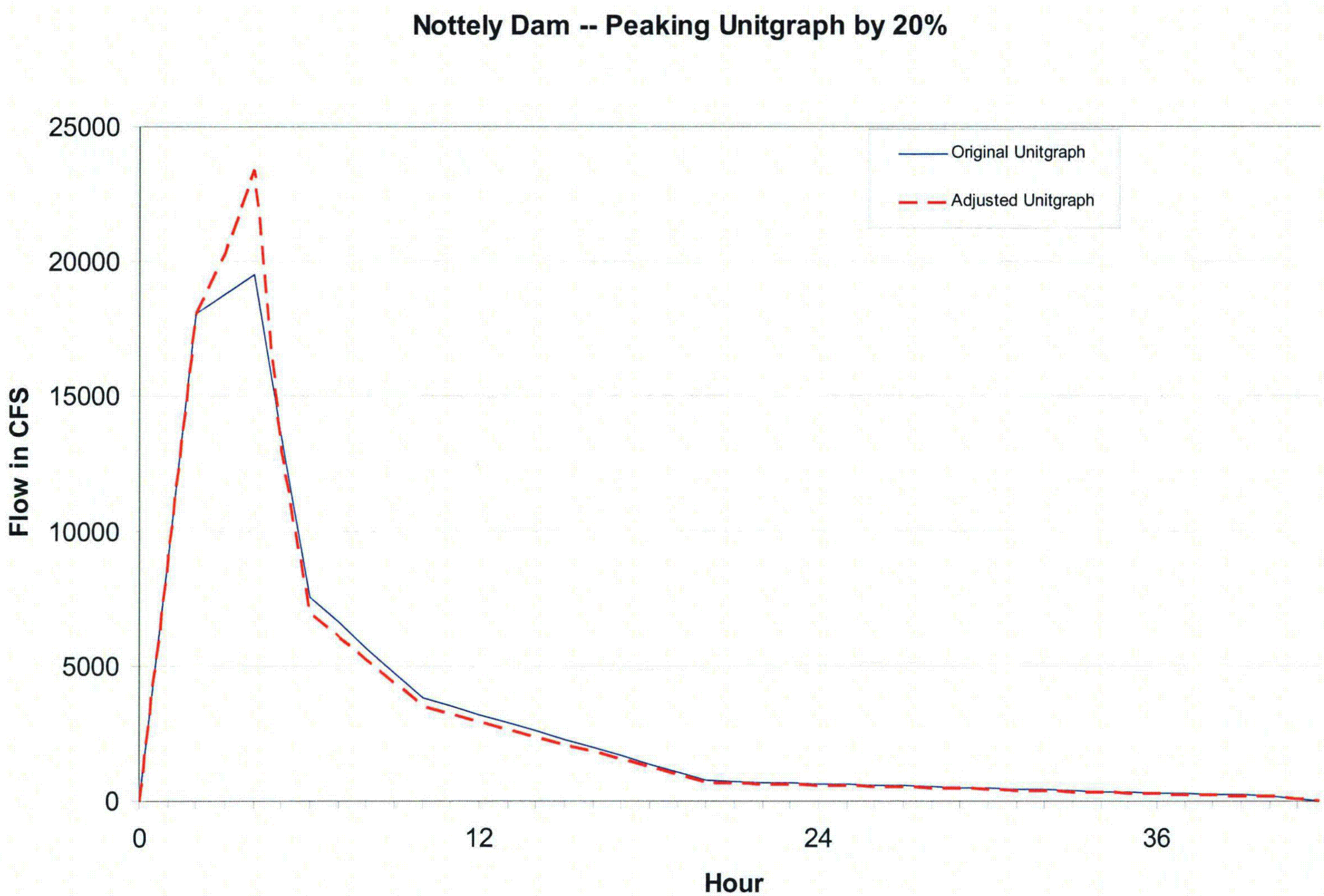
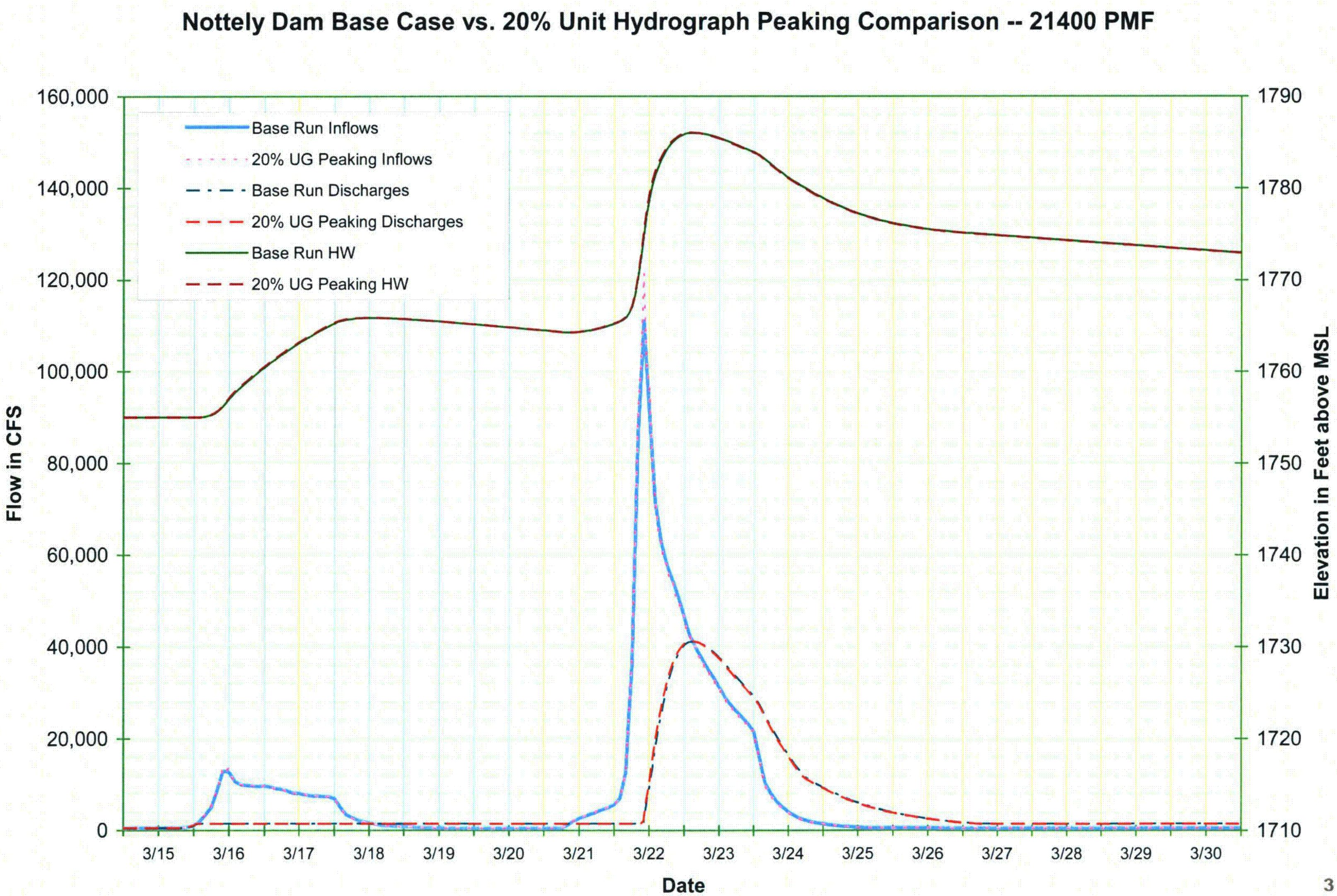
Sensitivity Analysis – 20% Peaking of Unit Hydrograph

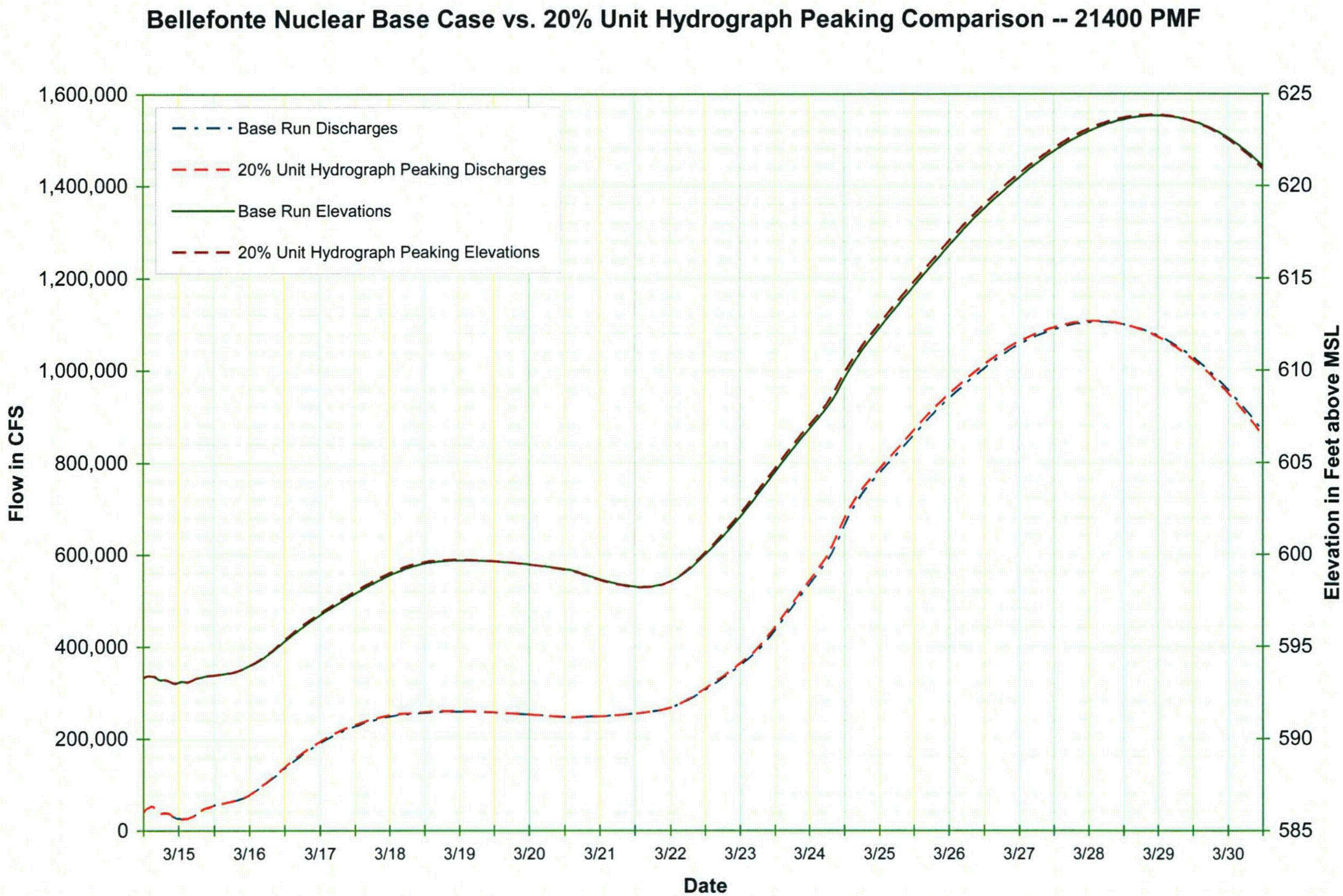
Peaking of Unit Hydrograph



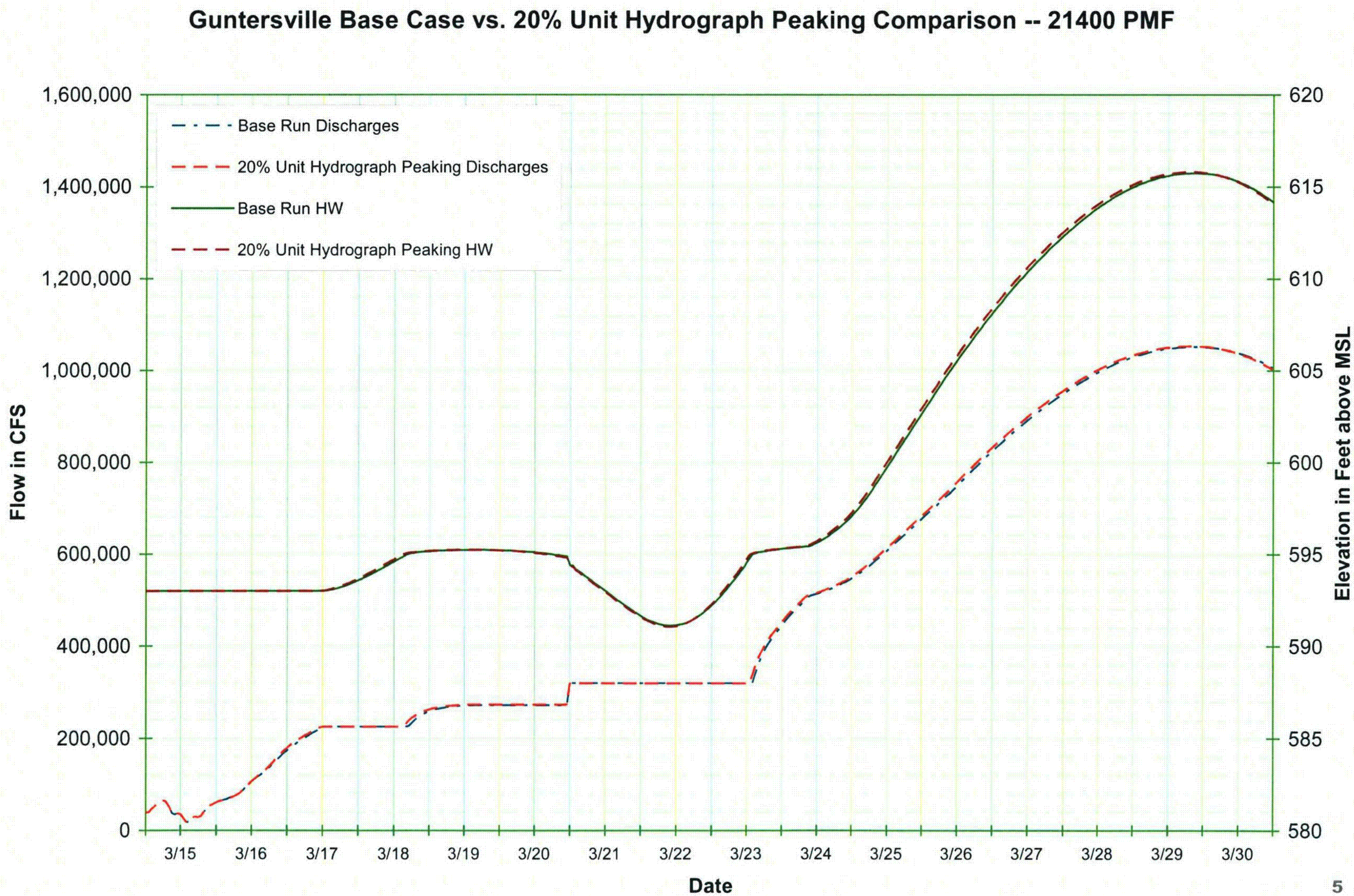
Base Case vs. 20% Peaking – Nottely Outflow



Base Case vs. 20% Peaking - BLN



Base Case vs. 20% Peaking – Guntersville Dam



TVA

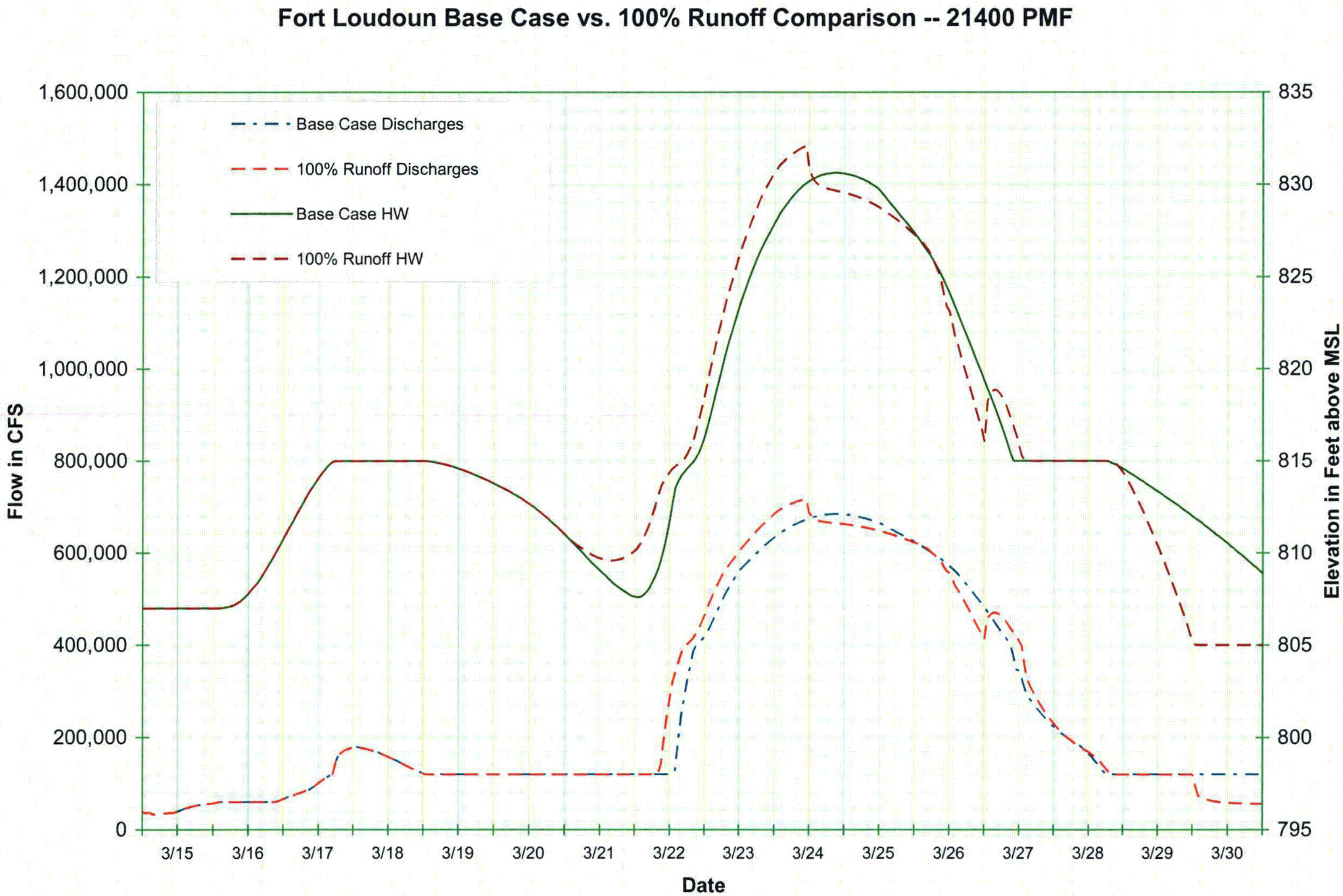
Base Case vs. 20% Peaking

Base Case vs. 20% Unit Hydrograph Peaking Comparison -- 21400 PMF

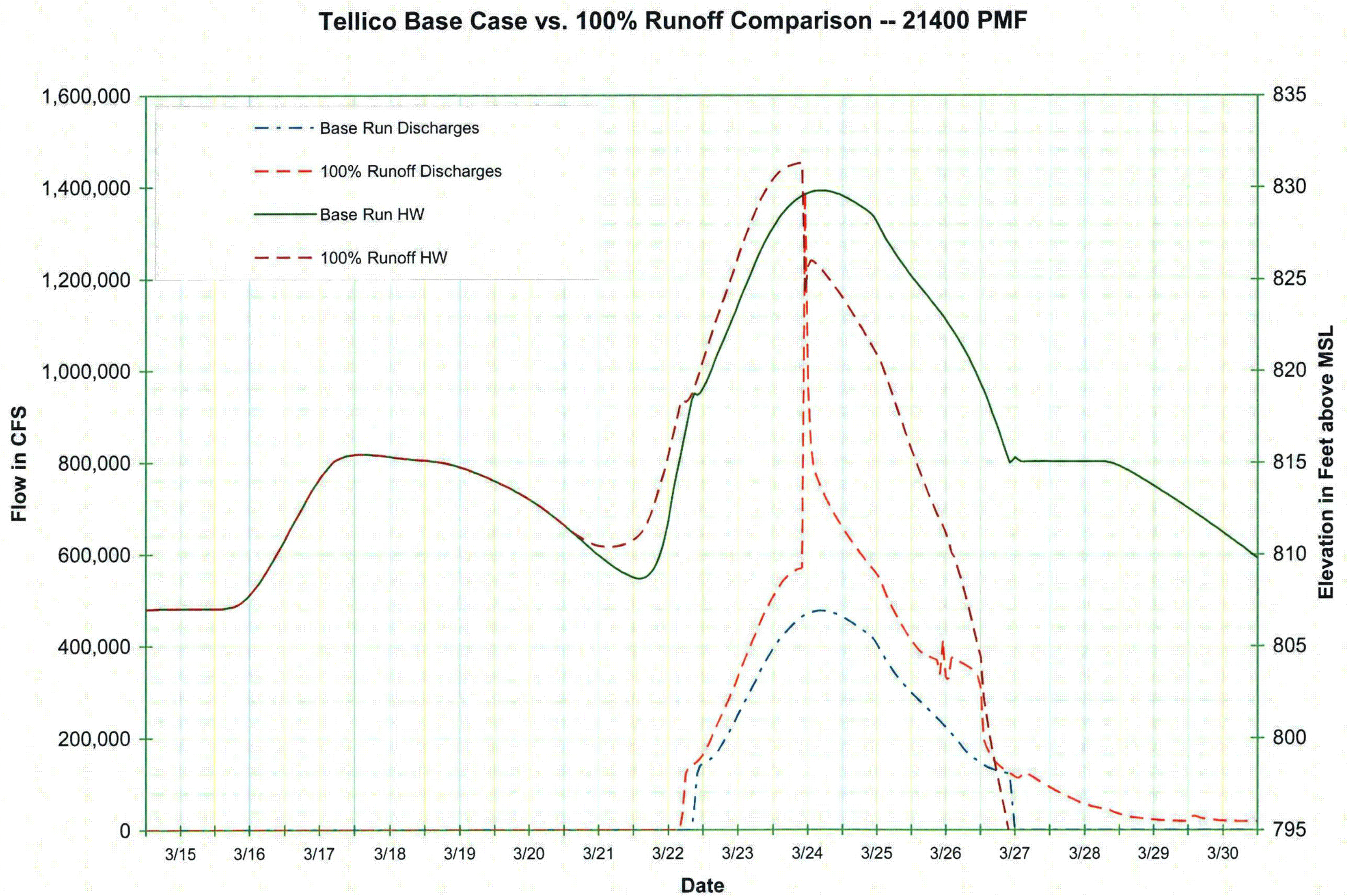
Nuclear Plant	Base Case Elevation (Feet above MSL)	Base Case Flow (cfs)		20% Unit Hydrograph Peaking Elevation (Feet above MSL)	20% Unit Hydrograph Peaking Flow (cfs)
Watts Bar	734.36	1,230,000		734.39	1,228,000
Sequoyah	718.68	1,208,000		718.72	1,209,000
Bellefonte	623.82	1,105,000		623.86	1,107,000

