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

ASSOCIATED ATTACHMENTS/ENCLOSURES:

Attachment 02.04.03-8M: Dam Rating Curves, Hiwassee

(218 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 090109 001	calculations(nuclear)	L58 091230 025

Calc Title: Dam Rating Curves; Hiwassee

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV
CURRENT	CN	NUC	GEN	CEB	CDQ000020080012	1	2
NEW							

REVISION APPLICABILITY
Entire calc ☒
Selected pages ☐

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

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

DCN,EDC,N/A	APPLICABLE DESIGN DOCUMENT(S) N/A	CLASSIFICATION
*See Below		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
wbbondurant	901-755-7166	CEB	Design Review	☐ Yes ☒ No

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
Bryant Bondurant Bryant Bondurant	12/22/09	Andrew Murr Andrew Murr	12/22/2009
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
Andrew Murr Andrew Murr	12/22/2009	K. R. Spotes K. R. Spotes 12/22/09	12/23/09

STATEMENT OF PROBLEM/ABSTRACT

Headwater rating curves for 20 dams are required as inputs to TVA's SOCH and TRBROUTE models, which perform flood-routing calculations for the Tennessee River and tributaries. The headwater rating curves for each dam provide total dam discharge as a function of headwater elevation. This calculation presents headwater rating curves for Hiwassee Dam.

Note: The headwater rating curve provided in this calculation is limited in application to maximum PMF headwater elevation of 1542.00 feet (See Section 5.0 in the calculation for the basis of this limiting condition).

*EDCN 22404 (SQN), EDCN 54018 (WBN), EDCN Later (BFN)

This calculation contains electronic attachments and must be stored in EDMS as an Adobe .pdf file to maintain the ability to retrieve the electronic attachments.

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

☐ LOAD INTO EDMS AND DESTROY
☒ LOAD INTO EDMS AND RETURN CALCULATION TO CALCULATION LIBRARY. ADDRESS:LP4D-C
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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 090109 001	calculations(nuclear)	L58 090216 001

Calc Title: Dam Rating Curves, Hiwassee

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV	REVISION APPLICABILITY
CURRENT	CN	NUC	GEN	CEB	CDQ000020080012	0	1	Entire calc ☒
NEW	CN	NUC						Selected pages ☐

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

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

DCN,EDC,N/A	APPLICABLE DESIGN DOCUMENT(S)	CLASSIFICATION
N/A	N/A	E

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

PREPARER ID	PREPARER PHONE NO	PREPARING ORG (BRANCH)	VERIFICATION METHOD	NEW METHOD OF ANALYSIS
C. SATTLER	632-6443	CEB	Design Review	☐ Yes ☒ No

PREPARER SIGNATURE	DATE	CHECKER SIGNATURE	DATE
Clint Sattler	2/6/09	Sara Martinez	2/9/09
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
Andrew Tinsley	2/10/09	K.R. Spates	2/13/09

STATEMENT OF PROBLEM/ABSTRACT

Headwater rating curves for 20 dams are required as inputs to TVA's SOCH and TRBROUTE models, which perform flood-routing calculations for the Tennessee River and tributaries. The headwater rating curves for each dam provide total dam discharge as a function of headwater elevation. This calculation presents headwater rating curves for Hiwassee Dam.

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

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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 090109 001	calculations(nuclear)	N/A

Calc Title: Dam Rating Curves, Hiwassee

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	CUR REV	NEW REV
CURRENT	CN	NUC					
NEW	CN	NUC	GEN	CEB	CDQ000020080012	N/A	0

REVISION APPLICABILITY: Entire calc ☐ Selected pages ☐

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

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

DCN,EDC,N/A	APPLICABLE DESIGN DOCUMENT(S) N/A	CLASSIFICATION
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
C. SATTLER	632-6443	CEB	Design Review	☐ Yes ☒ No

PREPARER SIGNATURE Clint Sattler	DATE	CHECKER SIGNATURE	DATE
C. Sattler R.B. Williston	12-17-2008	JANIE B. MAUTER	12/18/08
VERIFIER SIGNATURE	**DATE**	**APPROVAL SIGNATURE**	**DATE**
ANDREW C. MURR / R.B. Williston	12-22-08 / 12-18-08	E.R. SPATES	1/9/09

STATEMENT OF PROBLEM/ABSTRACT

Headwater rating curves for 20 dams are required as inputs to TVA's SOCH and TRBROUTE models, which perform flood-routing calculations for the Tennessee River and tributaries. The headwater rating curves for each dam provide total dam discharge as a function of headwater elevation. This calculation presents headwater rating curves for Hiwassee Dam.

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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Revision 0 Coversheet Included for Reference Only

NPG CALCULATION COVERSHEET/CCRIS UPDATE

CALC ID	TYPE	ORG	PLANT	BRANCH	NUMBER	REV
	CN	NUC	GEN	CEB	CDQ000020080012	2

ALTERNATE CALCULATION IDENTIFICATION

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

CATEGORIES SR / LC

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	
D	S	CN	GEN	CEB	CDQ000020080054	
A	S	CN	GEN	CEB	CDQ000020080053	

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 CDQ000020080012

Title: Dam Rating Curve, Hiwassee

Revision No.	DESCRIPTION OF REVISION
0	Initial Issue — Total Pages - 83
1	Upper limit of Headwater raised to 1545' — Total Page – 95 Changes to pages 5, 7, 10-12, 14-16, 18-21 (including 18a and 19a), A6, C2, B1-B3 Changes to Attachments 4, 5, 15, A13-1, A13-2 Added pages B4-B7, Added Attachments B1-B5 Attachments 1-6, 9-11, 13-15, 17, 18, 34, A1-A4, A6, A8, A10-A12, A14, A15, B1-B5 – 1 Page Each Attachments 8, 12 – 2 Pages Each Attachment 16, A9 – 3 Pages Each Attachment A13 – 4 Pages Attachments A5, A7 – 5 Pages Each
2	This calculation was revised to address the following: • PER 203951-The verification of the original calculation was completed by personnel who had not completed the required NEDP-7 Job Performance Record (JPR). A verification JPR is now in place for all personnel engaged in verification tasks. Checking included only changes made in this revision as the checking of the calculation was not impacted by PER 203951. The verification is inclusive of work completed prior to this revision. • PER 203872- replace NEDP-2 forms on Pages 1 through 5 and Page 7 with the forms from the NEDP-2 Revision in effect at the time of calculations issuance • Per 204081-The verification of Revision 2 of the calculation was completed by a TVA Project Engineer with expired qualifications. • Added Appendix D to evaluate the margin of forces on tainter gates. • Revised to eliminate Unverified Assumptions 3.2.1 and 3.2.2 and added Assumption 3.1.4 and 3.1.5 on Page 11; added Reference 22 in Section 2; revised coversheet and CCRIS input sheet on Page 2; added Design Verification sheet for Page 6 • Assumption 3.14 is based on Ref. 22 and Appendix D (3 pages) Significant changes in Revision 2 are noted with a right margin revision bar. Administrative changes and typos are excluded. Pages Added: 1b, 6a, D