Sensitivity Analysis – 100% Runoff

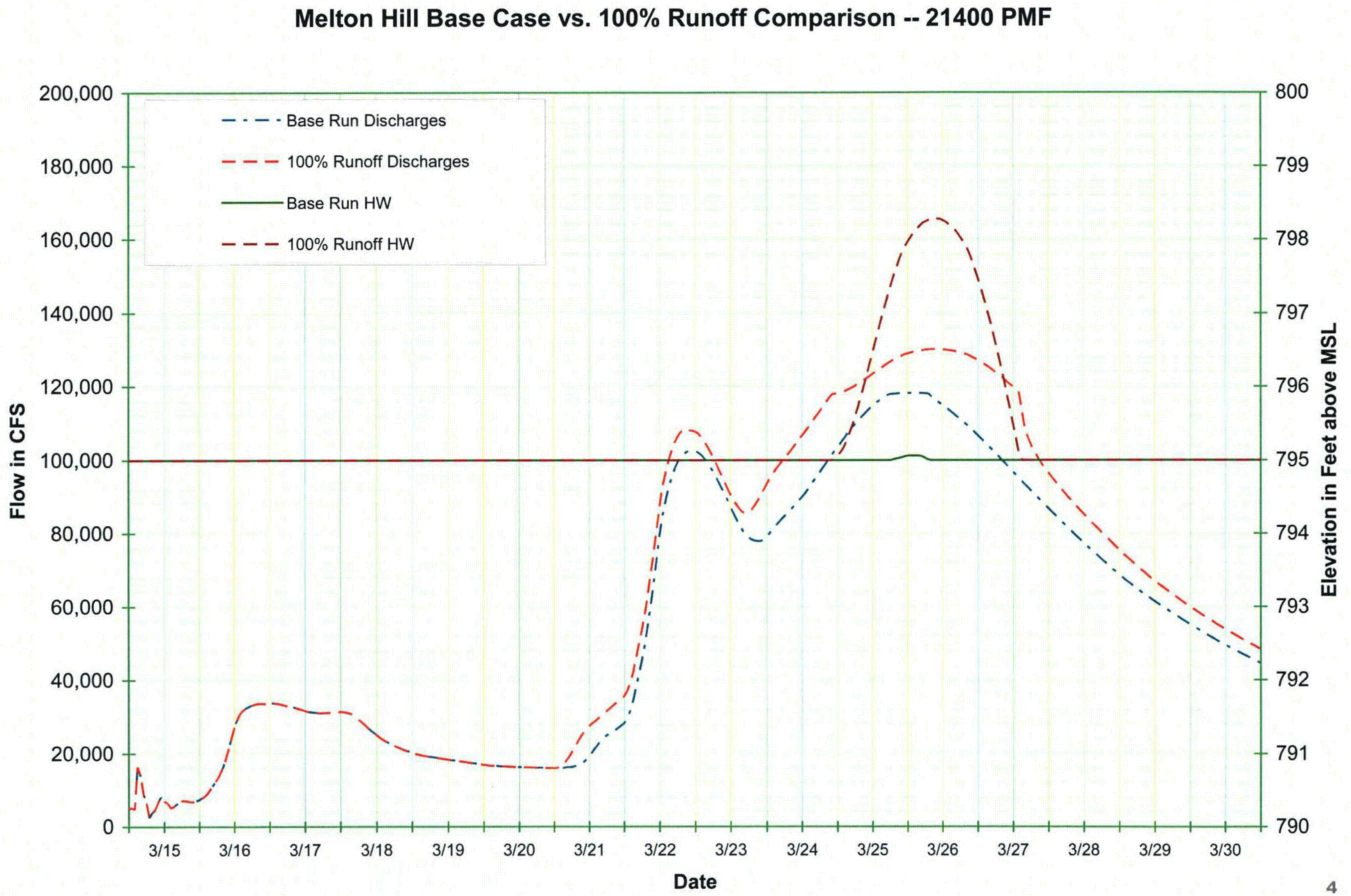
Base Case vs. 100% Runoff



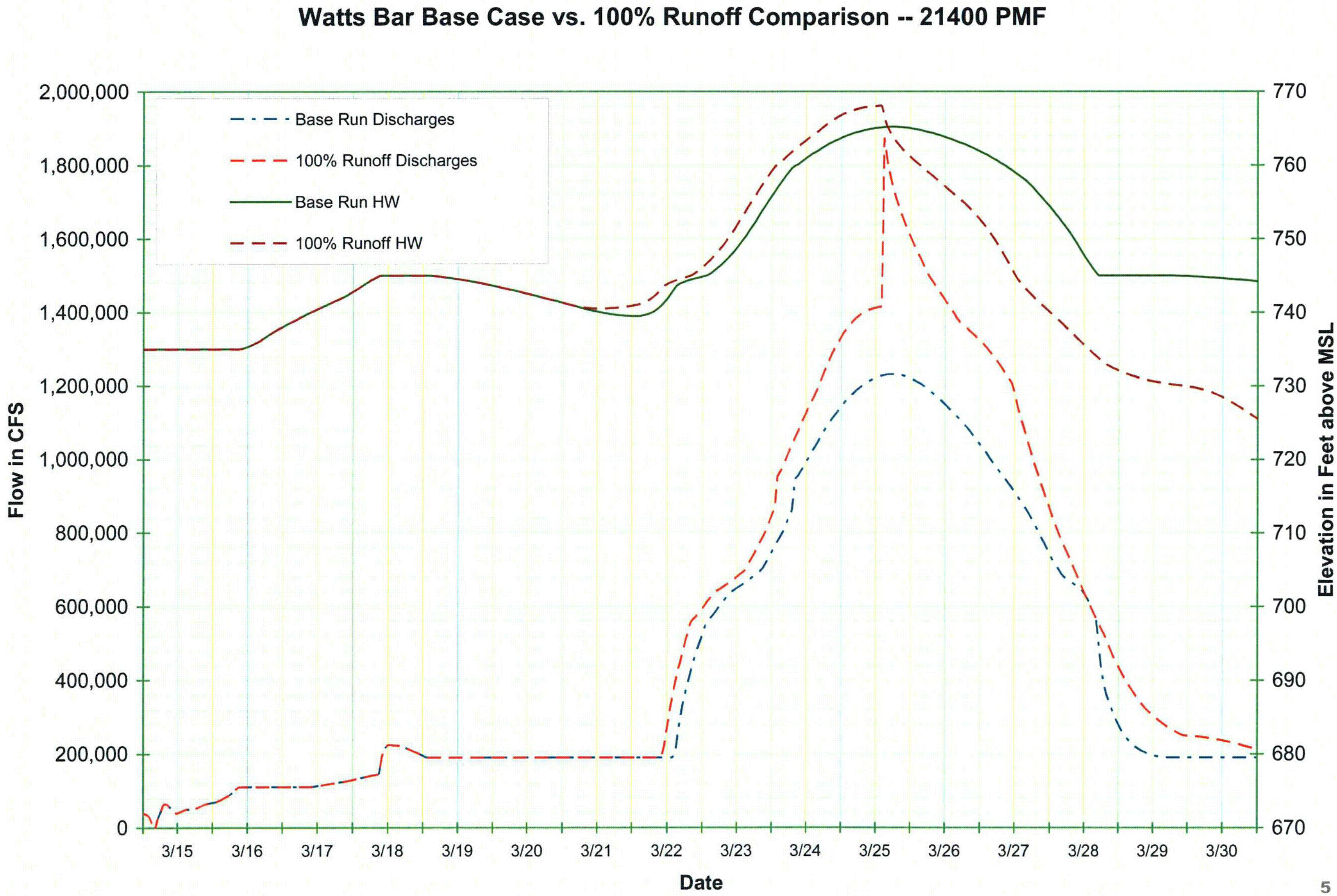
Base Case vs. 100% Runoff



Base Case vs. 100% Runoff

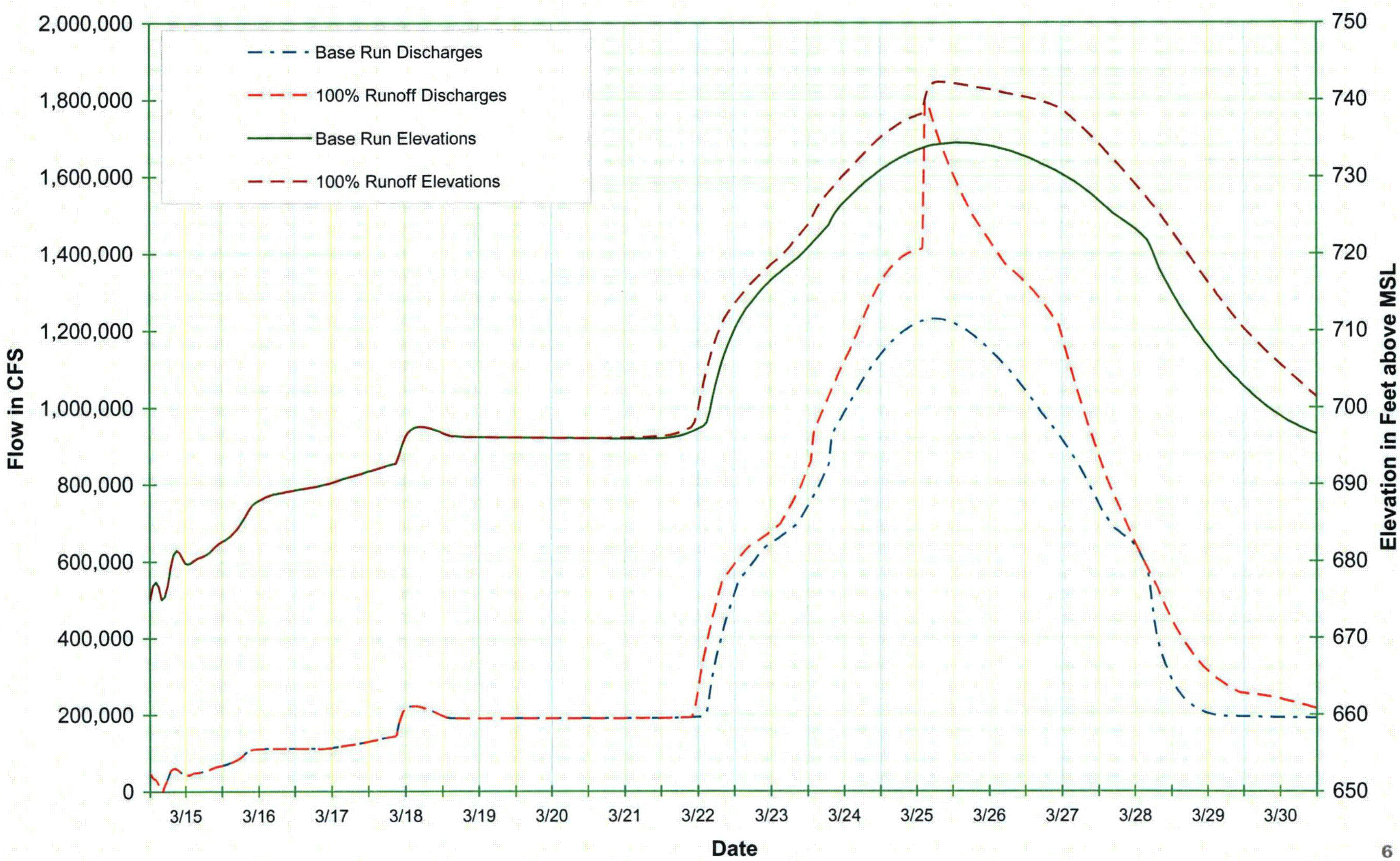


Base Case vs. 100% Runoff

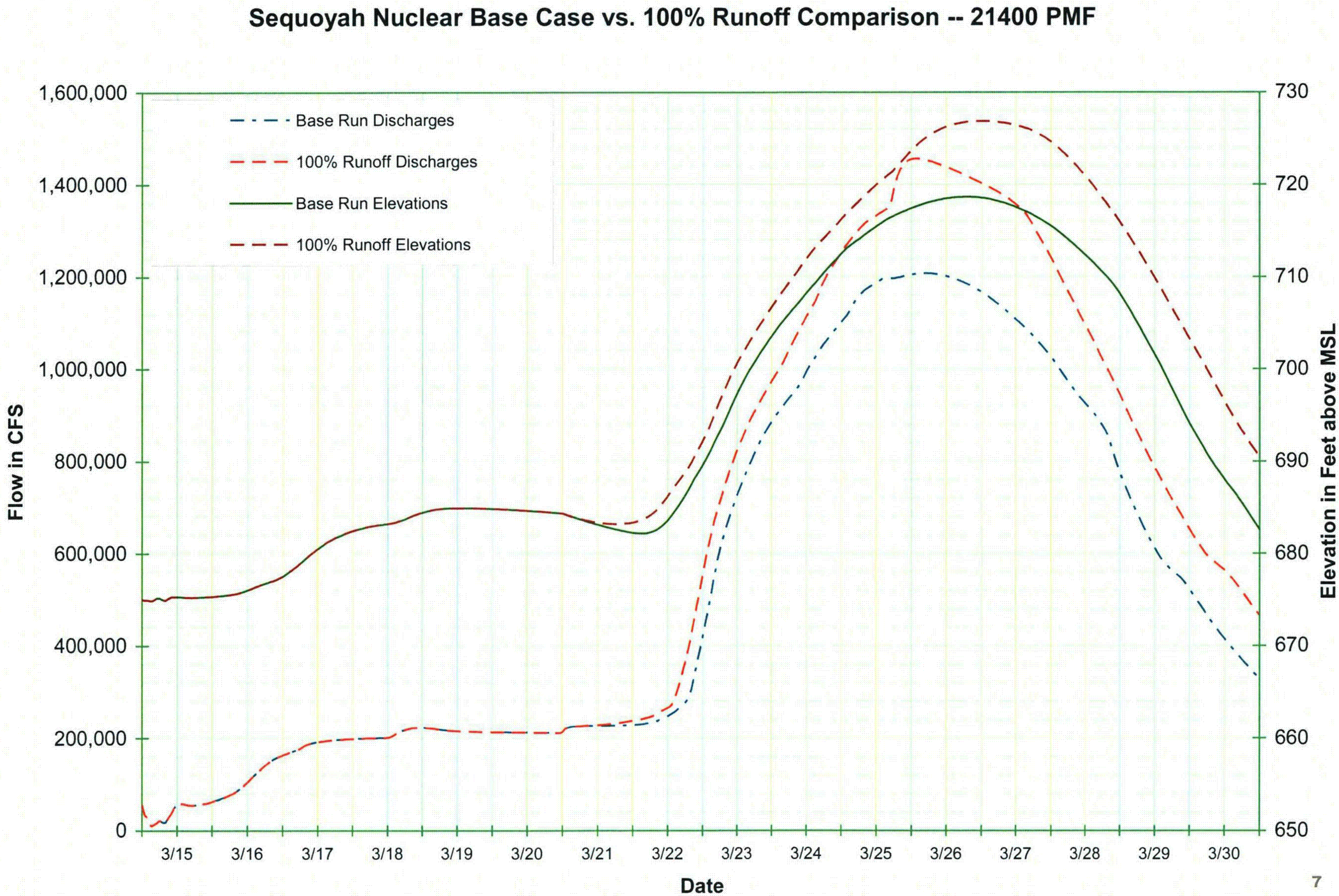


Base Case vs. 100% Runoff

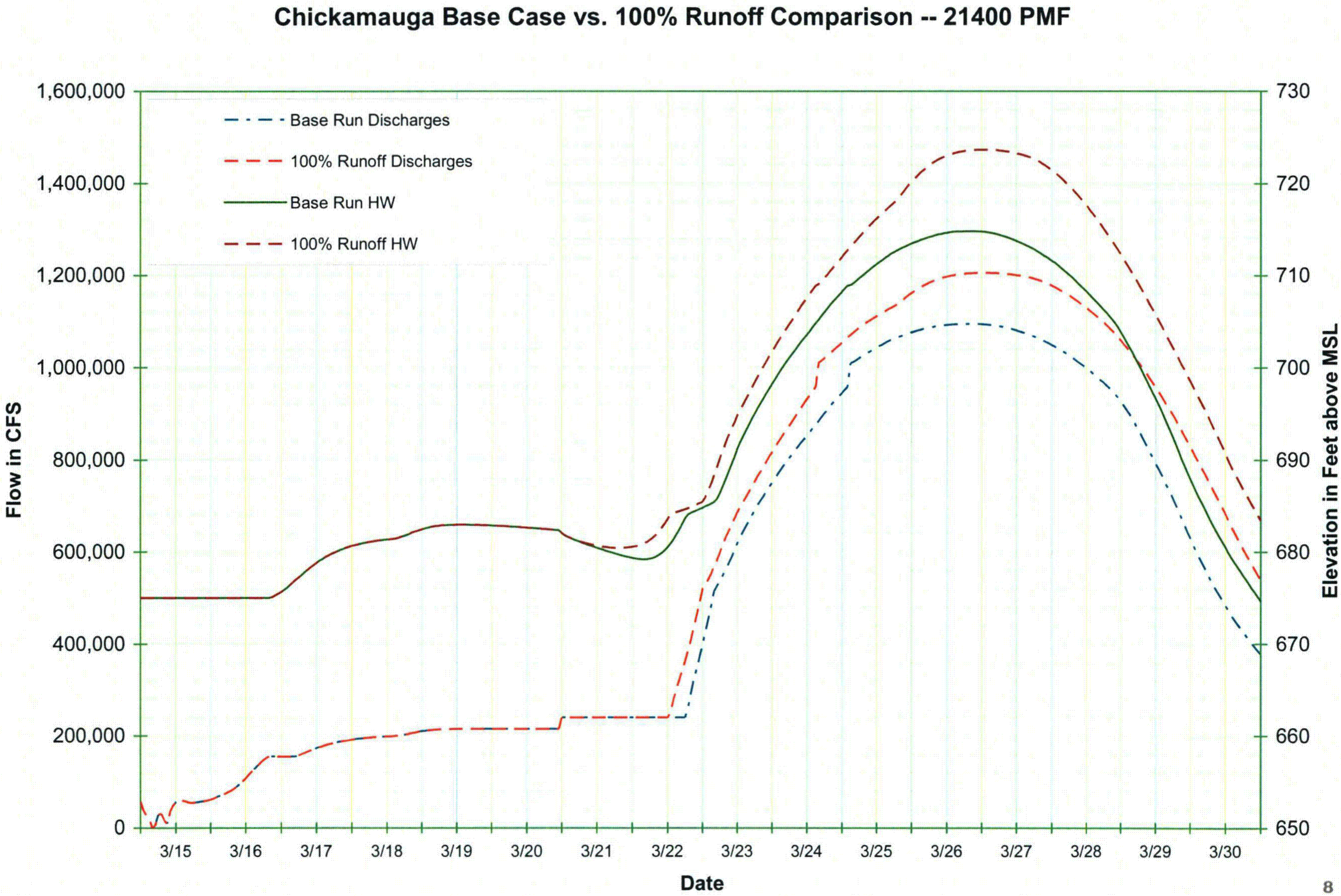
Watts Bar Nuclear Base Case vs. 100% Runoff Comparison -- 21400 PMF



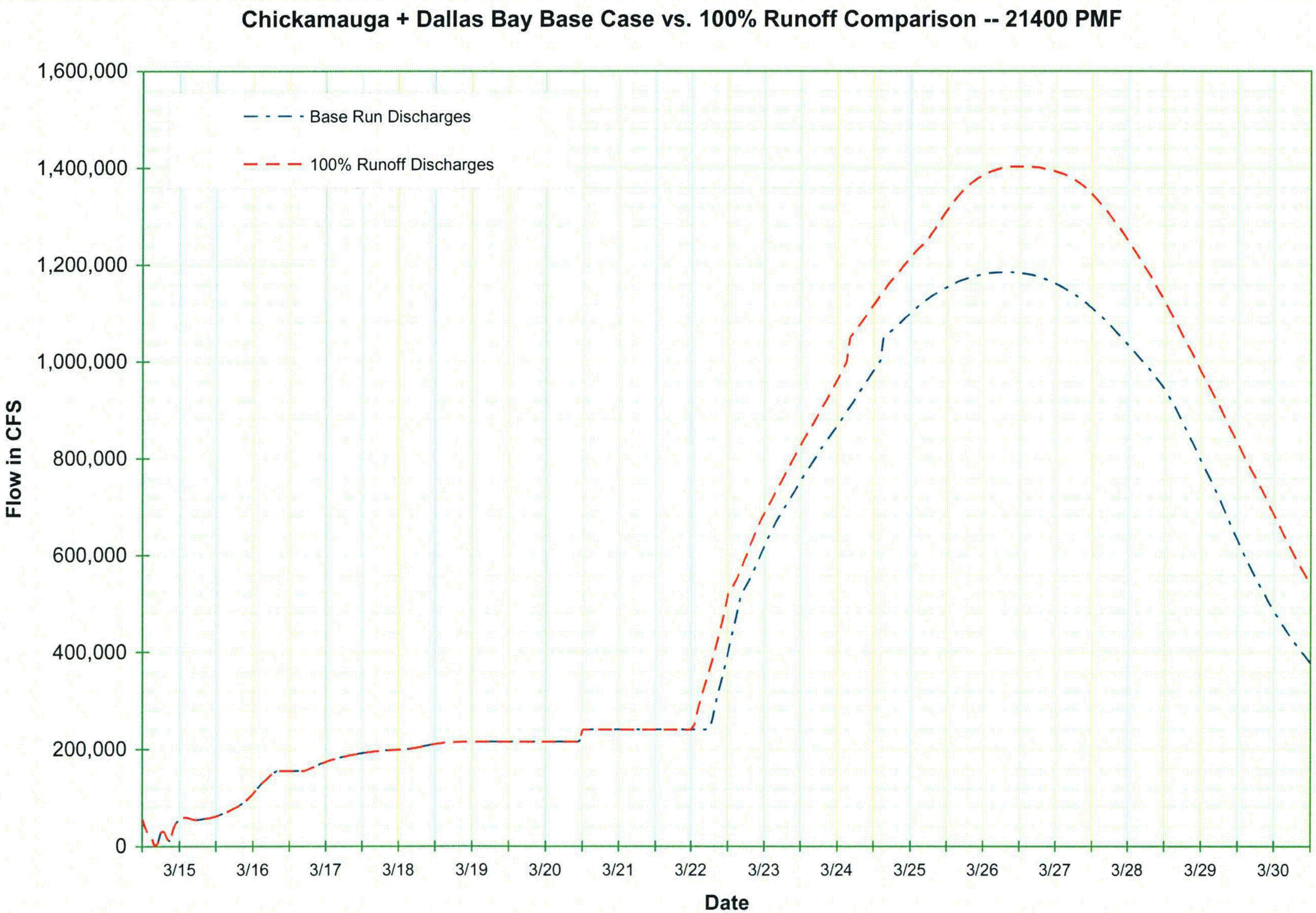
Base Case vs. 100% Runoff



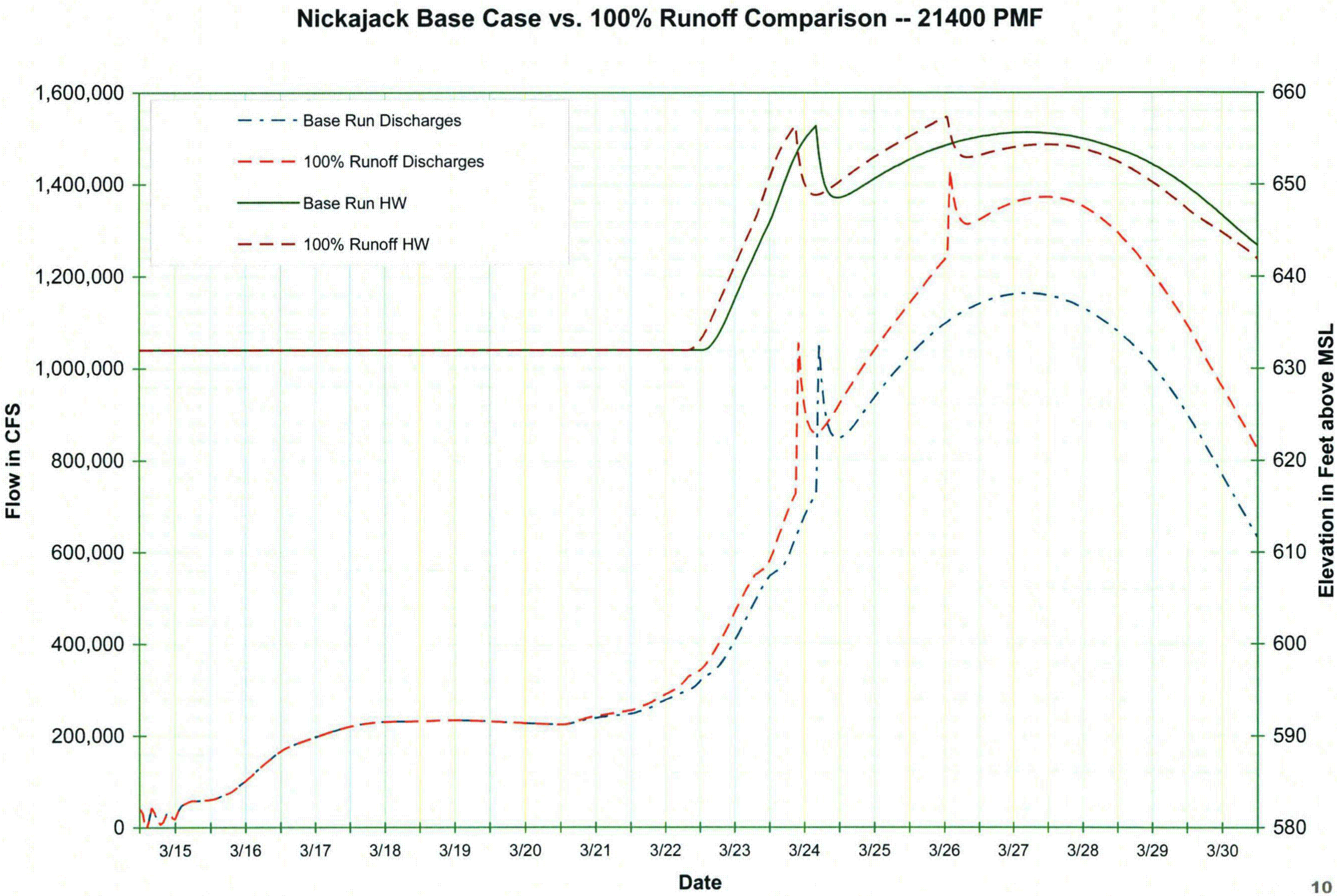
Base Case vs. 100% Runoff



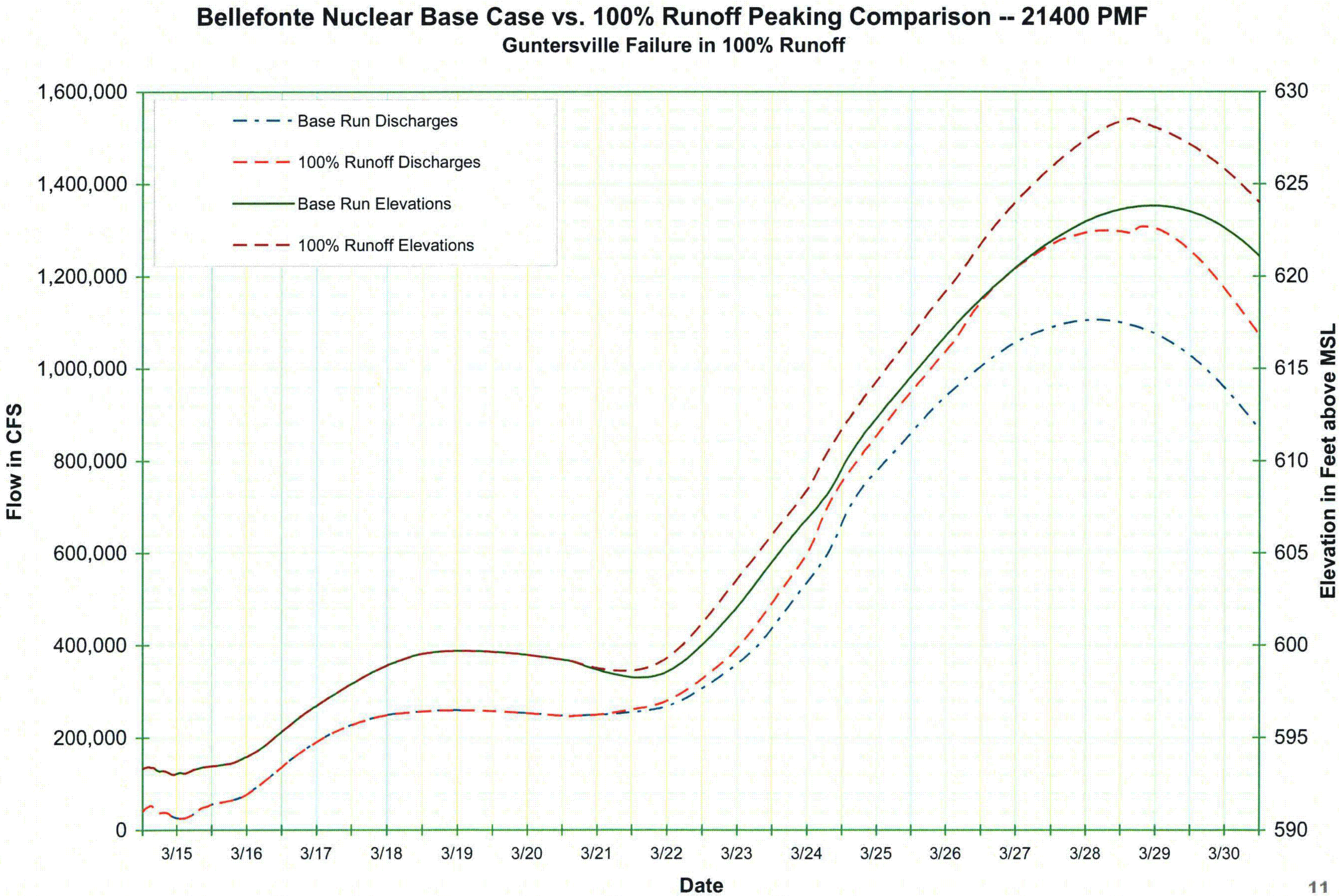
Base Case vs. 100% Runoff



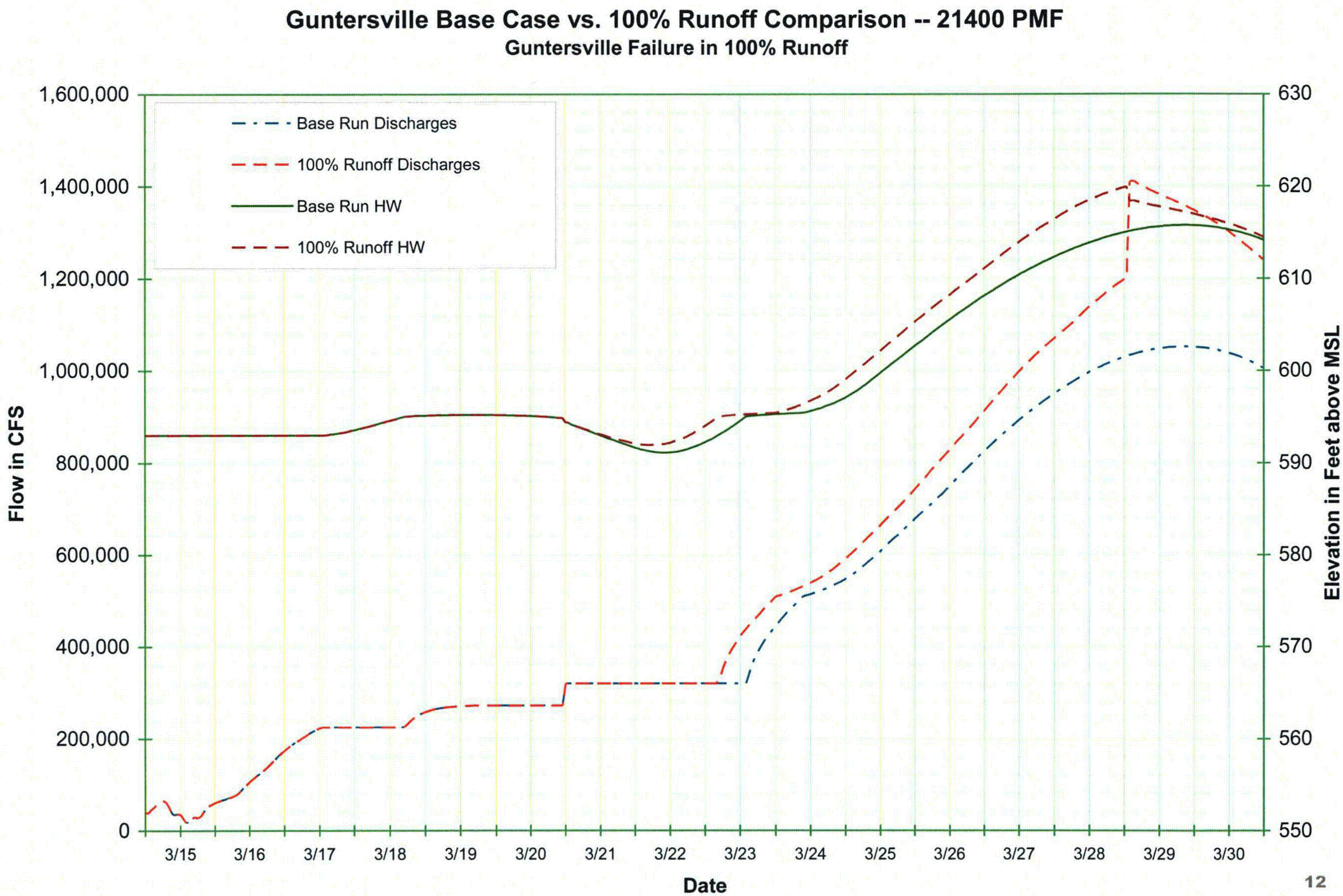
Base Case vs. 100% Runoff



Base Case vs. 100% Runoff



Base Case vs. 100% Runoff



Base Case vs. 100% Runoff

Nuclear Plant	Base Case Elevation / HW (Feet above MSL)	Base Case Flow cfs		100% Runoff Elevation / HW (Feet above MSL)	100% Runoff Flow cfs
Watts Bar	734.36	1,230,000		742.29	1,793,000
Sequoyah	718.68	1,208,000		726.87	1,456,000
Bellefonte	623.82	1,105,000		628.55	1,307,000
Projects					
Fort Loudoun	830.64	684,000		832.11	717,000
Tellico	829.82	476,000		831.32	1,393,000
Melton Hill	795.06	118,000		798.28	130,000
Watts Bar	765.21	1,232,000		768.09	1,875,000
Chickamauga	714.81	1,185,000		723.66	1,403,000
Nickajack	656.43	1,163,000		657.44	1,432,000
Guntersville	615.75	1,052,000		619.96	1,411,000

Summary

See Updated Slide

- Assumed 100% runoff for the main storm for the entire watershed above Guntersville Dam.
- Most of the additional runoff occurred during the first day of the main storm – as the original analysis was already at 100% for day last 18 hours of day 2 and 3 of main storm.
- Same operational guides followed at tributary dams.
- Main River dams that failed include: Tellico (provided relief for Fort Loudoun), Watts Bar, Chickamauga, Nickajack, and Guntersville.
- **Elevation at BLN 628.5 (0.5 feet above plant grade)**

TVA

Summary

Updated Slide

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- Same operational guides followed at tributary dams.
- Main River dams that failed include: Tellico (provided relief for Fort Loudoun), Watts Bar, Chickamauga, Nickajack, and Guntersville.
- **Elevation at BLN 628.5 (Just below plant grade elevation 628.6)**

Headwater Rating Curve Review

①

Introduction

- Many of the existing curves were computed in the 1970's and 1980's
- Many sites have since undergone dam safety modifications – curves need to be extended to higher headwaters
- Verification desired for all curves

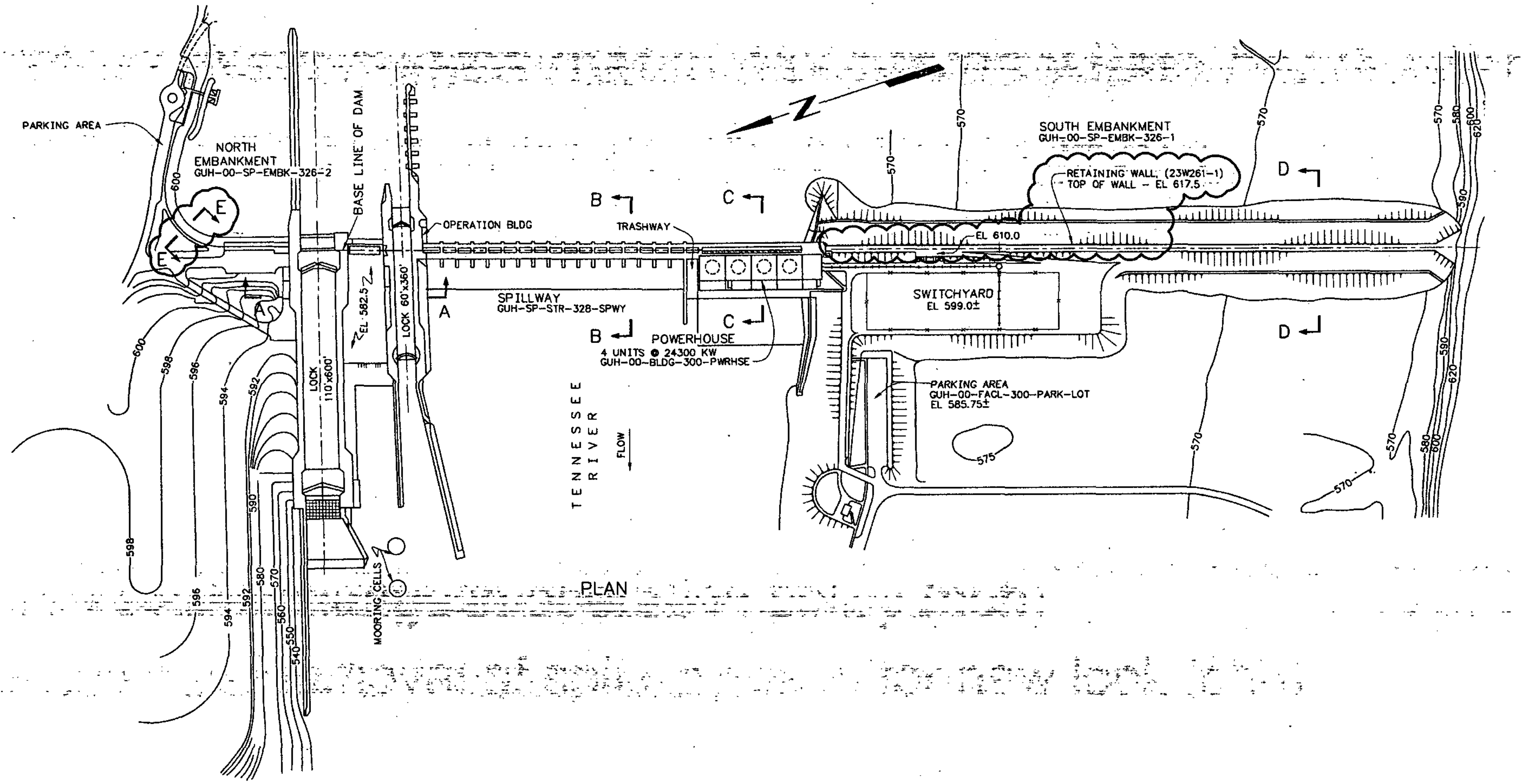
Approach

- Re-compute curves taking advantage of modern spreadsheet software
- Use knowledge of spillway operation and model test data to improve estimation of spillway discharge at high headwaters
- Update dam and embankment overflow calculations to account for dam safety modifications

Findings

- New curves match old curves within headwater range of spillway discharge tables
- Differences at higher headwaters due to
  - maximum opening and "orifice flow" assumptions for radial gates (aph, boh, chh, dgh, fnh, fph, hih, mhh, weh)
  - as-constructed modification differs from plan (brh)
  - change in operation policy (noh)
  - removal of spillway bays for new lock (chh)

Guntersville Dam



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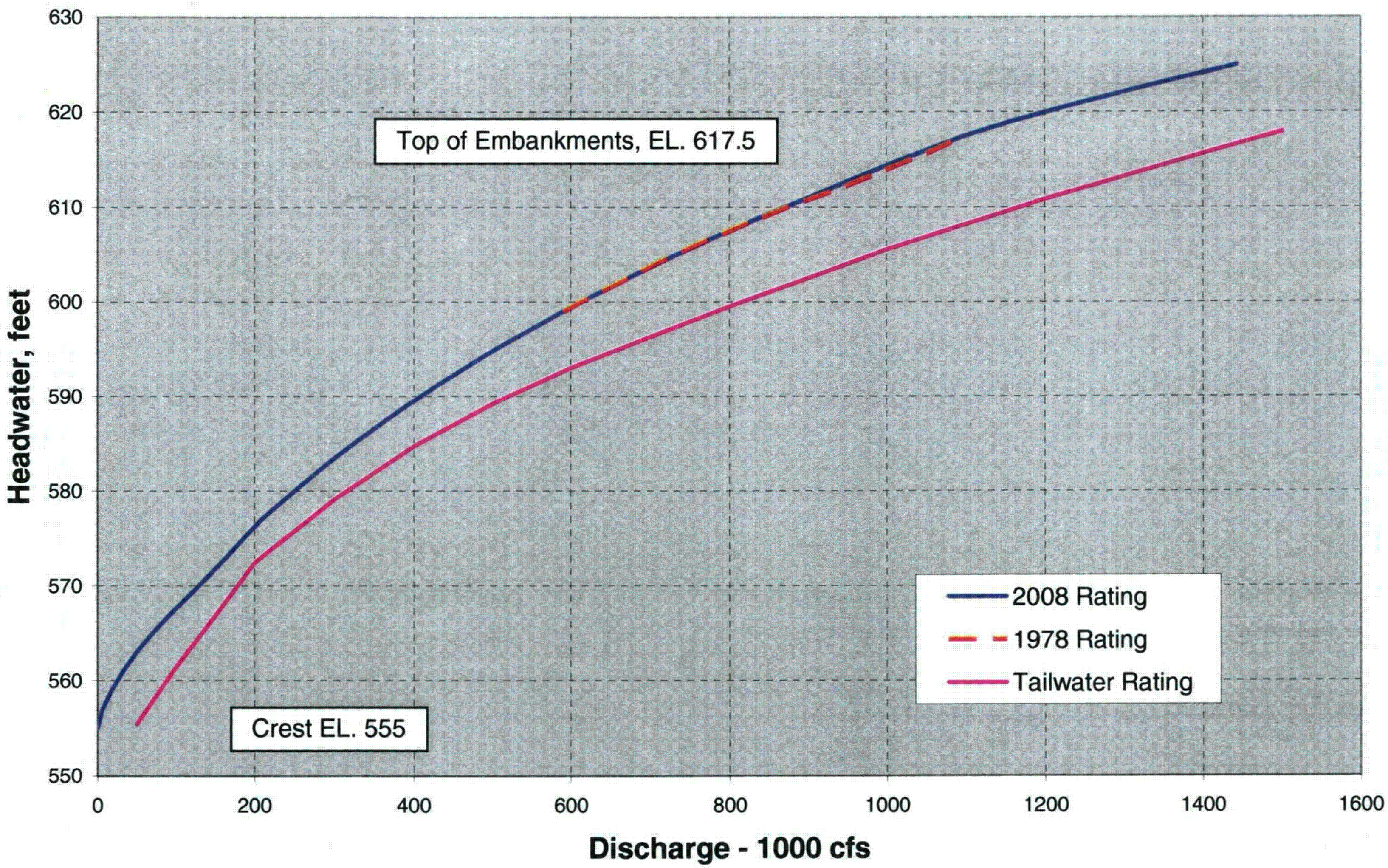
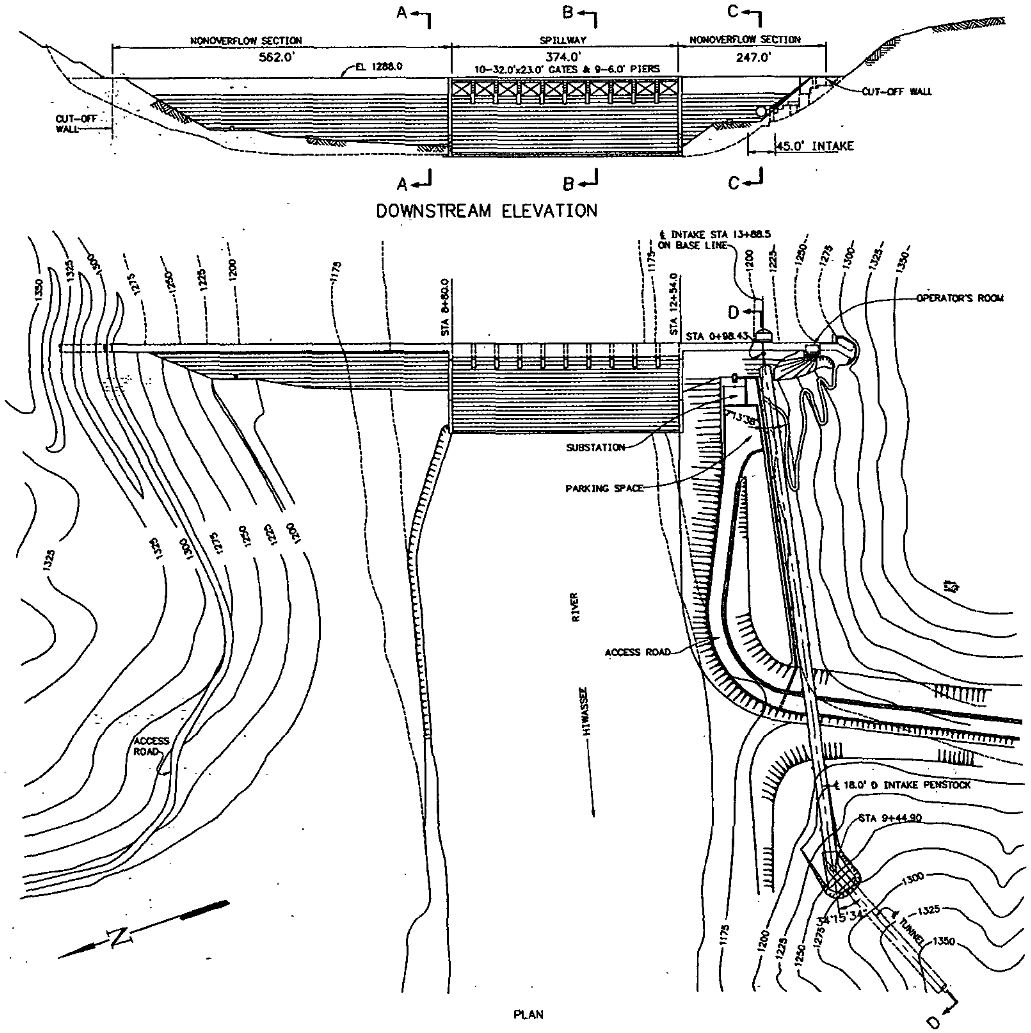
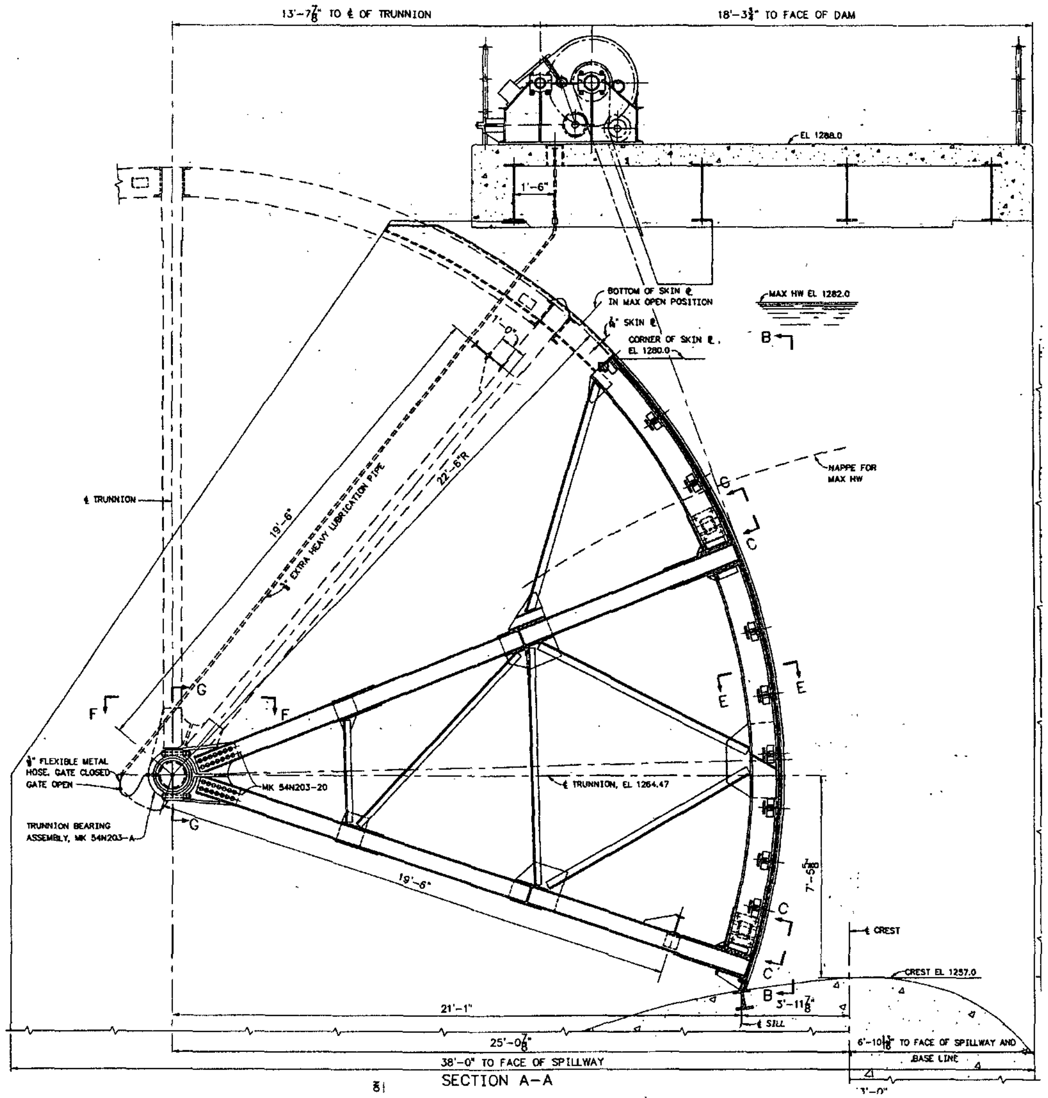
Guntersville Rating Curves



Apalachia Dam

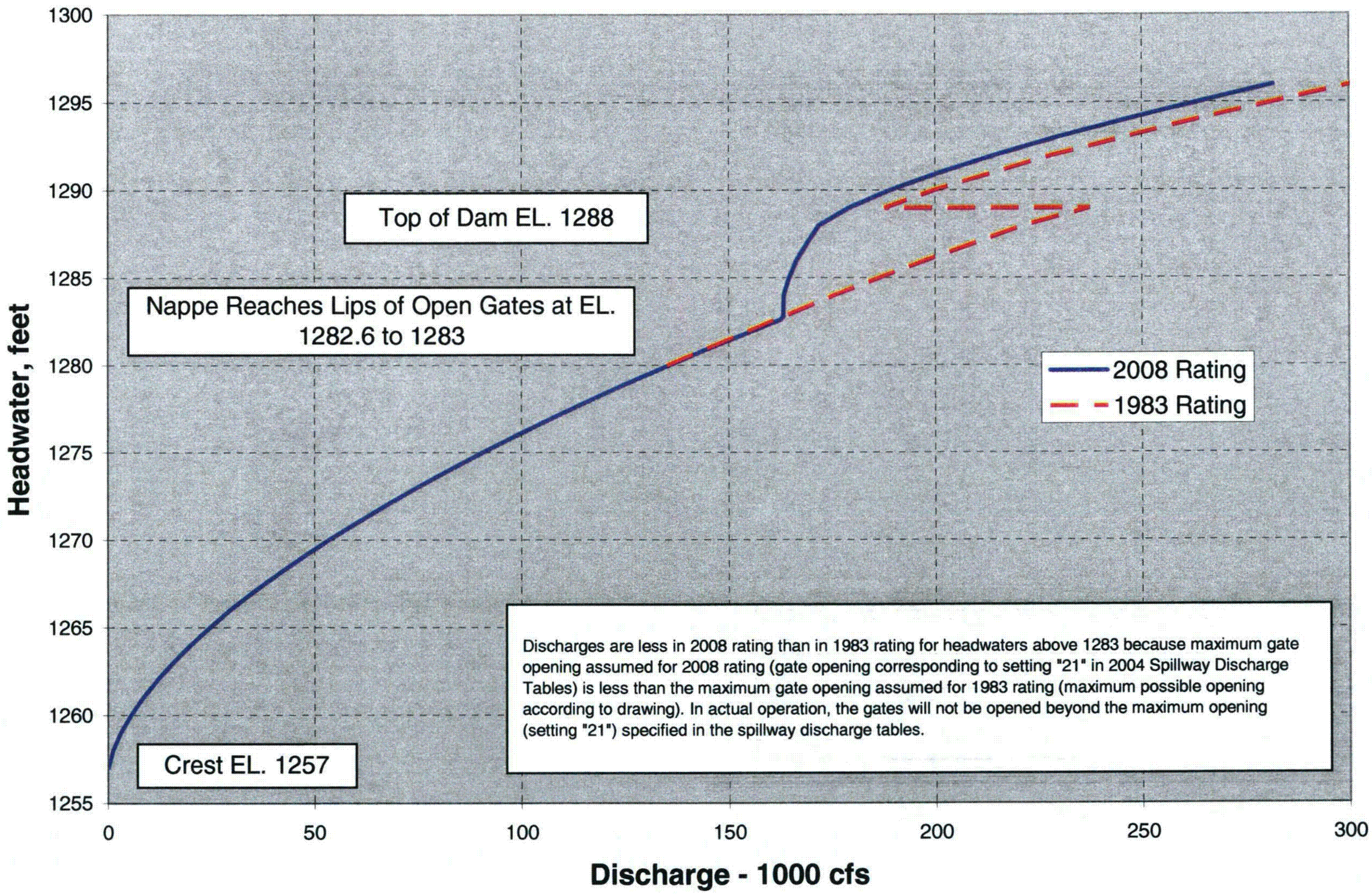


Apalachia Dam

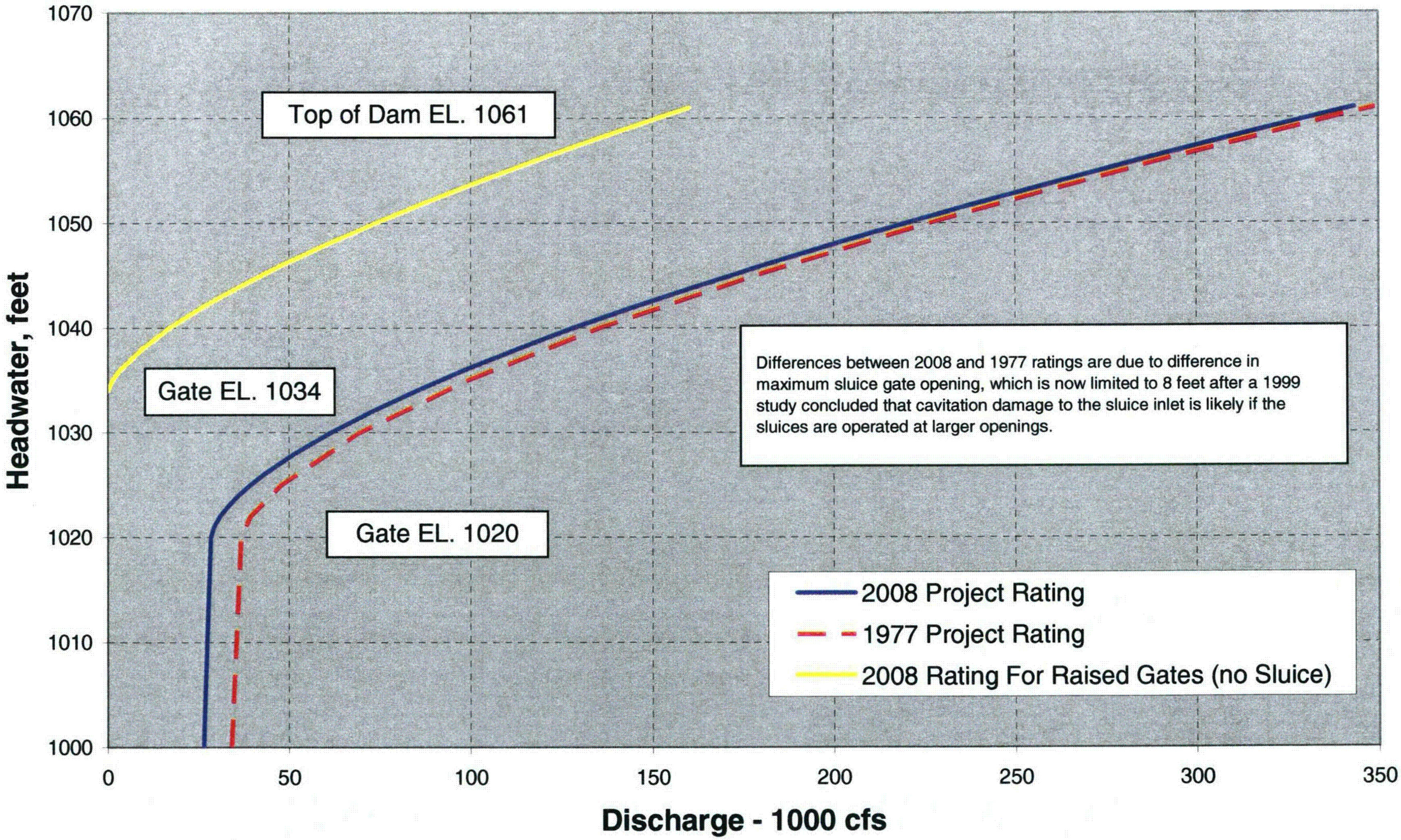


(7)

Apalachia Rating Curves



Norris Rating Curves



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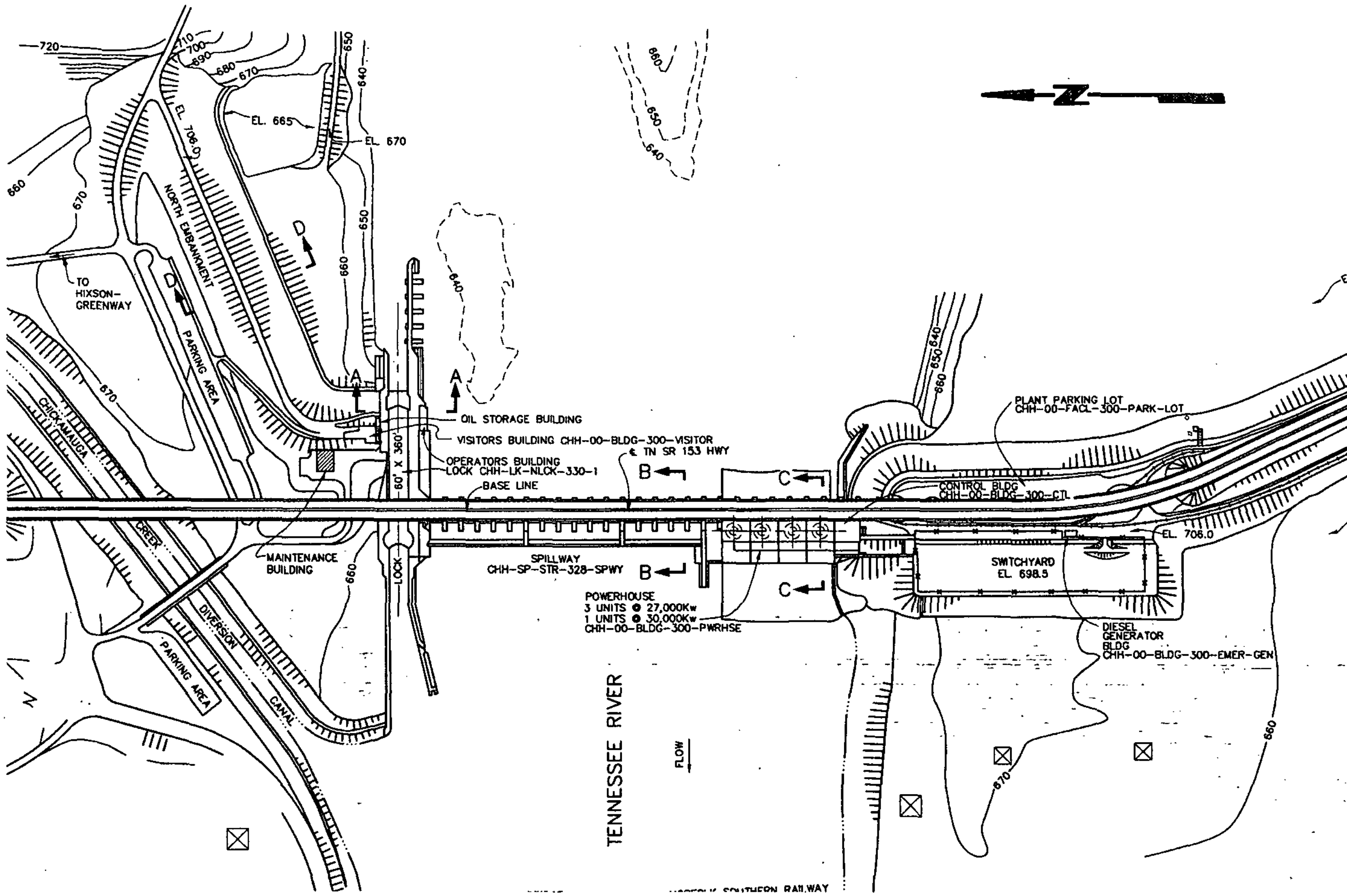
Chickamauga Dam



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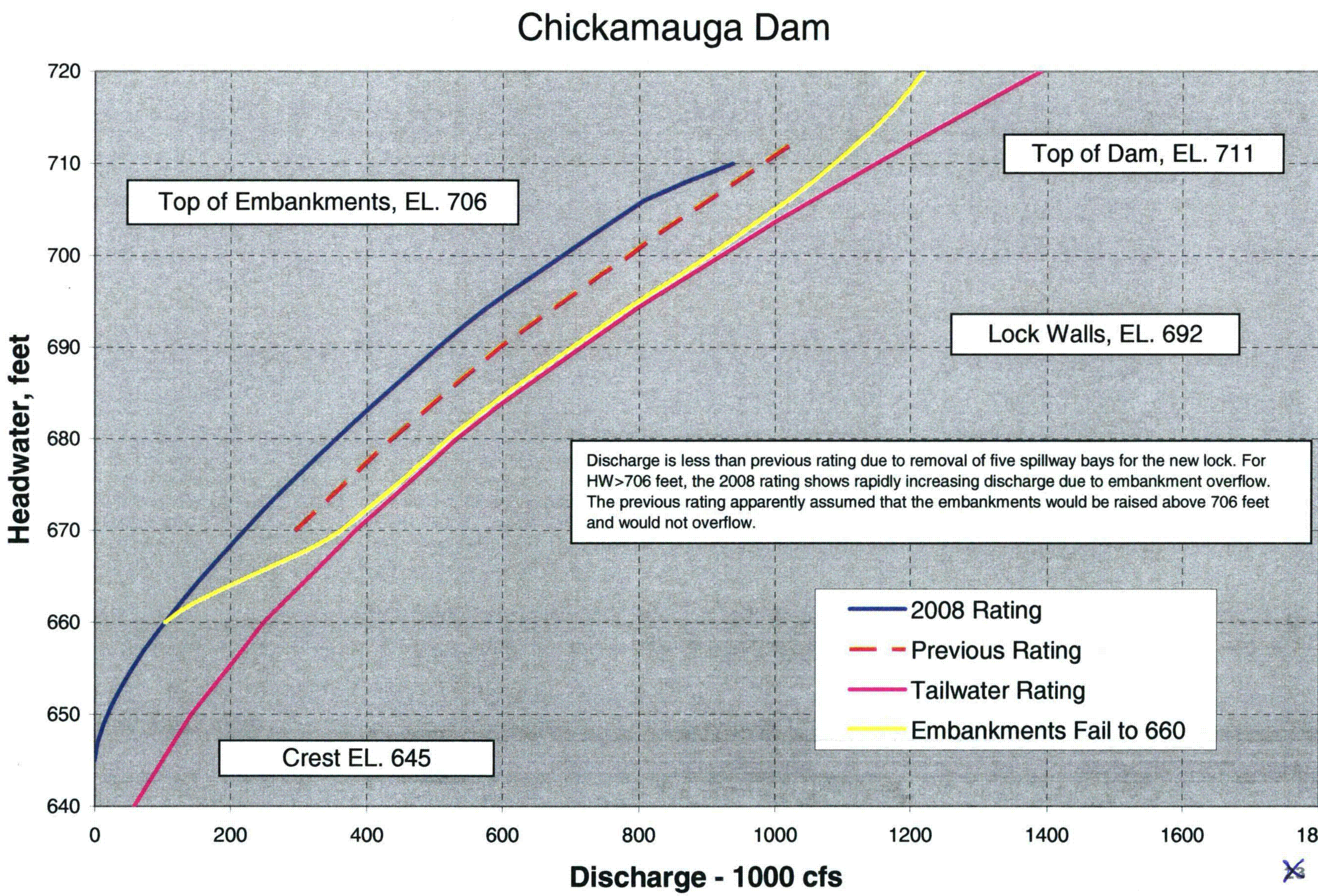
Rating Curves — BLN Unit 1 and 2 / BLN Unit 3 and 4



Conclusion

- Updated rating curves now available for 20 of the 21 dams for which they are needed

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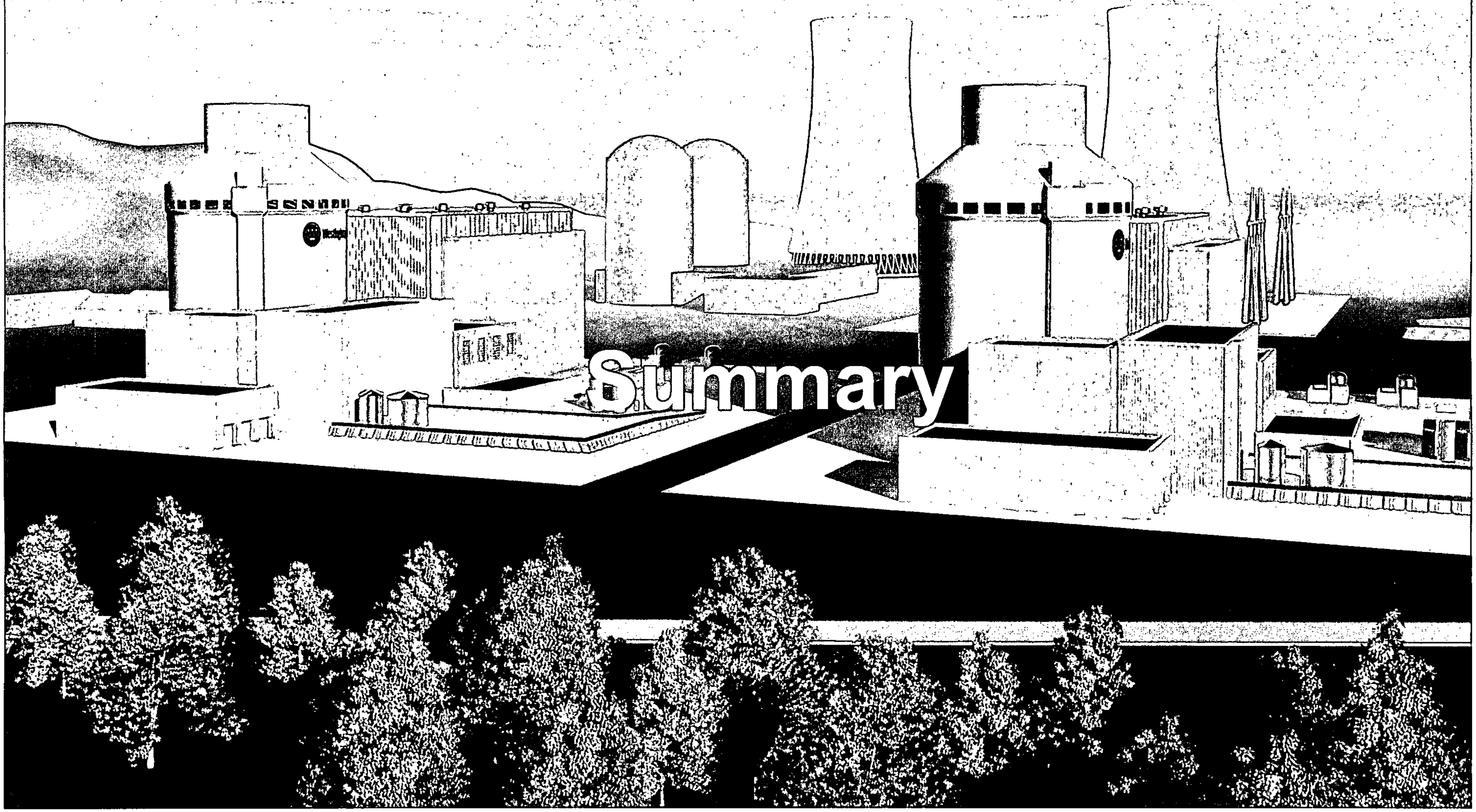
TVA/NRC Workshop
June 23 – 27, 2008



Summary

Summary

- Development of the existing TVA watershed model required extensive effort and commitment of resources
- Updating inputs with new data – also requires an extensive effort and commitment of resources
- Confirmatory Effort
- End Product:
  - Thoroughly documented analysis
  - New / Latest data
  - Confirmation of SOCH90PC replicates SOCH88
- Results – Similar / close to existing values

Basis for Confidence

- SOCH90PC Replicates SOCH88
- 20% Peaking Sensitivity – Watershed is not very sensitive to changes to Unit Hydrographs – composite effect will be small
- 100% runoff Sensitivity – This sensitivity run effectively bounds a worst case scenario – Final PMF level will be less than 628.6
- Even with the discovery of the Dallas Bay Breach error, 10% of input flow excluded, the resulting PMF level only changed by less than 1.3 feet.
- TVA will provide by end of 2008, a final PMF level for BLN along with a draft FSAR revision, with low risk of subsequent changes.
- Updated / validated model, using recent data, fully documented, will provide the required objective evidence of BLN being a dry site.

Path Forward

- Schedule – Key Milestones
  - New controlling PMF level will be established by end of year, using current, verified data
  - Draft Revised FSAR available by end of year
  - All confirmatory runs, sensitivity runs, and documentation by Spring 2009
- Use of SOCH90PC and Manual to further develop RAIs
- Use of NPOC office in Rockville for material review
- Follow up Progress Reporting
  - TVA offers to hold monthly phone calls
  - Discussion of any adverse findings
  - Progress made to date
  - RAI Discussions / Clarifications

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Key Milestones

Activity	Milestone Date
Whitepaper revision	07/25/08
All Users Manuals Complete	08/22/08
Excel codes - issued document	08/29/08
Dam rating curves verified	10/03/08
Geometry Input Data Packages verified	10/31/08
All Changes to Inputs Identified – Start final SOCH runs	11/14/08
Unit Hydrograph input packages verified	12/19/08
New Controlling PMF Level Established / Draft FSAR Markup for review - High Confidence / Low risk of subsequent changes	12/31/08
Input Data File Packages signed/available for review	01/05/09
Software V&V Documents Issued	02/27/09
Phase 1 Documentation (Controlling) Complete	03/16/09
Phase 2 Documentation (Non-Controlling) Complete	04/28/09

Bellefonte Design Basis Flood

Verification and Validation

June 26, 2008

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Objective

Provide an overview of the approach, processes, and progress to date

Work Scope

Bechtel Power has been contracted to assist TVA in the documentation and verification of all input data and the validation of the computer programs used in hydrologic modeling for the Probable Maximum Flood (PMF) and Dam Break Analysis.

Work Scope (continued)

This includes

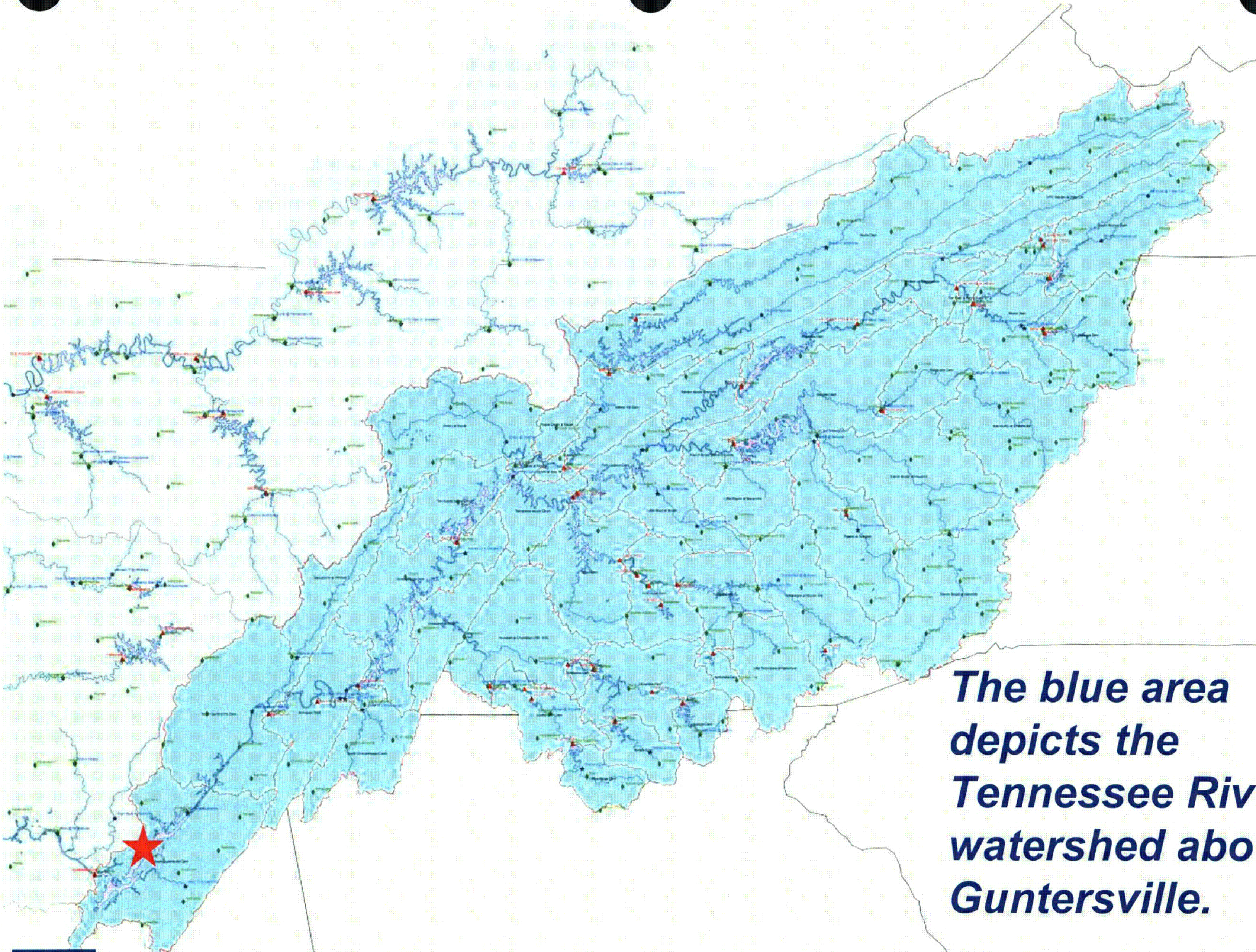
- Verification of Unit Hydrographs
- Verification of Cross-Sectional Data and other Geometric Parameters
- Verification of Dam Rating Curves
- Software Verification, Validation, and Documentation

Progress to Date

- Kick-off Meeting May 6
- Trained to TVA procedures
- Detailed schedule development
- Unit hydrographs
  - Evaluated and categorized 46 sub-basins
  - Defined/refining verification process
- Channel geometry data
  - Defined/refining verification process
- Software Verification & Validation
  - Drafted SOCH user's manual

Background

- Over the past 30 years, TVA has developed hydrologic models of the Tennessee River watershed that have been used for planning and for river operations and flood forecasting on a day-to-day basis.
- The hydrologic model adopted for the Bellefonte SAR includes 46 sub-basins in the 24,450 square mile watershed upstream of Guntersville.



The blue area depicts the Tennessee River watershed above Guntersville.

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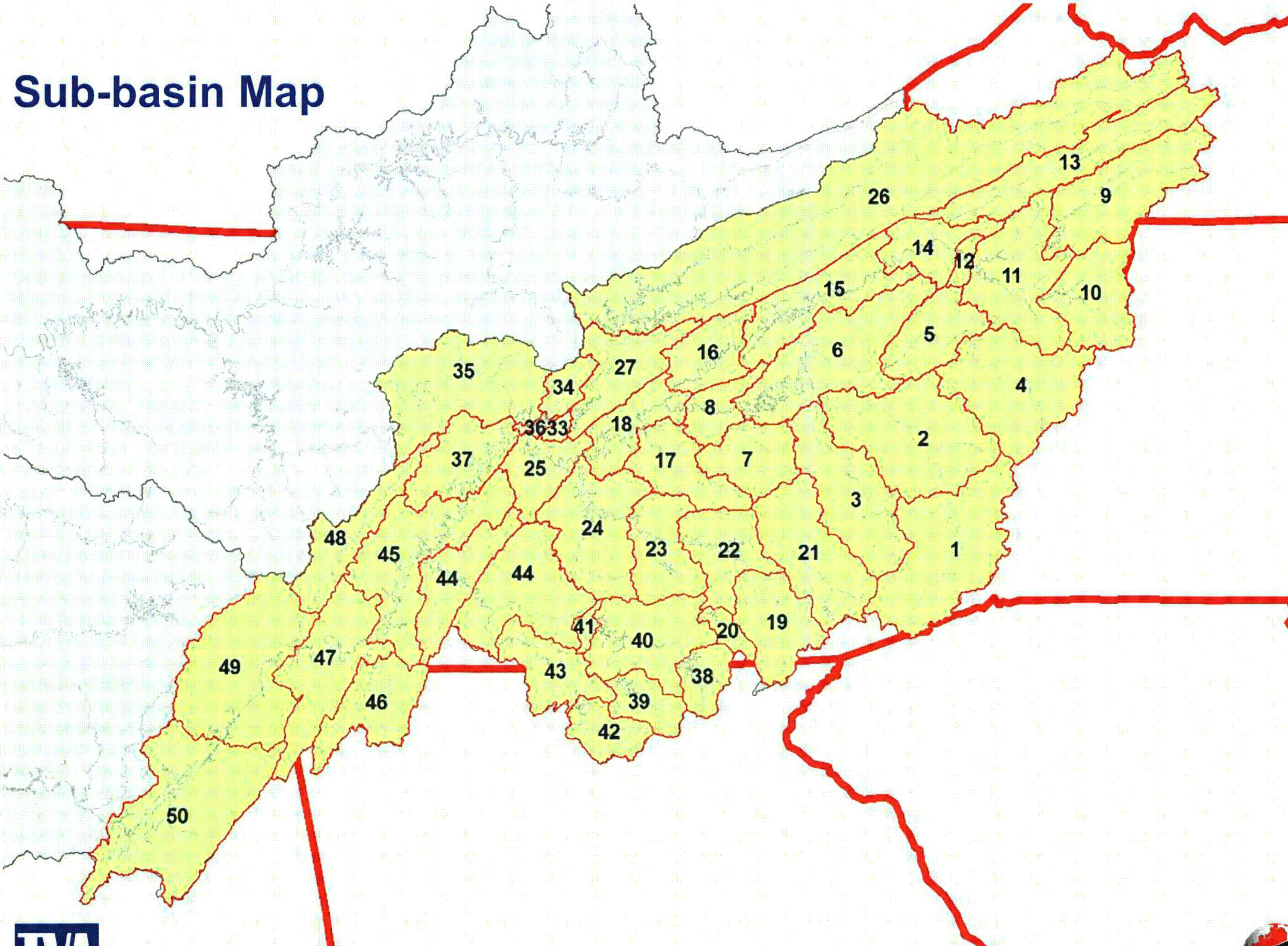
Background (continued)

TVA developed unit hydrographs for each of the 46 sub-basins to provide input to the SOCH model which dynamically routes runoff from each sub-basin through the stream network and system of dams.

Sub-basin Map



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List of 46 Sub-basins

1. French Broad at Asheville
2. French Broad at Newport
3. Pigeon at Newport
4. Nolichucky at Embreeville
5. Nolichucky Dam
6. Douglas Dam
7. Little Pigeon at Sevierville
8. French Broad above Knoxville
9. South Holston Dam
10. Watauga Dam
11. Boone Dam
12. Fort Patrick Henry Dam
13. North Fork Holston at Gate City
14. Holston near Surgoinsville
15. Cherokee Dam
16. Holston above Knoxville
17. Little River at Mouth
18. Fort Loudon Dam
19. Little Tennessee at Needmore
20. Nantahala Dam
21. Tuckasegee at Bryson City
22. Fontana Dam
23. Chilhowee Dam
24. Tellico Dam
25. Tennessee above Clinch
26. Norris Dam
27. Melton Hill Dam
33. Clinch at Mile 16
34. Poplar Creek at Mouth
35. Emory at Mouth
36. Clinch at Mouth
37. Tennessee below Clinch
38. Chatuge Dam
39. Nottely Dam
40. Hiwassee Dam
41. Apalachia Dam
42. Blue Ridge Dam
43. Ocoee No. 1 Dam

44A. Hiwassee at Charleston (RM 18.9)

44B. Hiwassee at Mouth

45. Chickamauga Dam
46. South Chickamauga Creek
47. Nickajack Dam
48. Sequatchie at Whitwell
49. North Guntersville Dam
50. South Guntersville Dam

Unit Hydrograph (UH) Validation Process

1. Select an appropriate flood event and obtain observed precipitation data. Give preference to the largest among the flood events that occurred since the development of the original TVA unit hydrographs.
2. Convert observed rainfall to effective rainfall (e.g., TVA API-RI or initial/constant rate methods)
3. Obtain observed hydrograph data for the flood event and transfer to the sub-basin outlet as necessary using established hydrologic procedures to develop the required input hydrograph for UH optimization

UH Validation Process (continued)

4. Run optimization module of HEC-HMS to obtain the best-fit UH for the data
5. Compare with the UH previously developed by TVA for the same sub-basin
6. If the optimized UH does not agree with the one previously developed by TVA, select a second flood event to validate the UH derived in Step 4

Unit Hydrograph Development

Many candidate storms must be analyzed to obtain a data set that will provide representative rainfall and stream flow useful in deriving the unit hydrograph.

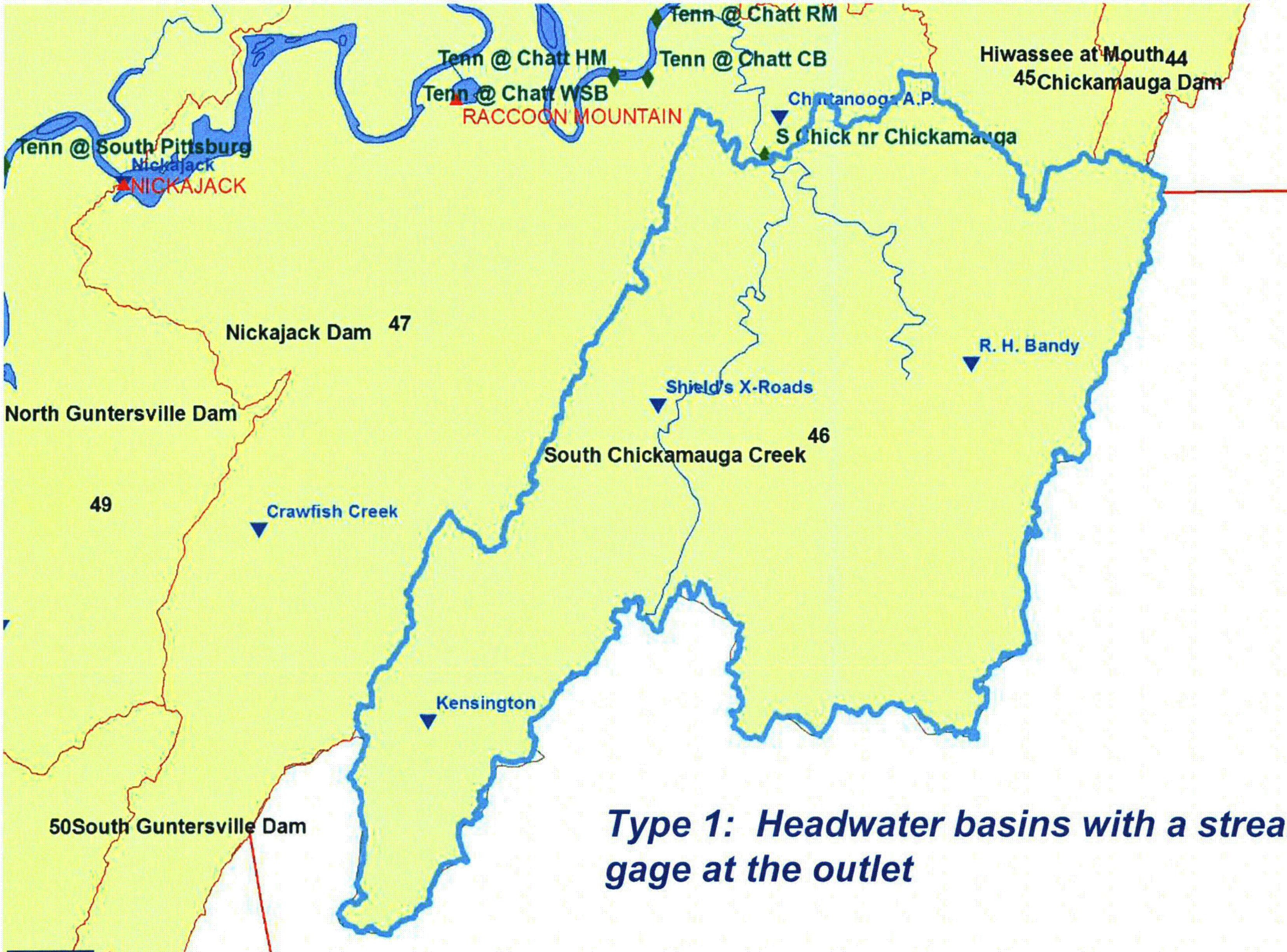
Operational problems include:

- Non-functioning recorders and stream gages
- Accounting for storage and backwater effects
- "Double-peaked storms"
- Antecedent moisture conditions
- Changes in watershed characteristics
- Non-linear effects not accounted for in UH theory may be more important in some events than in others

Unit Hydrograph Development (continued)

Obtaining the observed hydrograph series requires a different level of effort depending on the sub-basin in question.

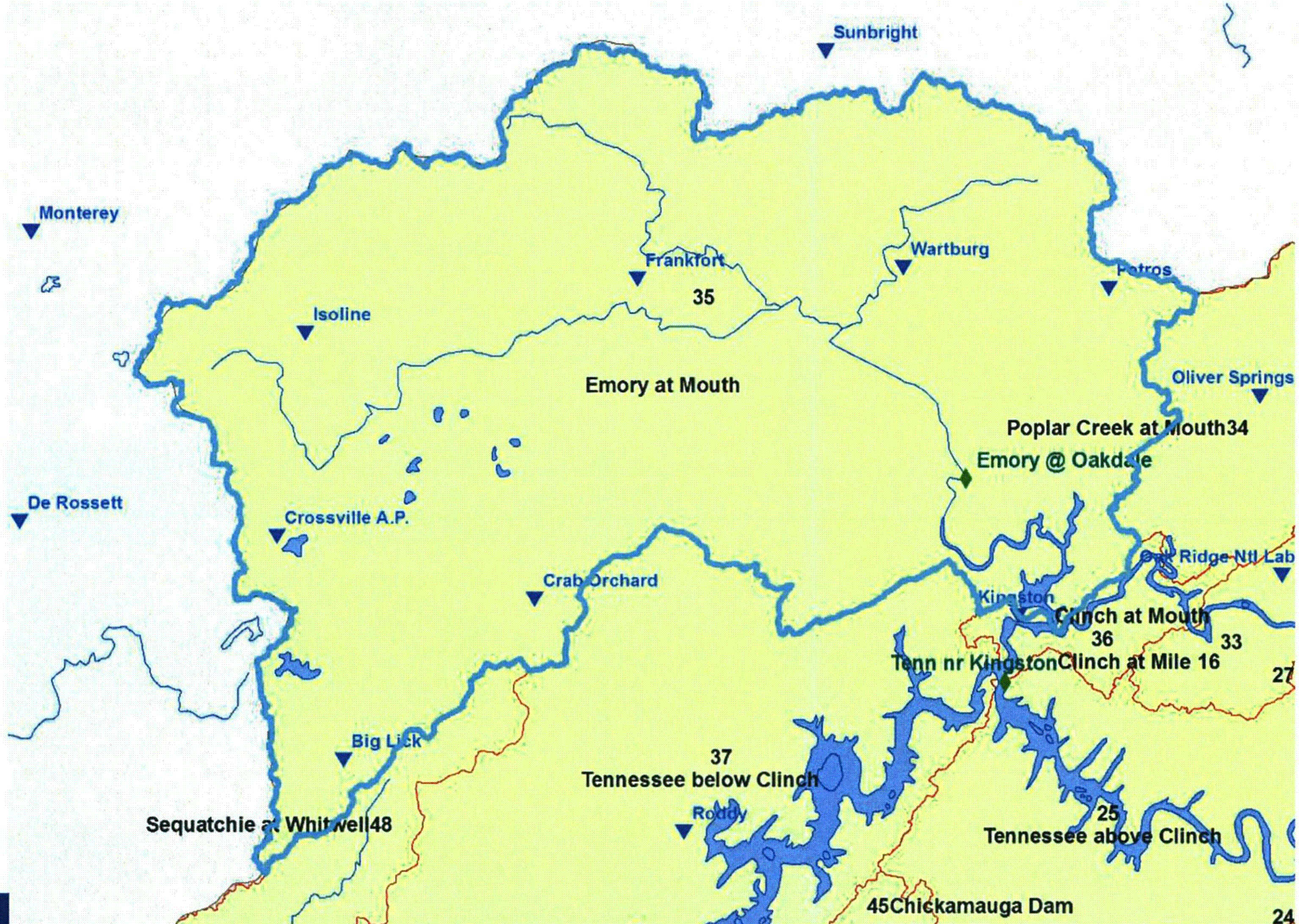
Based on a preliminary assessment of the steps for obtaining the hydrographs, the sub-basins have been grouped into six classes of difficulty in execution ranging from relatively straightforward exercises to complex calculations.



Type 1: Headwater basins with a stream gage at the outlet

PRELIMINARY

Type 2: Headwater basins and downstream sub-basins with no stream gage at the outlet, but with easily transferred flow series available



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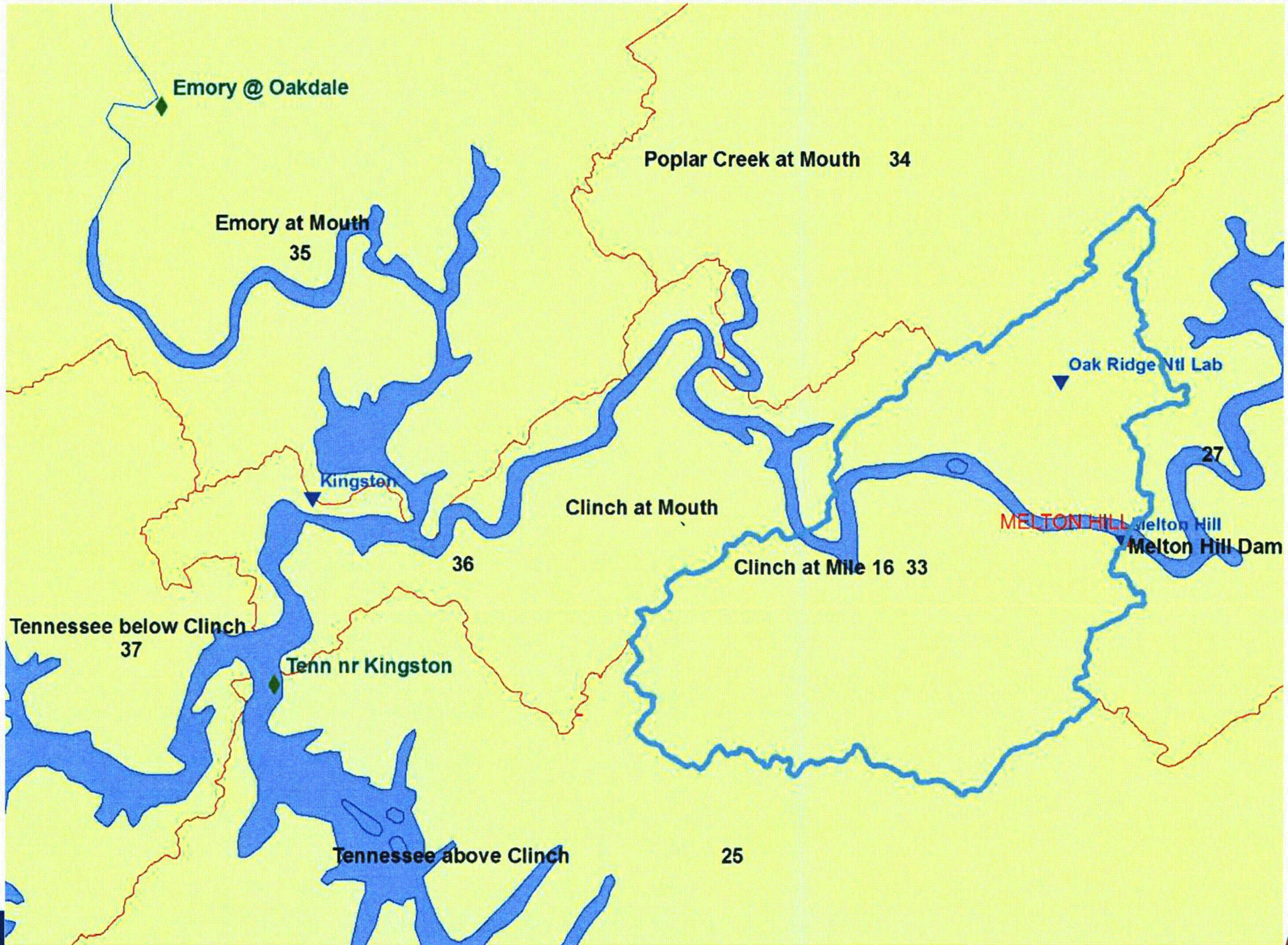
Type 3: Sub-basins without stream gages modeled with synthetic hydrographs



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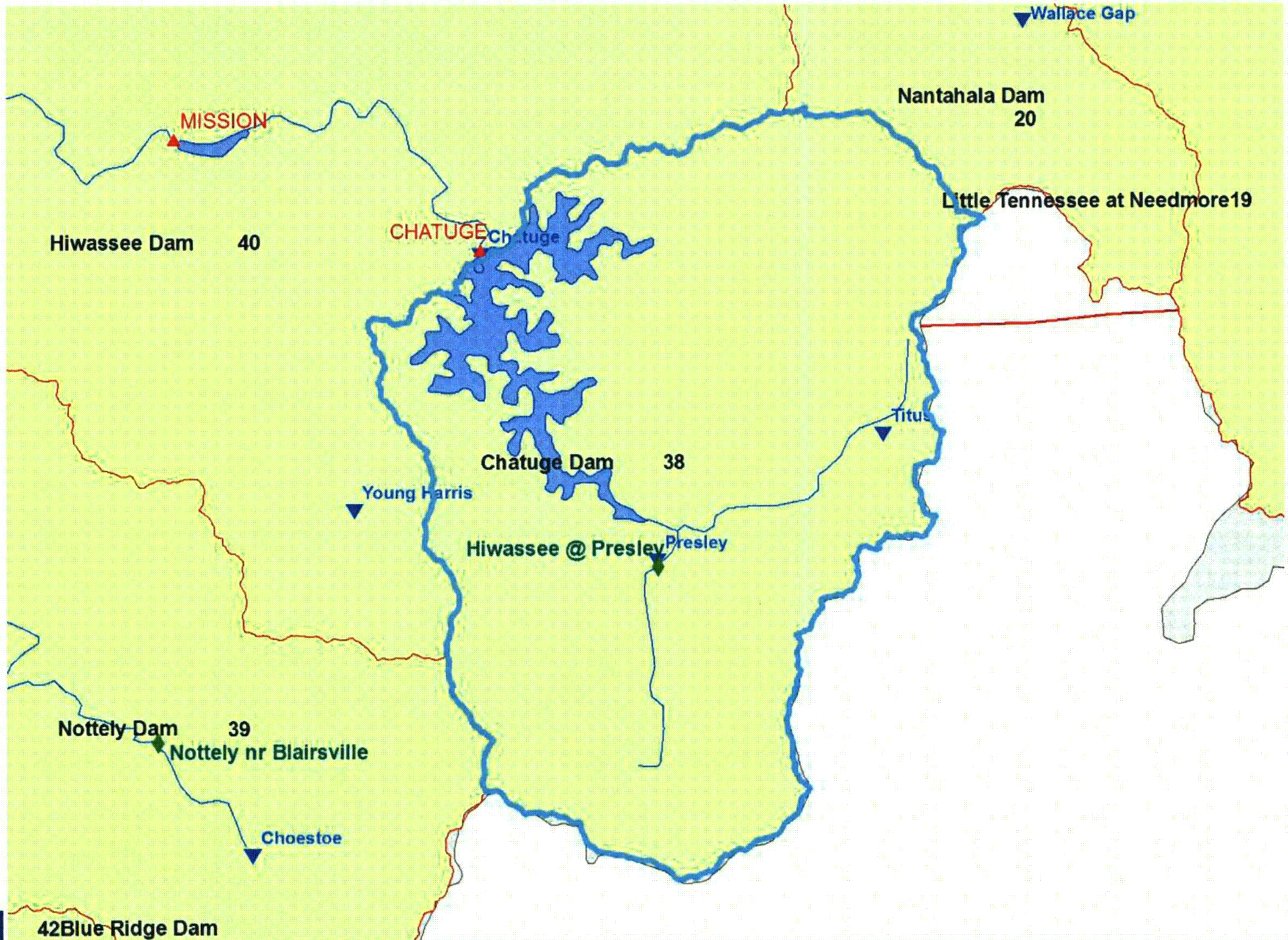
Type 4: Headwater sub-basins closed by dams with reliable datasets that can be used for reverse reservoir routing to provide reservoir inflow hydrographs



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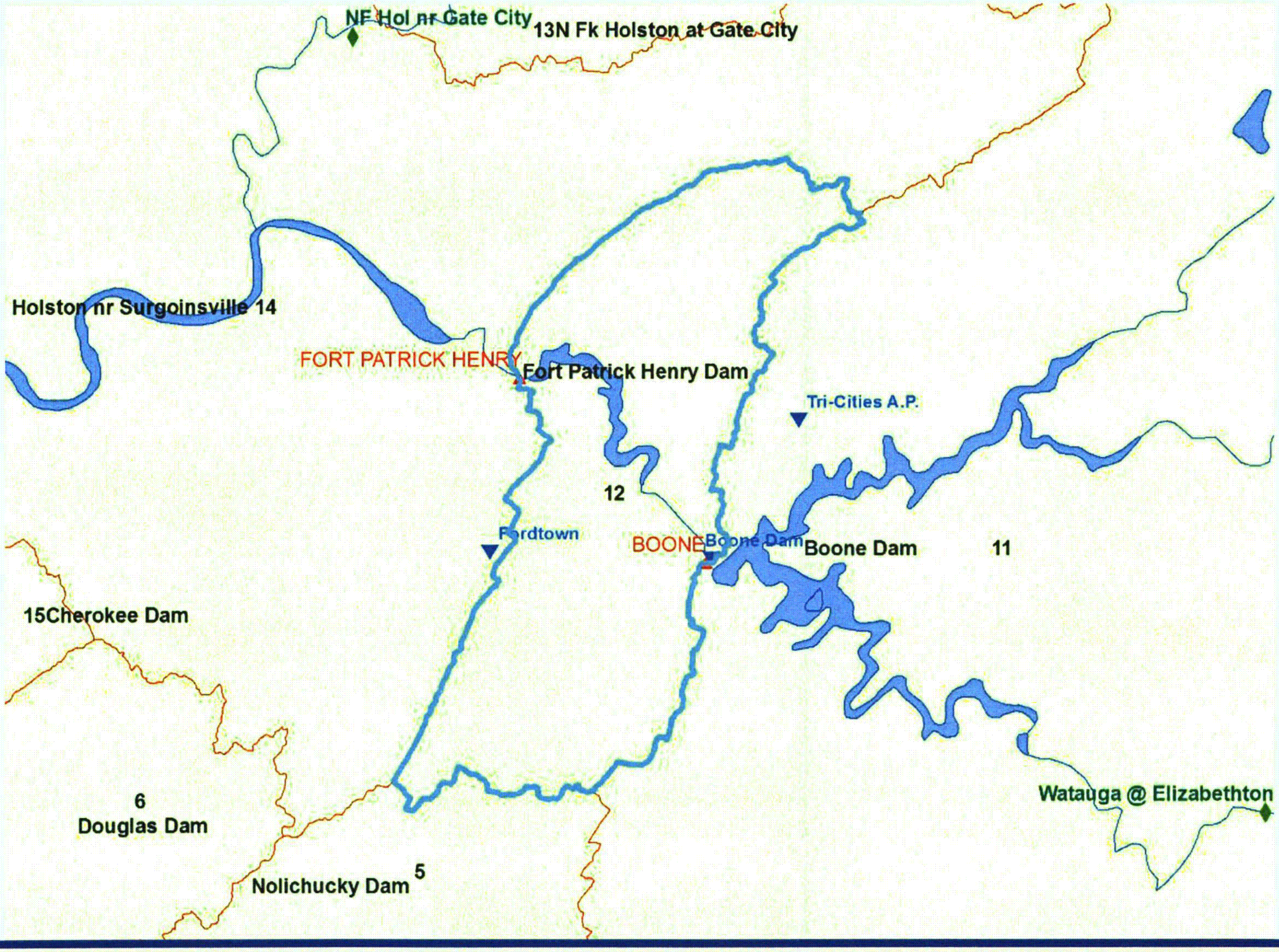
Type 5: Sub-basins closed by dams with reliable datasets, which require additional data manipulation due to the existence of upstream basins



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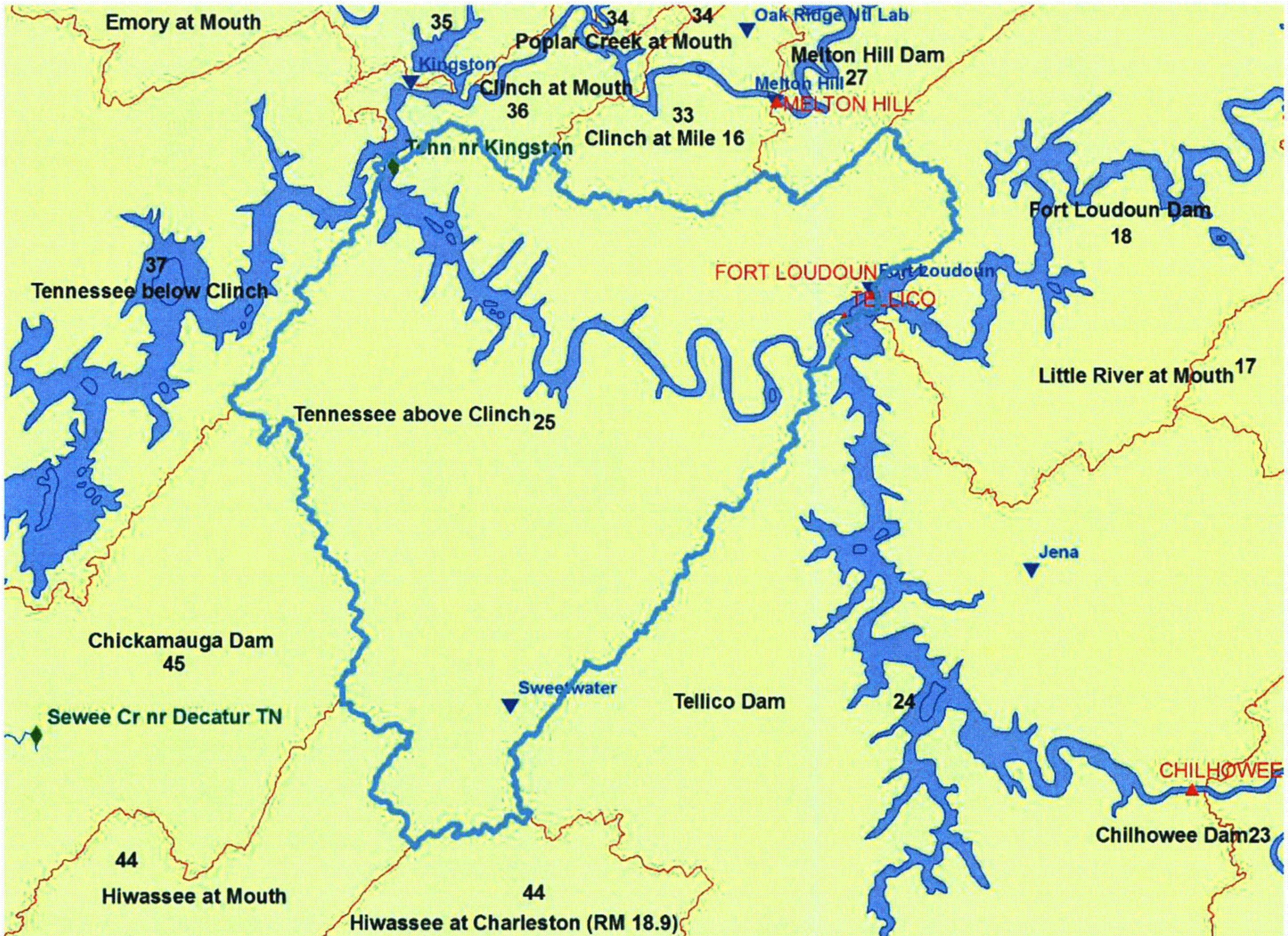
Type 6: Complex situations requiring significant manipulation of several sub-basins such as at insufficiently gaged tributaries and along the main stem of the Tennessee River



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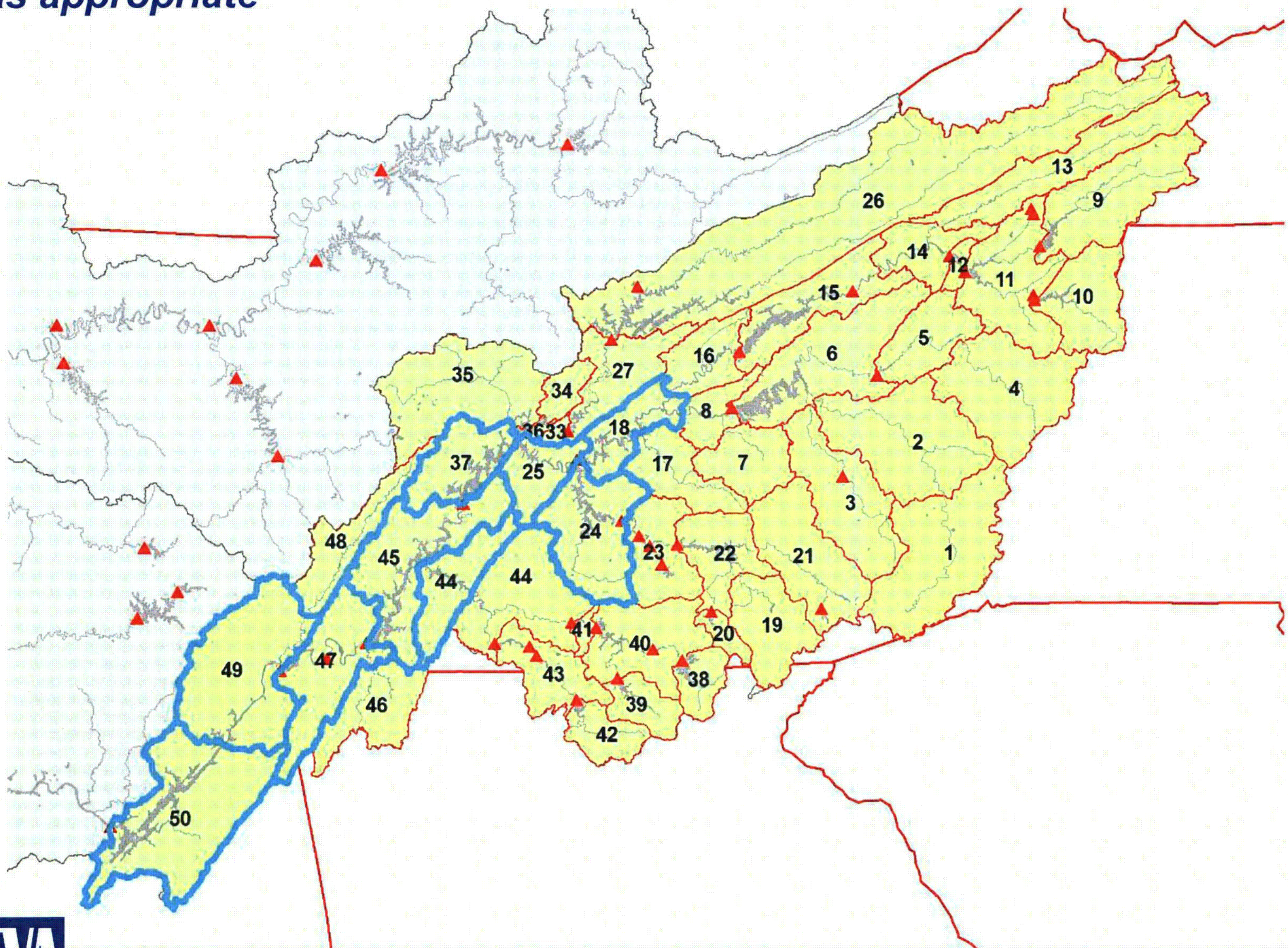
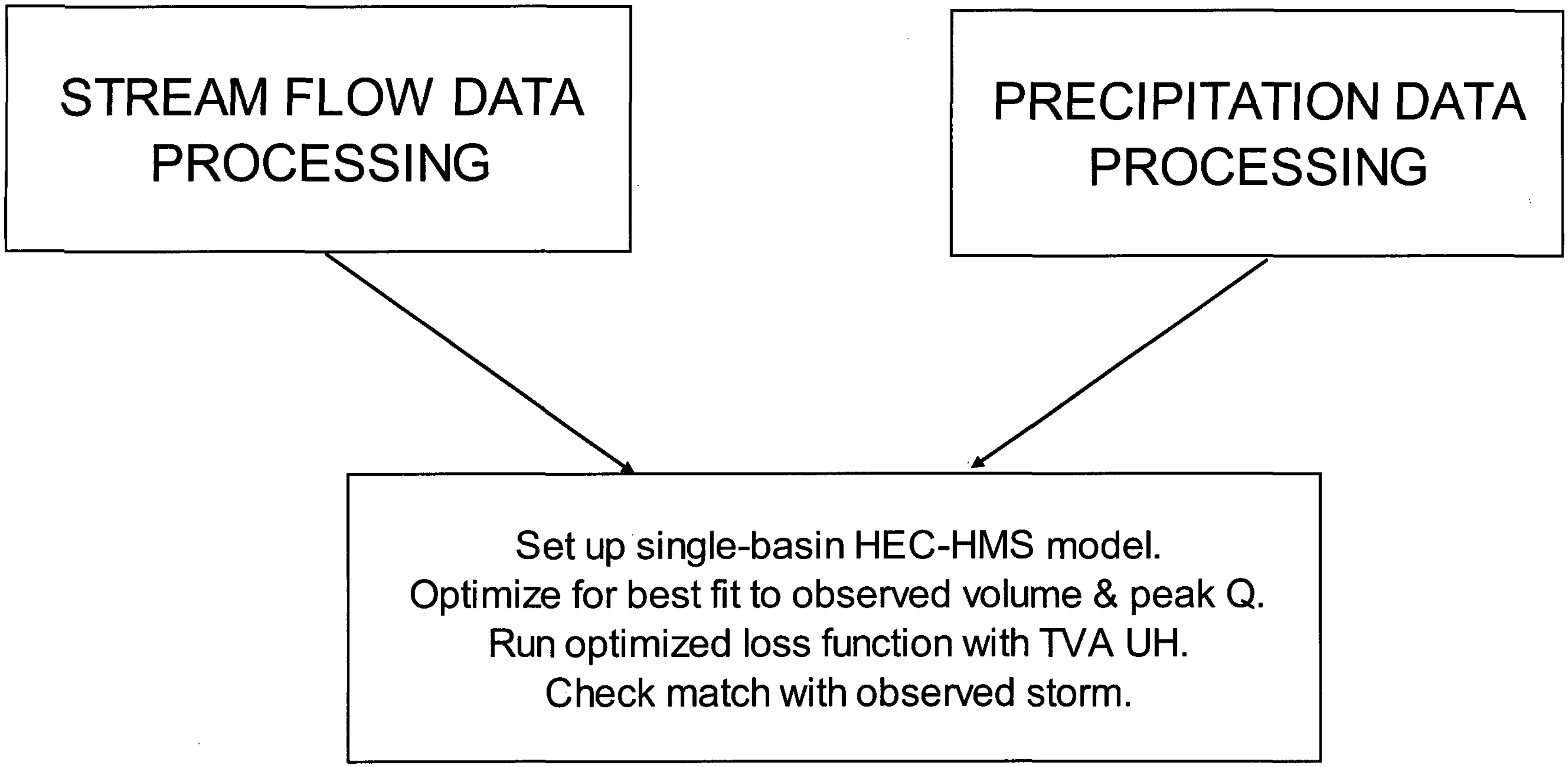
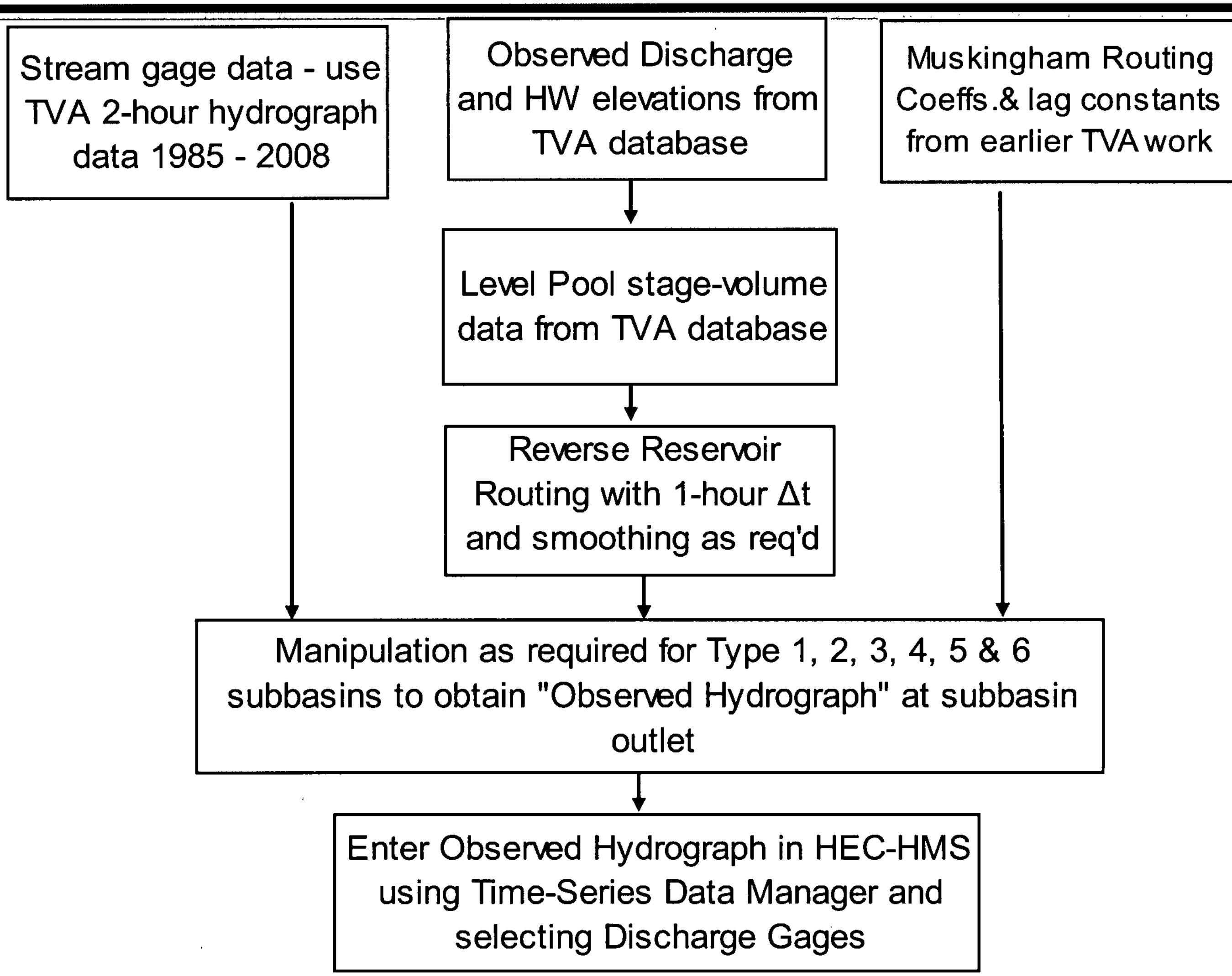
The Type 6, complex basins will be evaluated using SOCH model runs as appropriate



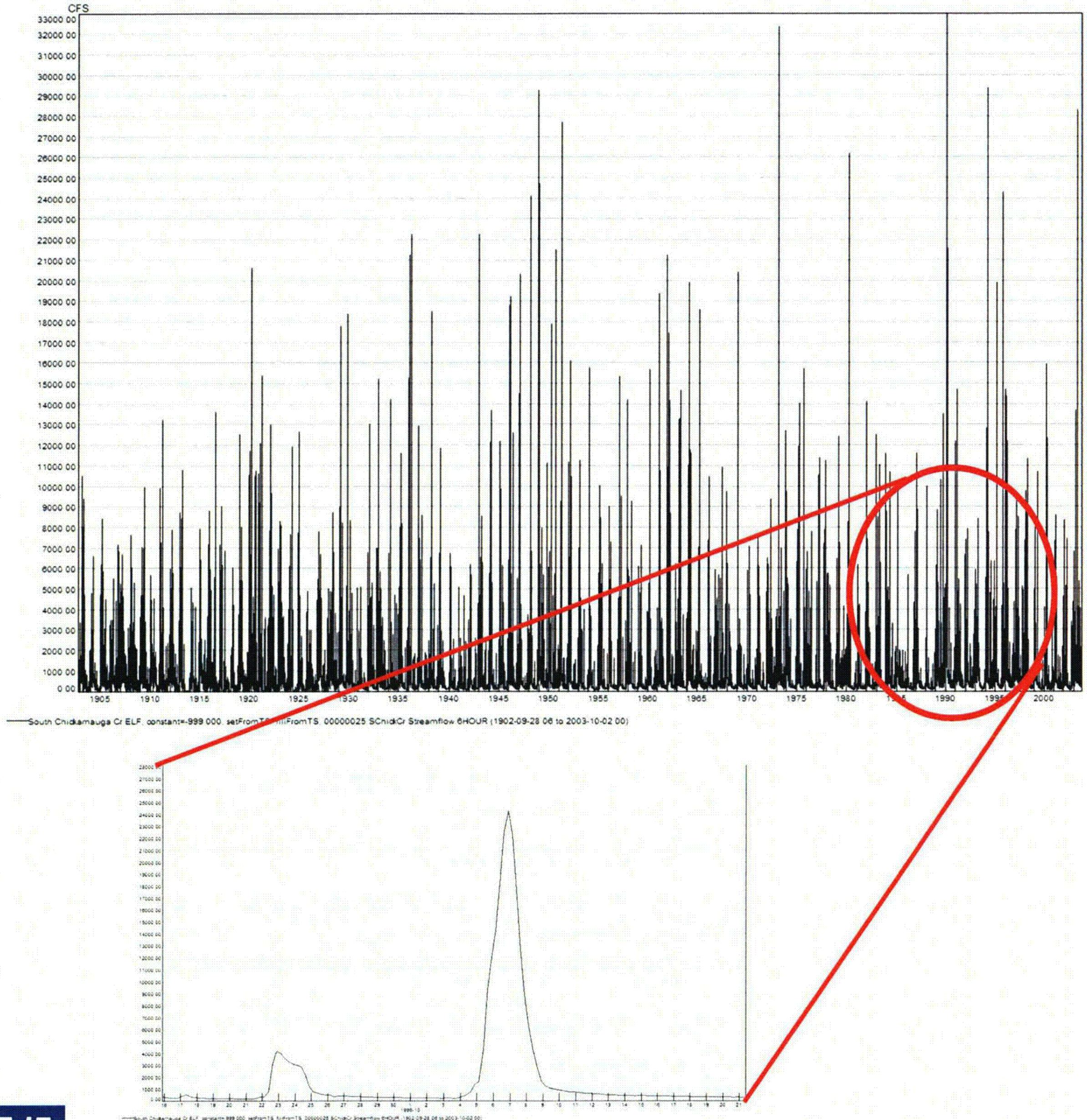
Work Process for UH Validation



Stream Flow Data Processing



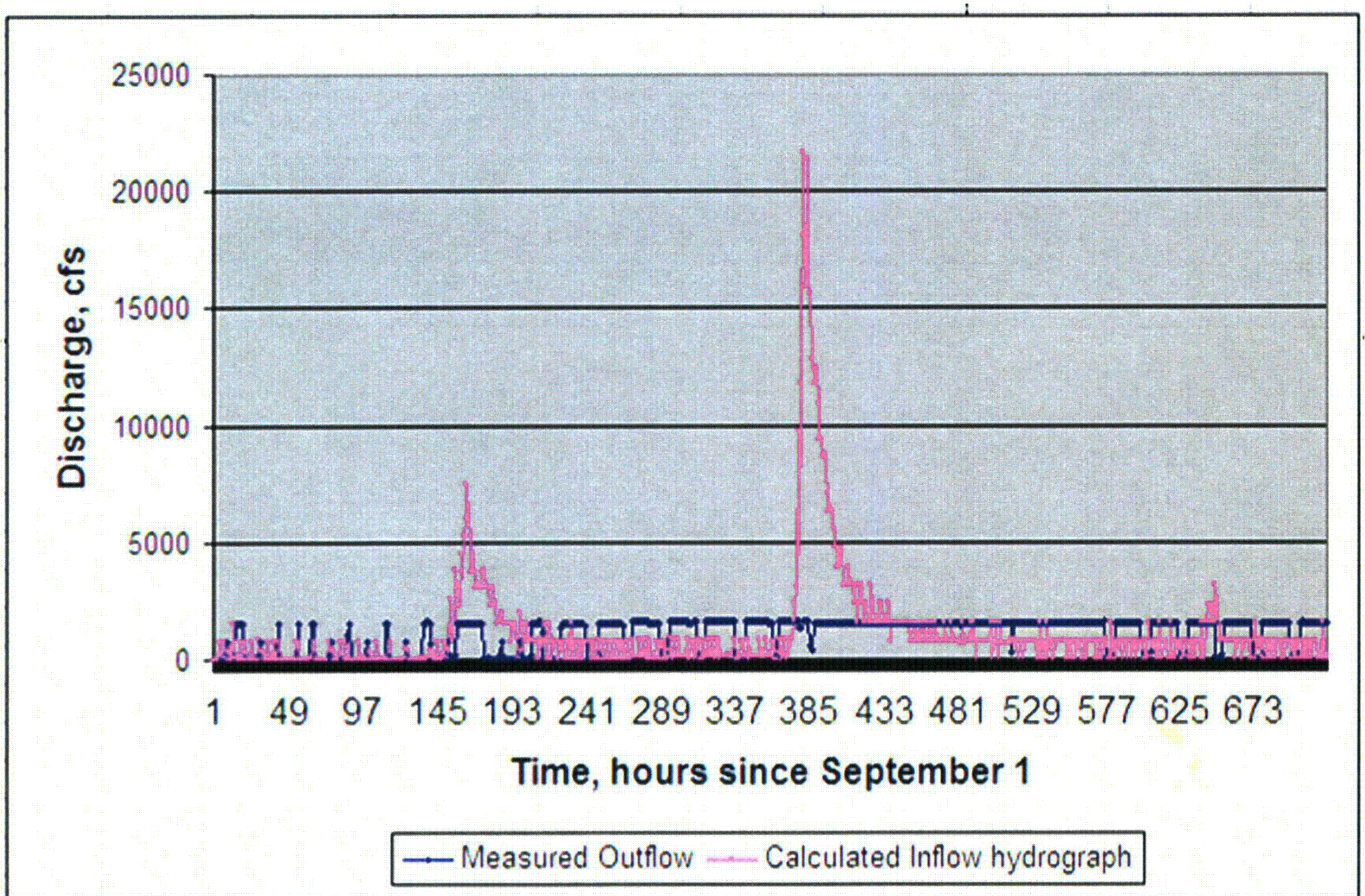
PRELIMINARY



Stream gage data for South Chickamauga Creek for entire period of record

PRELIMINARY

Reverse Reservoir Routing: $I - O = \Delta S$



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Note: Slide 25 is missing because of a numbering problem. No information is missing

Precipitation Data Processing

Precipitation Data 1986 - 1996

Review 6-hour TVA gage data for storms; identify short periods & obtain 15-minute or 1-hour data from TVA for all gages in basin

↓

Derive Thiessen weighting factors and use them to develop basin average precipitation depth for each time period

↓

Precipitation Data 1996 - 2008

Review maps of NWS gridded precipitation data in ArcView for each hour to identify storm to use

↓

Use GIS routine to get basin average precipitation depth for each hour of storm

↓

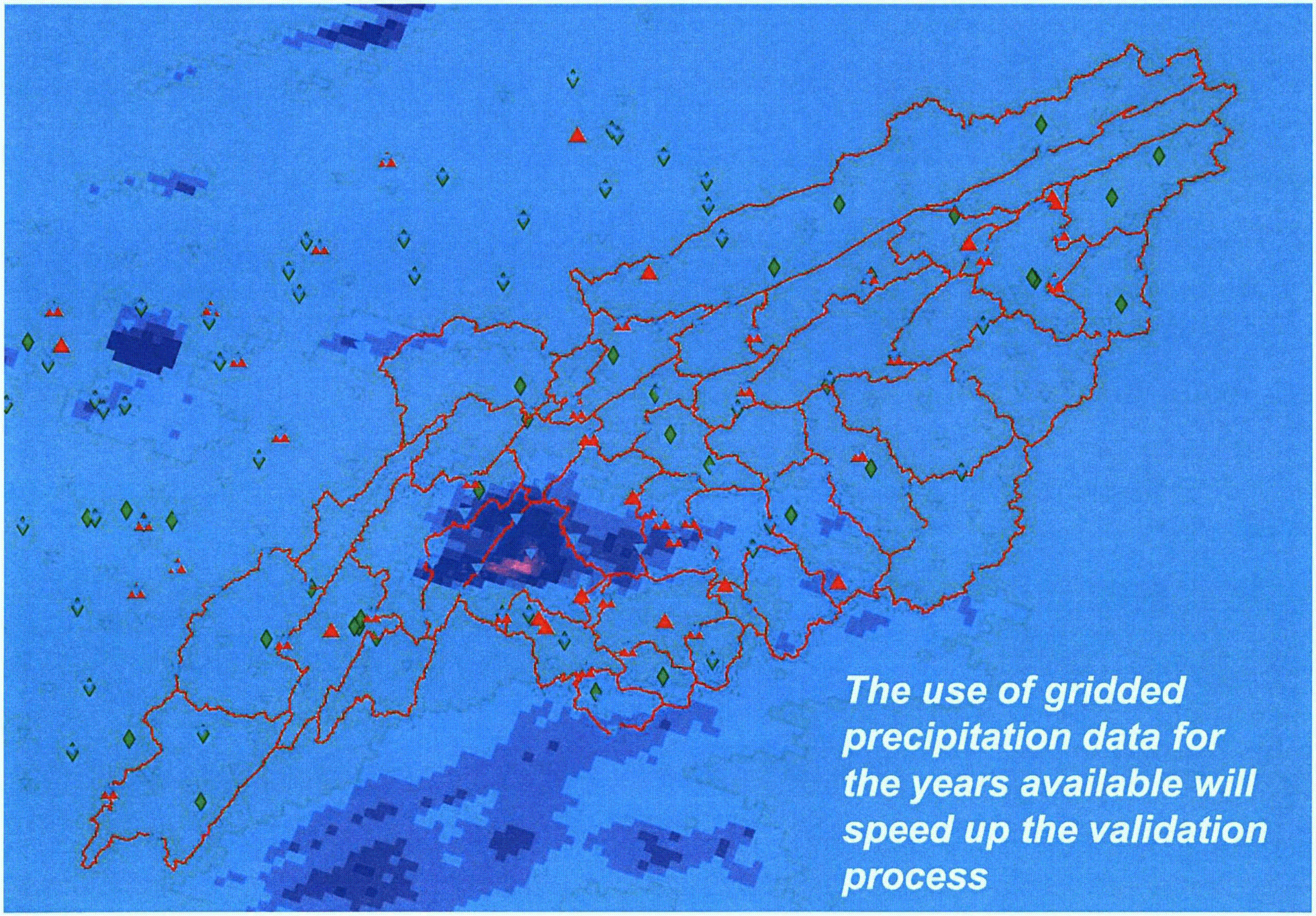
Calculate volume of precipitation for storm and ensure that it exceeds volume of observed runoff less base flow

↓

Enter precipitation hyetograph in HEC-HMS using Time-Series Data Manager and selecting Precipitation Gages

For the period from 1935 to 1985 it will be necessary to digitize paper records.

Plot of rainfall depth (mm) for May 5, 2003 at 20:00 hours GMT



The use of gridded precipitation data for the years available will speed up the validation process

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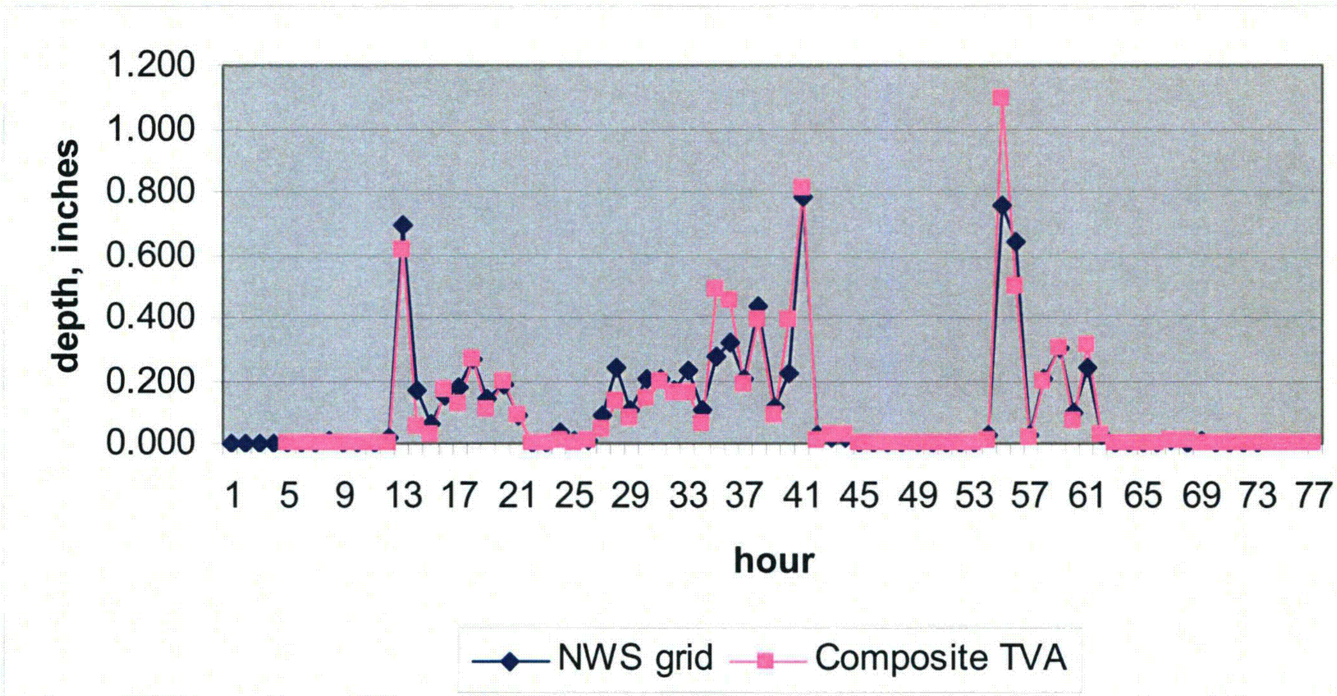
Use of Gridded Precipitation Data (continued)

Sub-basin average precipitation depth for each hour is obtained with a GIS utility developed for this work.

An excellent correlation was obtained between gridded basin average and point rainfall series.



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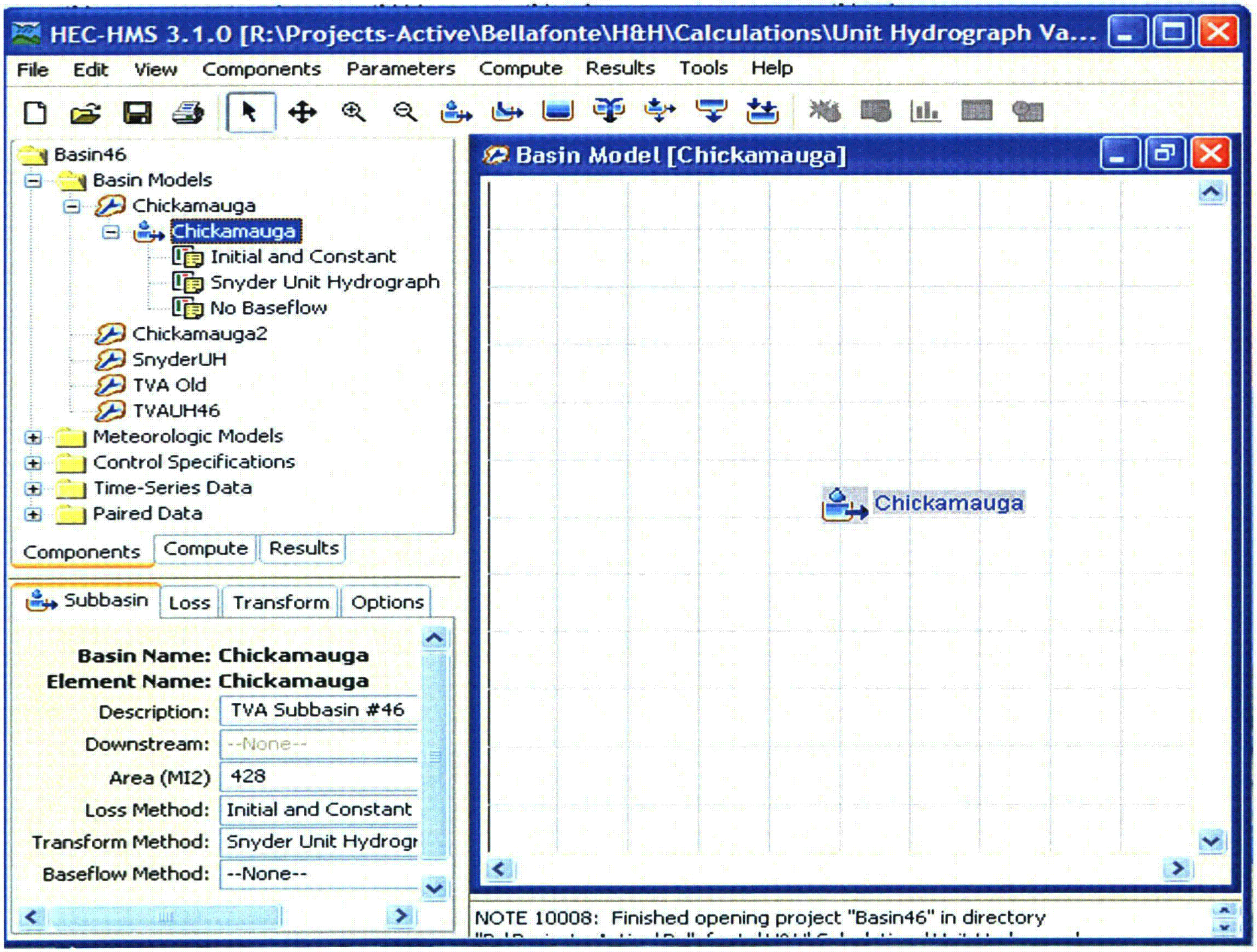
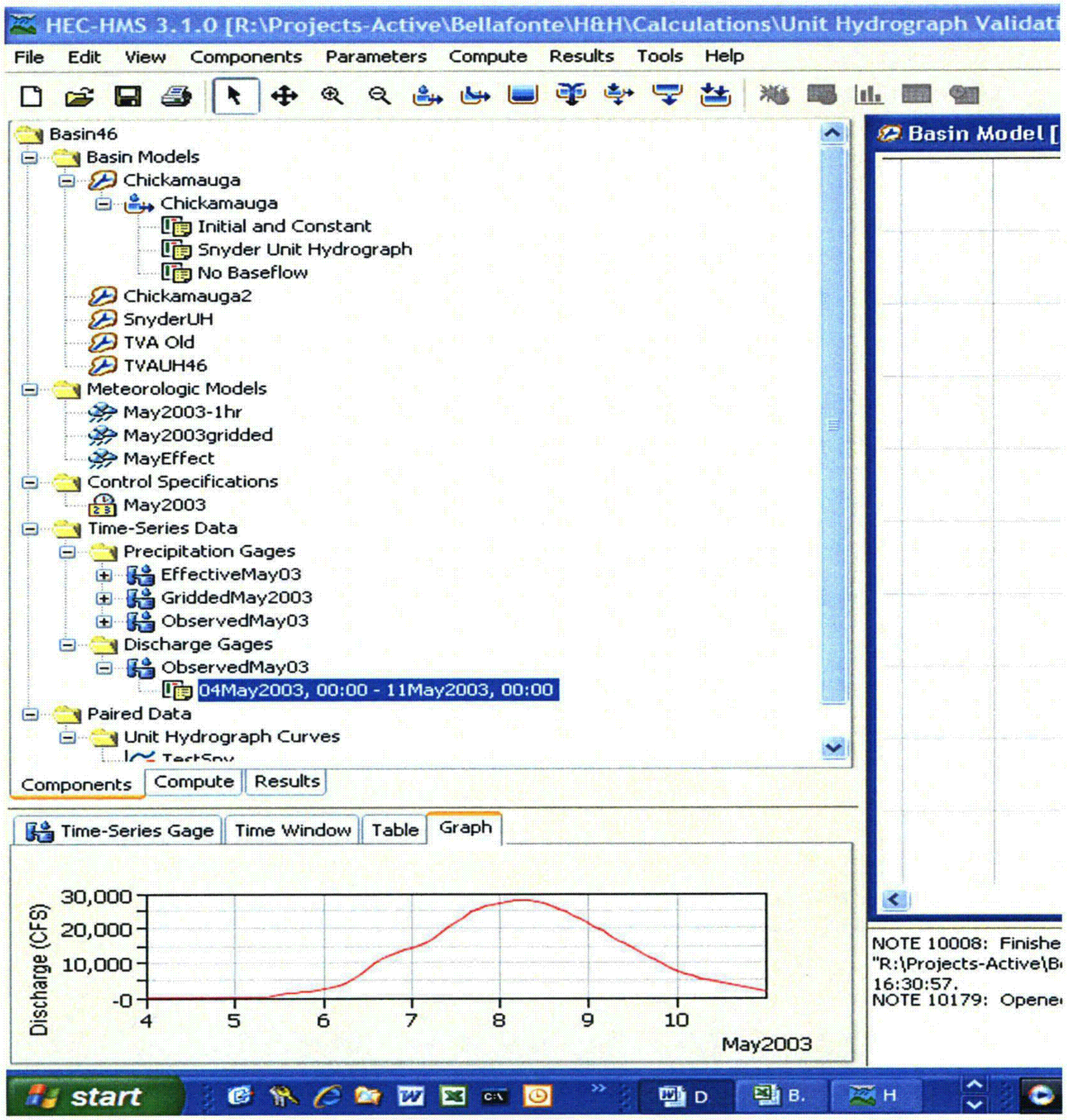
Setting up HEC-HMS Projects for each Sub-basin

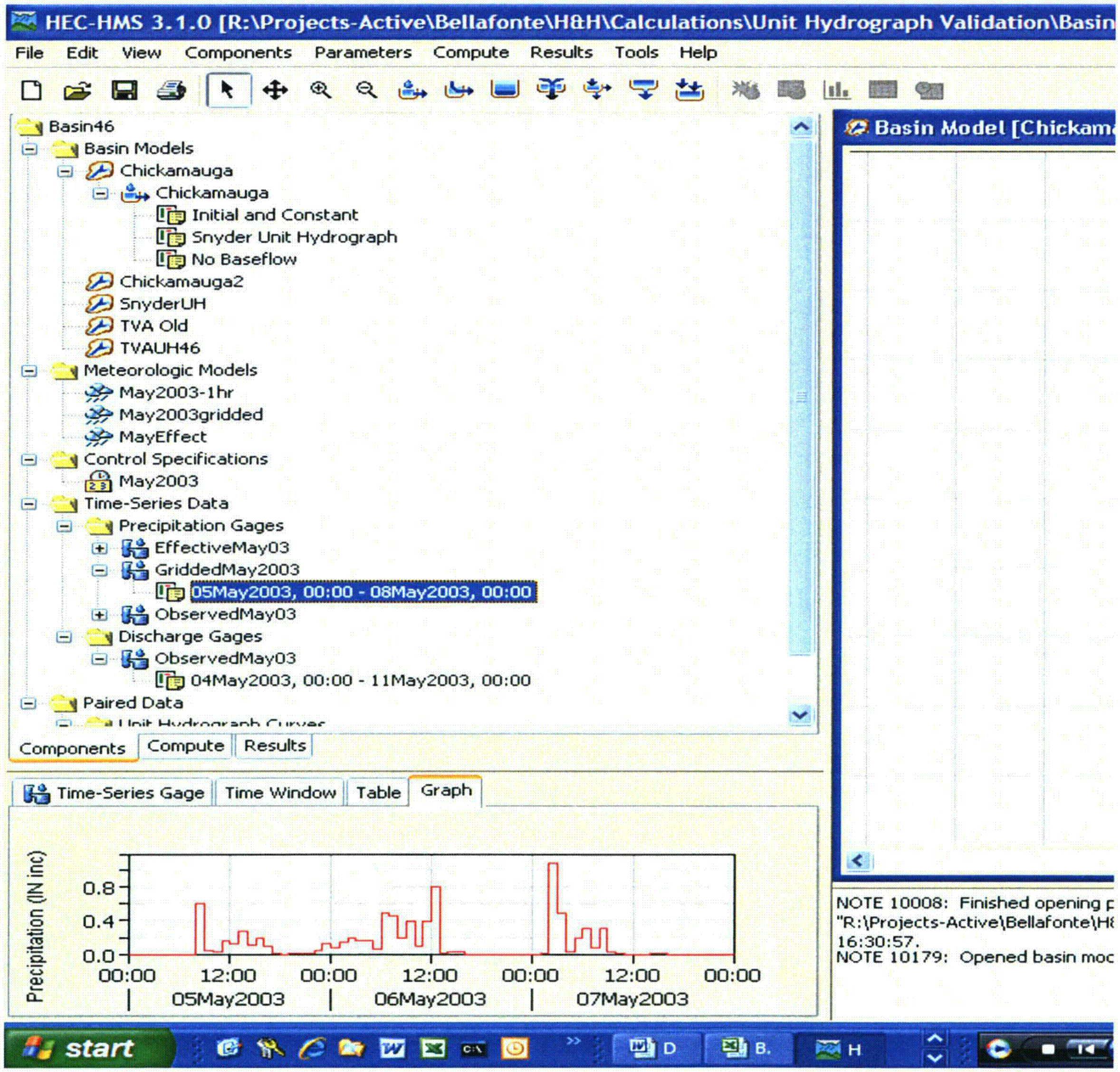


PRELIMINARY

Loading time series of observed stream flow into the model



Loading time series of observed precipitation into the model



TVA

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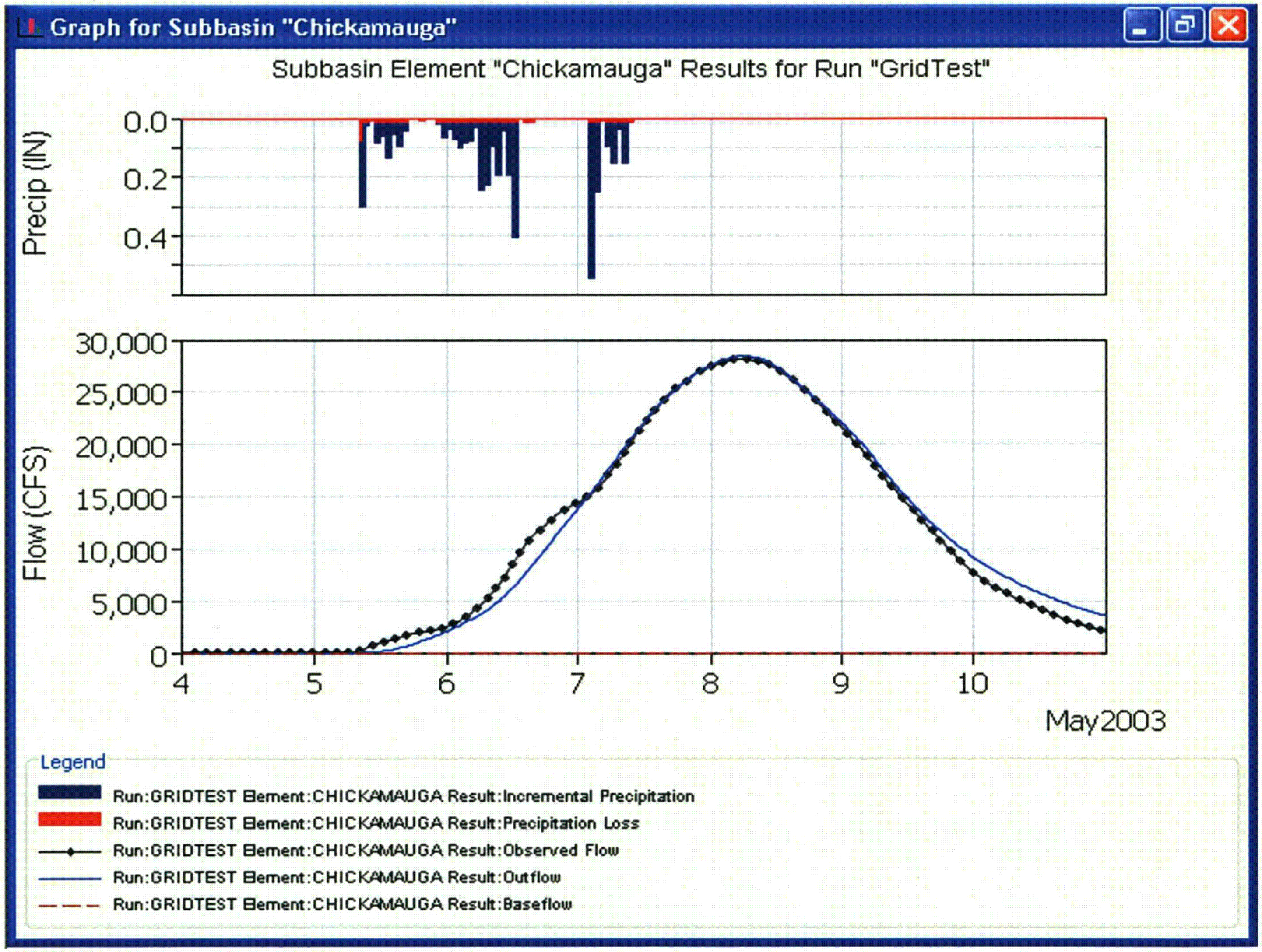
PRELIMINARY

Preliminary HEC-HMS Modeling, South Chickamauga Creek (#46) Type 1



TVA

PRELIMINARY

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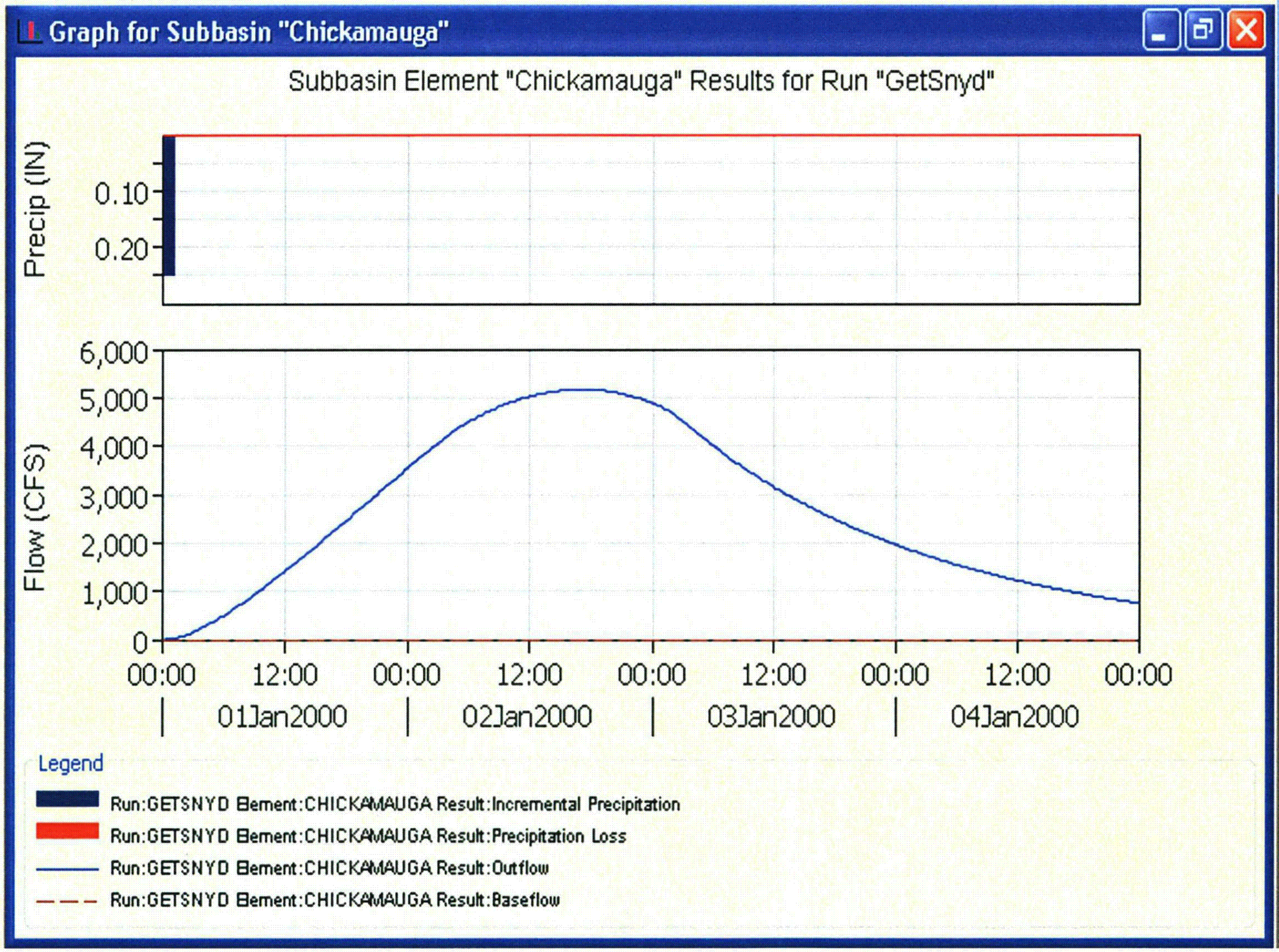
Snyder Unit Hydrograph Generated for Sub-basin 46



TVA

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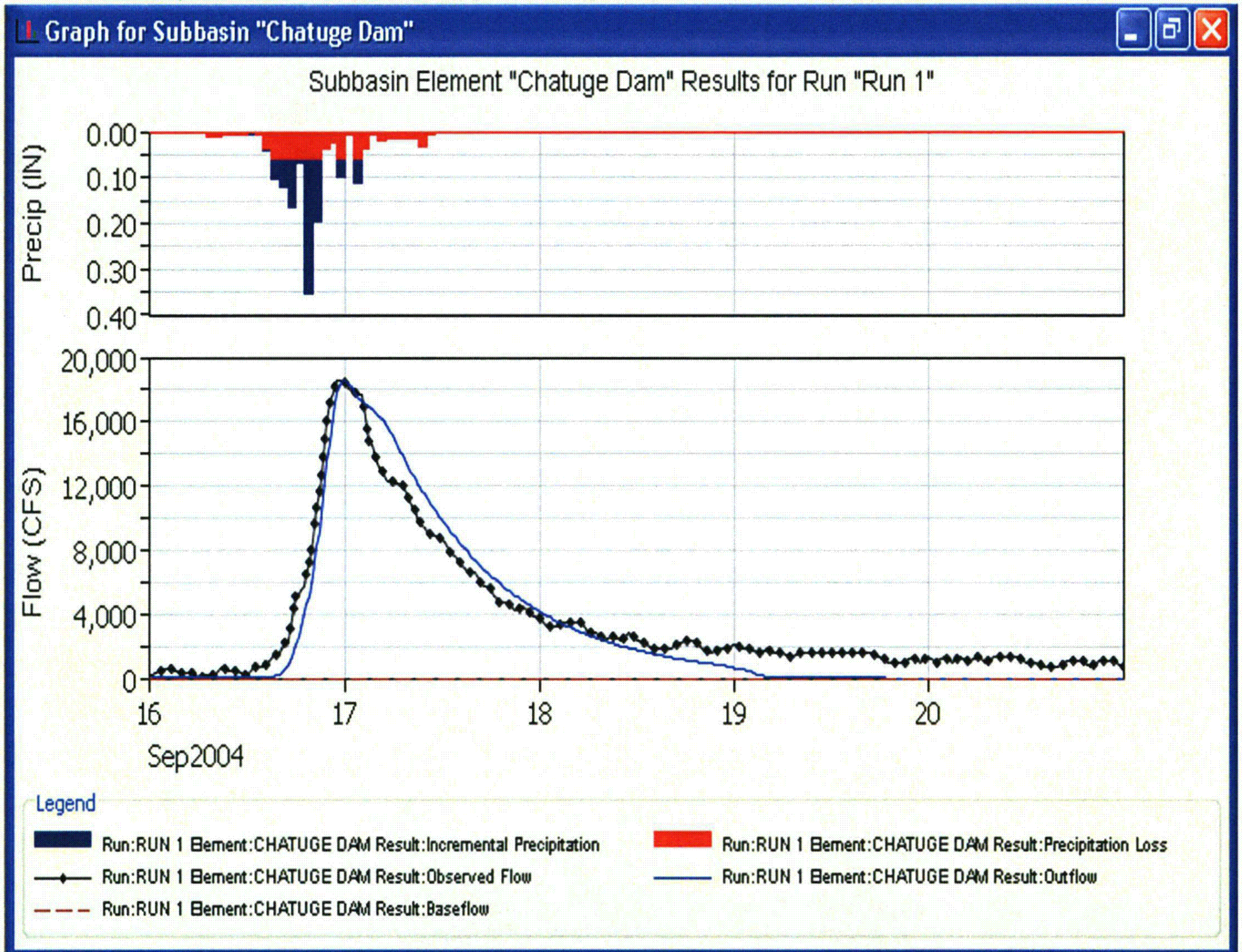
PRELIMINARY

Preliminary HEC-HMS Modeling, Chatuge Dam (#38) Type 4

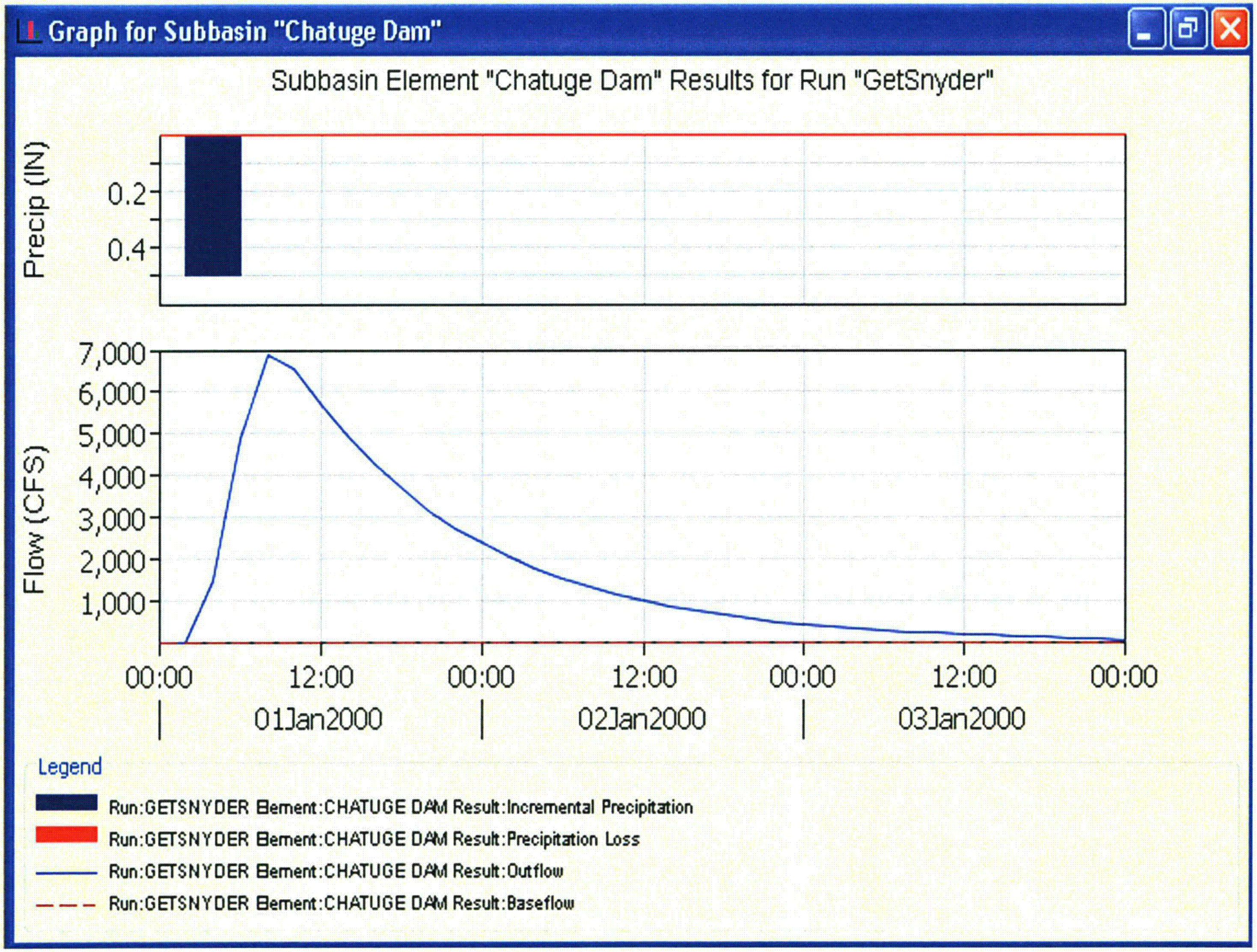


TVA

PRELIMINARY

BECHTEL

Snyder Unit Hydrograph Generated for Sub-basin 38



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PRELIMINARY

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Channel Geometry Verification Process

- For illustration purposes, the following viewgraphs outline the process that is being applied to the Guntersville reservoir.
- Guntersville, one of 11 river channel segments, includes 37 cross-sections.
- This process will be repeated for the remaining 10 river channel segments, ultimately addressing 321 cross-sections.

Channel Geometry Verification Process

1. TVA prepared maps of the bathymetry of Guntersville reservoir used to create the original HEC-2 cross-sections and graphical representations of each cross-section. Check HEC-2 against bathymetry and topographic contours

   Check the cross-sections entered into the original HEC-2 model with the bathymetric maps and graphical cross-sections to ensure that they are consistent

2. An EXCEL spreadsheet was used to convert the HEC-2 cross-sections to a "columnized" format (x-z columns). Check data transfer from HEC-2 to "Columnized" format

   Check that the macros properly reformatted the HEC-2 cross-section data

Channel Geometry Verification Process

3. An EXCEL spreadsheet was used to plot each cross-section in the Guntersville reservoir with the HEC-2 cross-sections, the interpolated COE sections, and the adjusted sections for use in HEC-RAS on the same graph. Check data transfer & plots of HEC-2 sections in EXCEL

   Visually check the HEC-2 cross-sections against the hard-copy plotted sections and numerically check the file against the HEC-2 input data to make sure they all agree

Channel Geometry Verification Process

4. TVA obtained recent bathymetric data of the Guntersville Reservoir from the COE, provided at approximately 500 ft intervals. The TVA GIS group then used these data to interpolate the bathymetry of the cross-sections used in the HEC-2 model. Check plots of interpolated COE sections in EXCEL

   Using the GIS files or print-outs of the COE bathymetric contours provided by TVA, check the COE cross-sections against the bathymetric map.

Channel Geometry Verification Process

5. Using both the HEC-2 and COE cross-sections, TVA produced "adjusted" cross-sections for use in HEC-RAS. Check adjustments to HEC-2 Sections (red line)
   - Review these "adjusted" sections for validity in their representation of the bathymetry.
6. The "adjusted" sections were imported into HEC-RAS. In HEC-RAS, the cross-sections were extended in the overbank areas. The extensions were based on printed contour maps of the area. Check import of COE sections into HEC-RAS and extension in overbank areas
   - Verify that the overbank extension is consistent with the maps.

Channel Geometry Verification Process

7. Prepare input file and run CONVEYANCE. TVA prepared an input file to CONVEYANCE.

   Check the input file for CONVEYANCE to confirm that it matches the HEC-RAS file, and that all other input parameters used by CONVEYANCE are entered correctly.

8. Check areas between sections at each of 4 elevations from GIS (at least 2 segments). SOCH uses weighted widths for the sections. To estimate the weighted widths, TVA used GIS to estimate the horizontal surface area between cross-sections at 4 different elevations.

   Check using a planimeter.

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Channel Geometry Verification Process

9. Prepare input file and run WTDWIDTH. The areas obtained in Step 8 were used to prepare the input file to WTDWIDTH.

   Check these areas to confirm that they match the WTDWIDTH input file, and that all other input parameters to WTDWIDTH are entered correctly.

Channel Geometry Verification Process

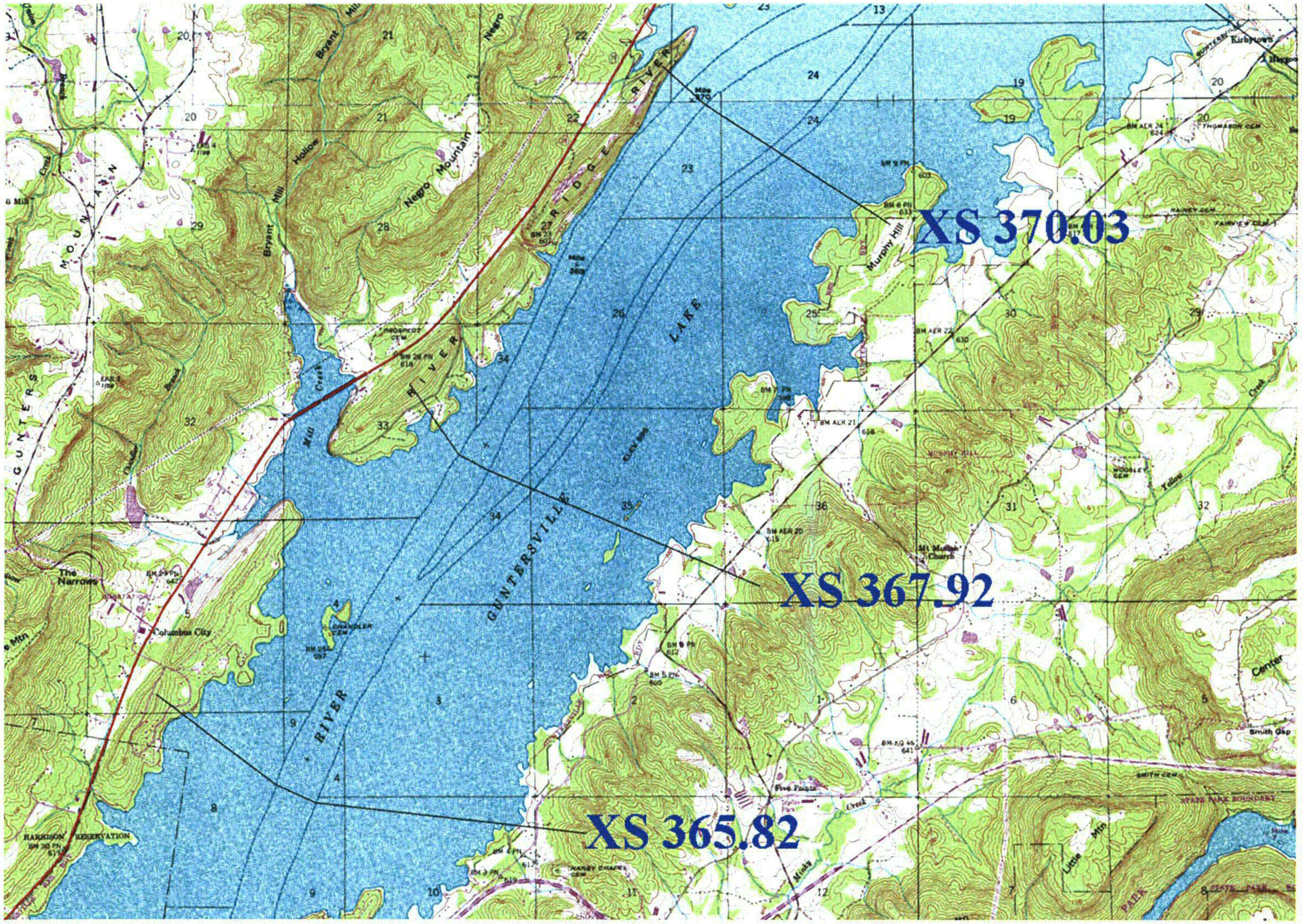
10. Get WTDWIDTH output and extrapolate. The output from WTDWIDTH covers elevations 595 to 660 ft only. Linear extrapolation is used to produce weighted widths for elevations 670 and 680. Weighted widths from the original SOCH geometry file are used to fill in weighted widths for elevations below 595.

Check that the weighted widths were properly extracted from WTDWIDTH, the extrapolation was correct, and that the weighted widths below elevation 595 were properly extracted from the original SOCH run.

Channel Geometry Verification Process

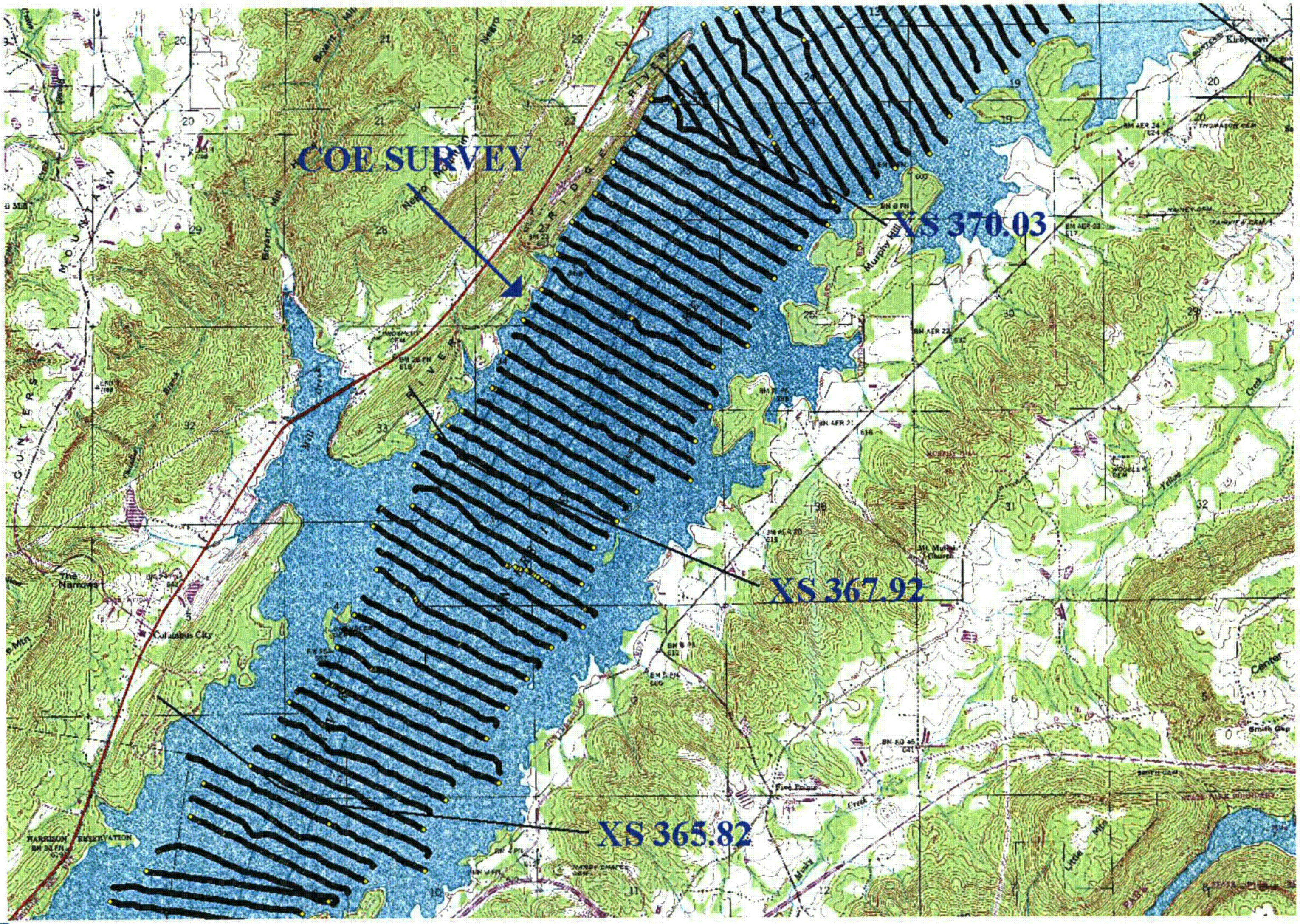
11. Adjust weighted widths based on reservoir volumes. The weighted widths obtained in Step 10 were adjusted to roughly match the reservoir volumes based on the published elevation vs. storage curves.
    - Check the calculation of these new weighted widths.
12. Get WTDWIDTH output and extrapolate. The adjusted weighted widths and CONVEYANCE output were then combined to create the input to the SOCH model.
    - Check the combined data to confirm that they match the CONVEYANCE output and adjusted weighted widths and that all other parameters were entered correctly.

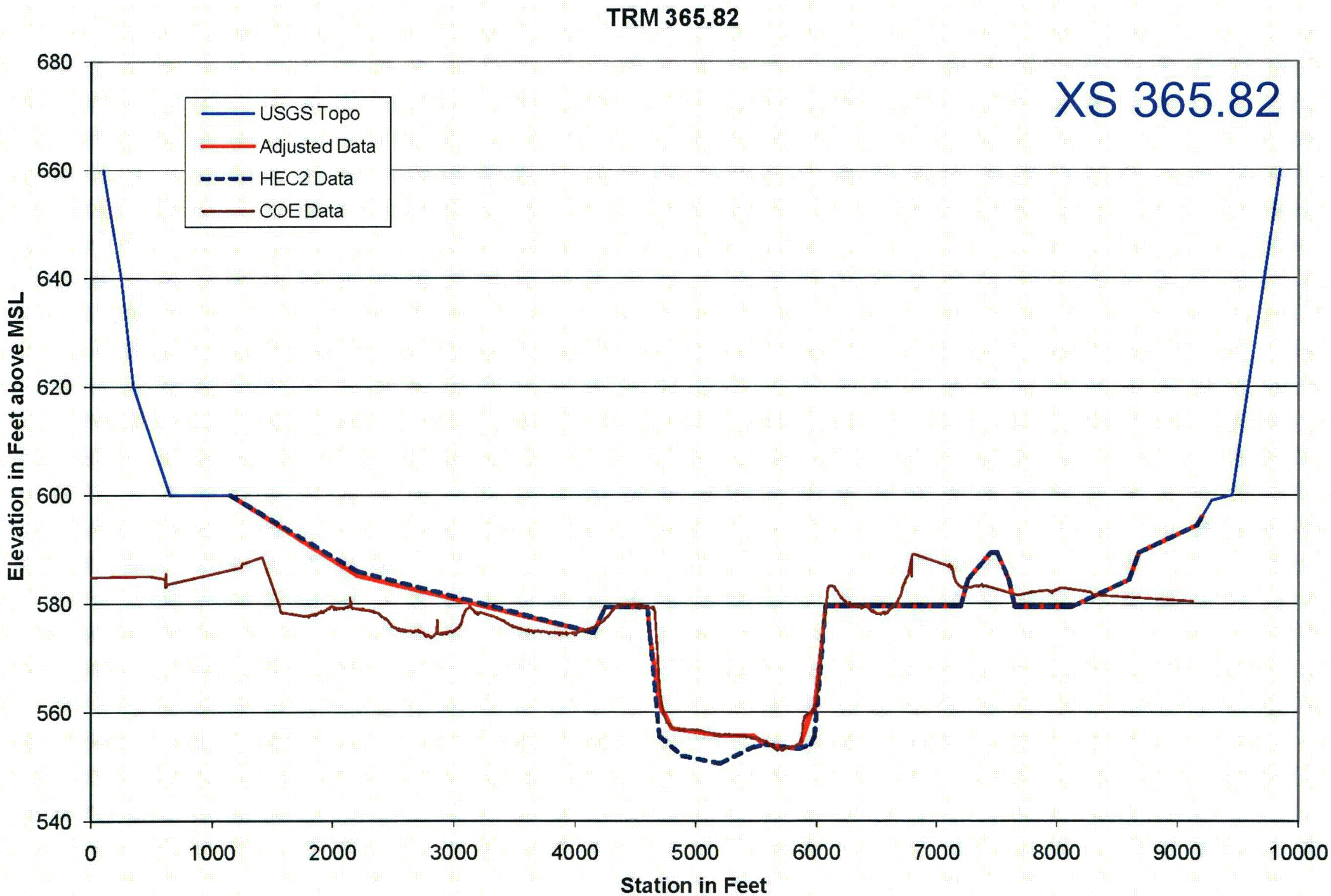
Tennessee River Cross Sections



PRELIMINARY

COE Survey





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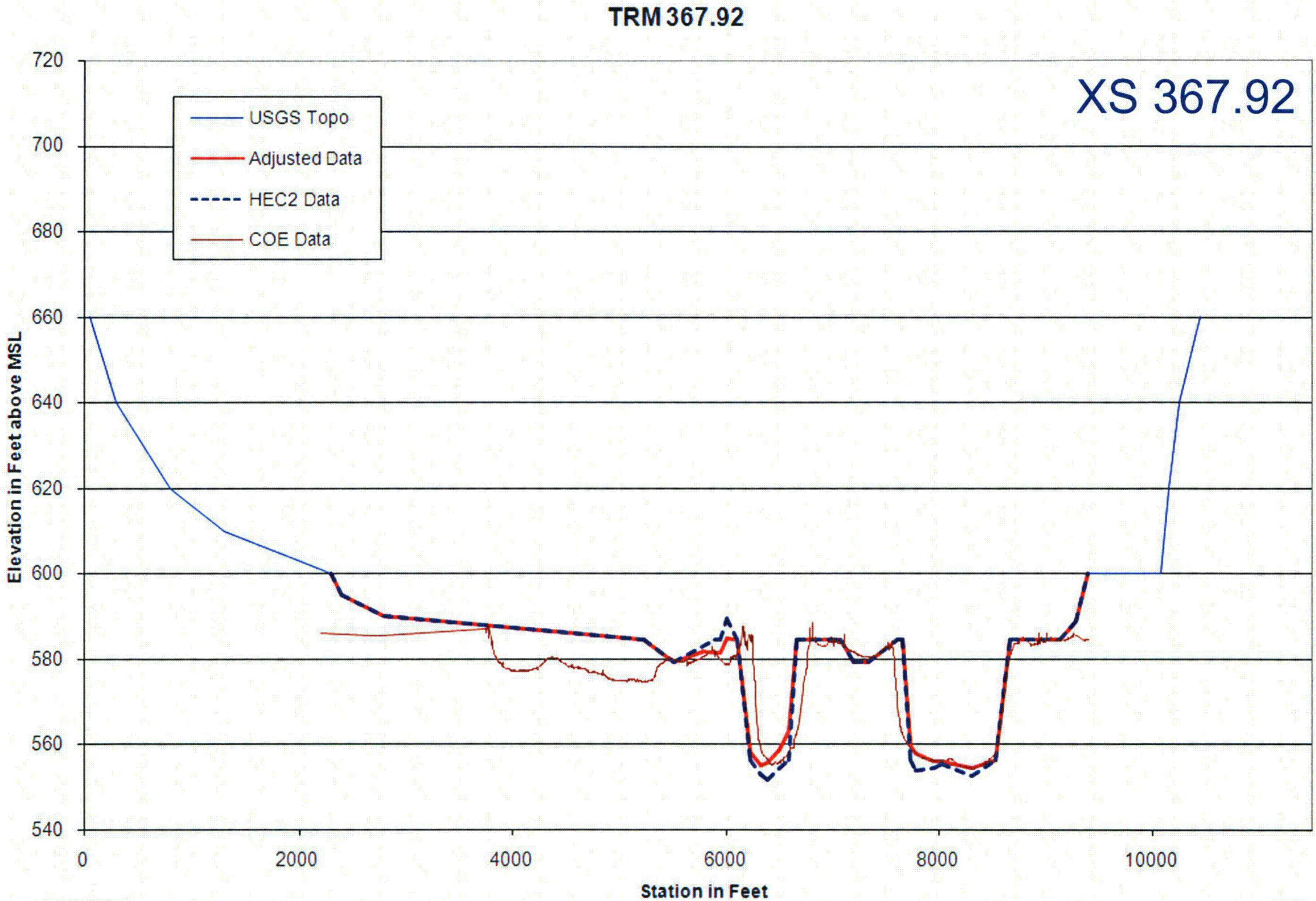

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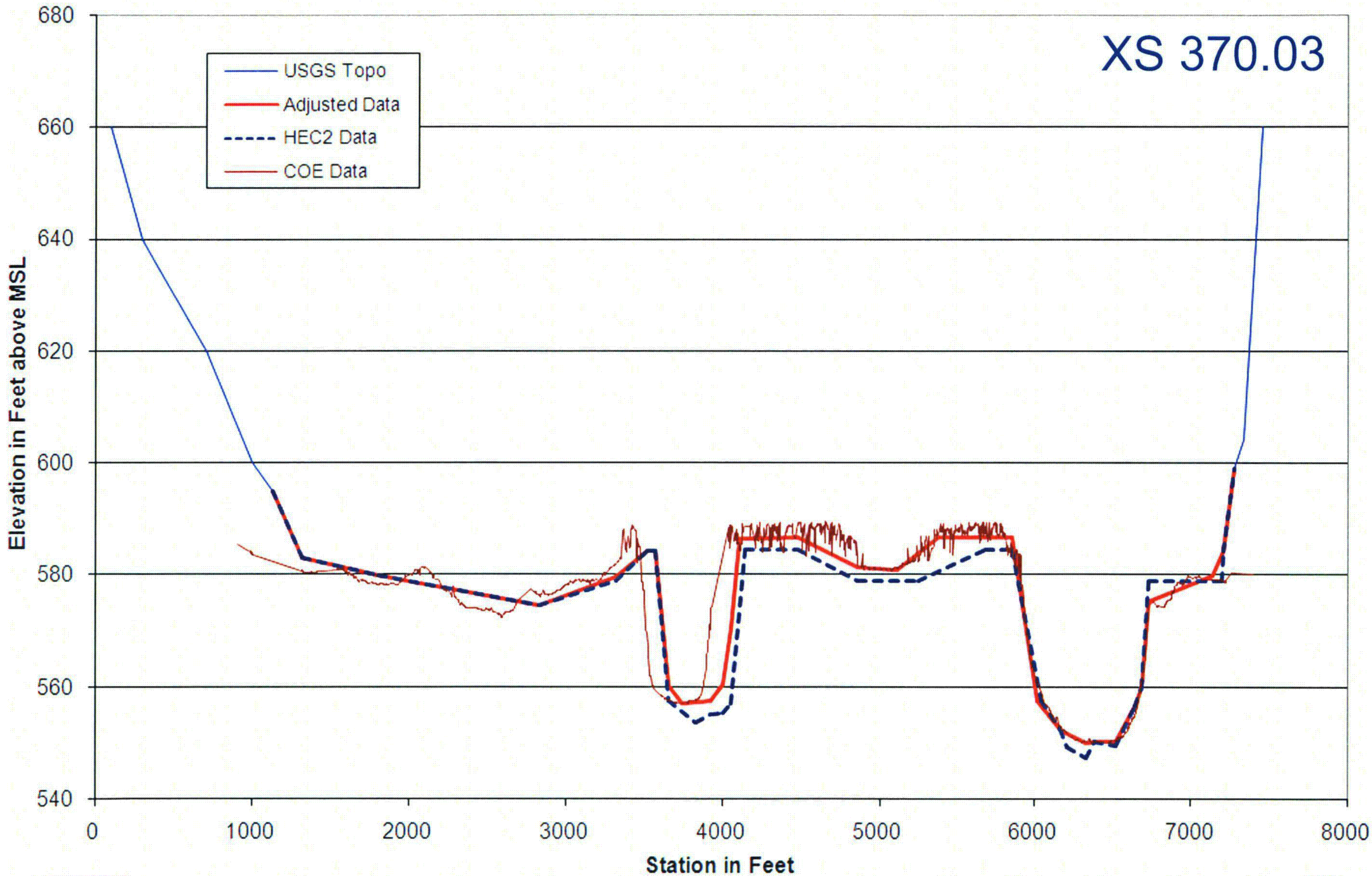
TRM 370.03



TVA

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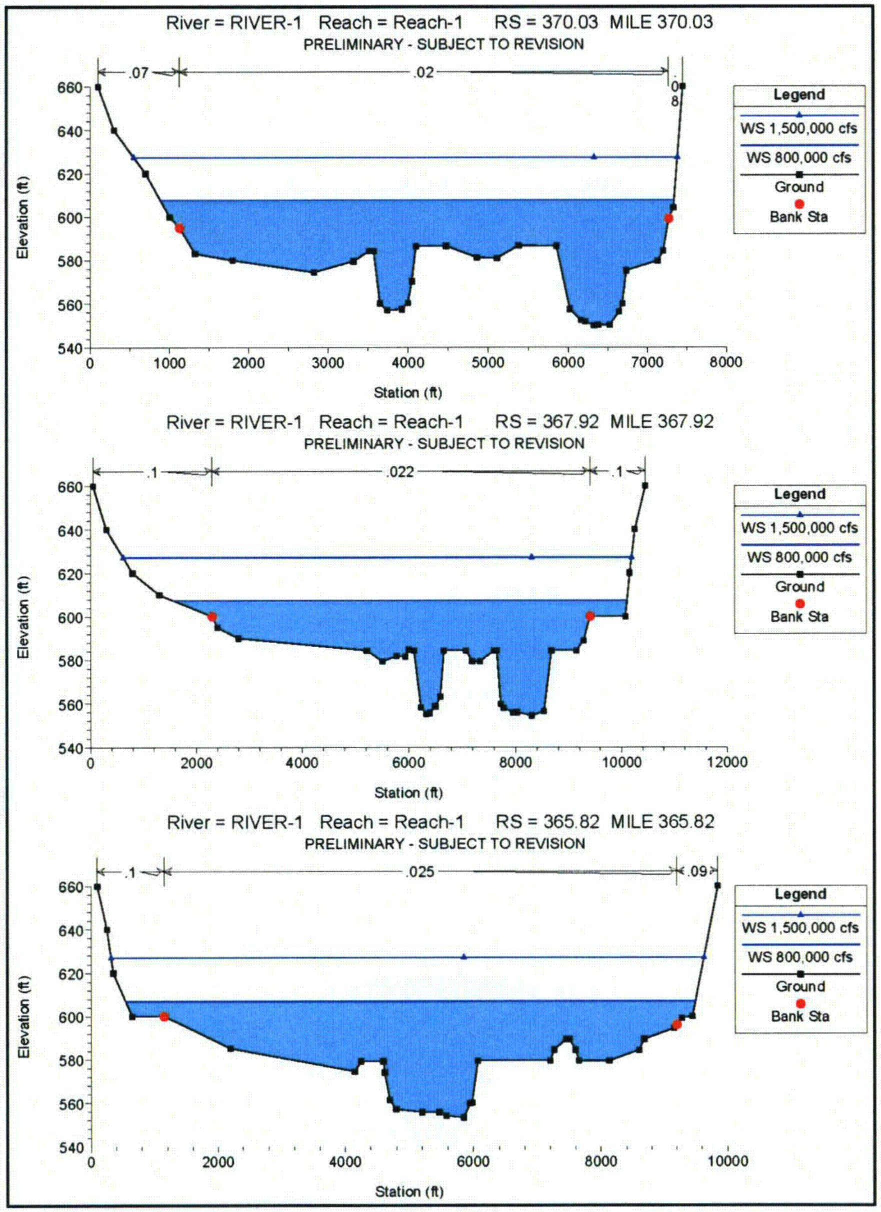

Water Surface Elevations (preliminary)

TVA

PRELIMINARY

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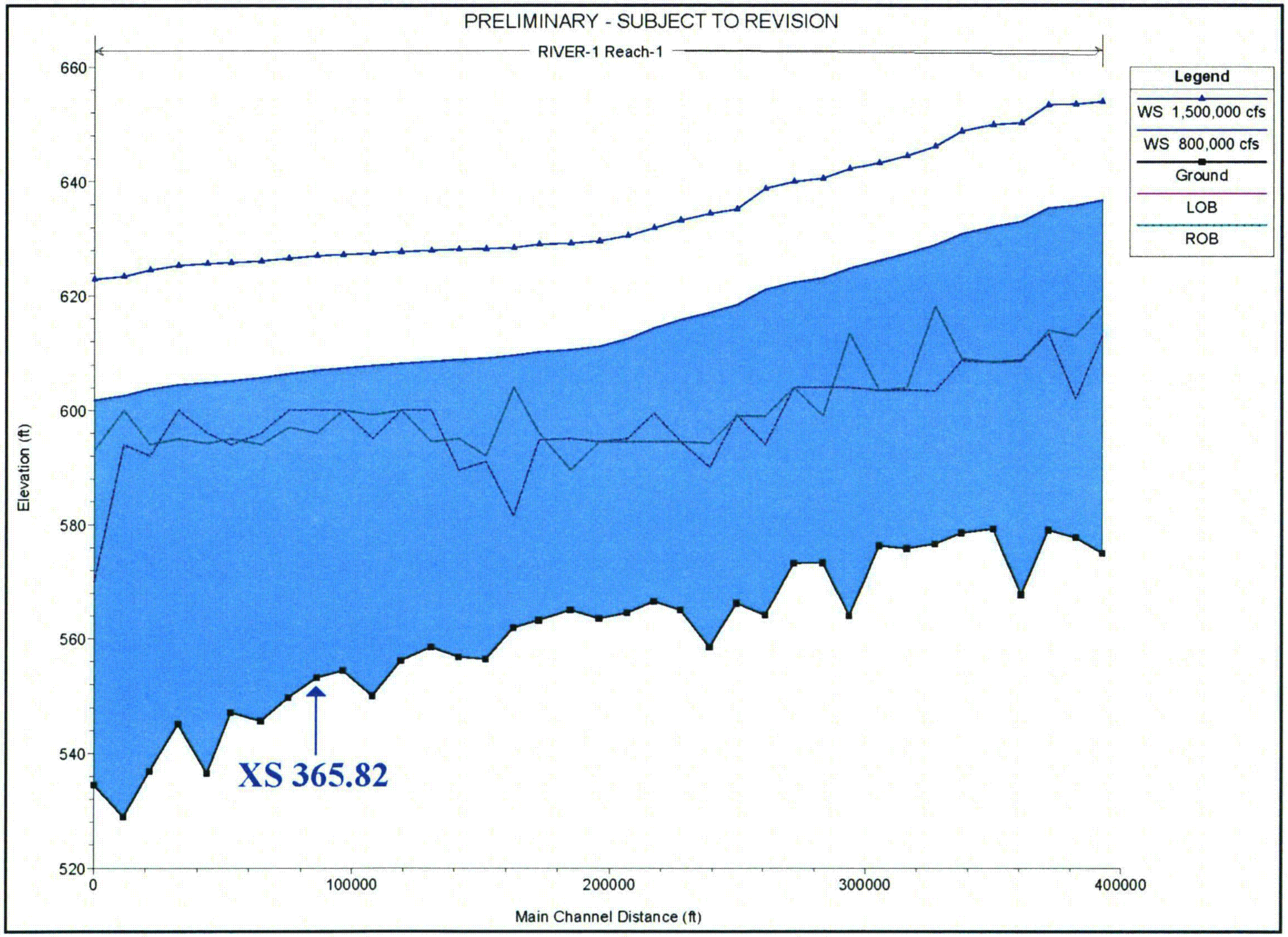
Water Surface Elevations (preliminary)



PRELIMINARY

Verification of Dam Rating Curves

- TVA is generating updated dam rating curves to match current configuration and operational practices
- Bechtel will independently review and verify these curves

Software Verification, Validation, and Documentation

- The TVA hydrologic modeling computer codes have been grouped as follows for purposes of V&V and documentation
  - SOCH
  - CONVEYANCE, WTDWIDTH
  - UNITGRAPH, FLDHYDRO, TRBROUT, CHANROUT
  - DBREACH
- Bechtel will prepare the following documents for each of these four groups of codes:
  - User's Manual,
  - Software Verification and Validation Report (SVVR),
  - Software Requirements Specification (SRS), and
  - Software Design Description (SDD)

Visualization – Reach Scale Geometry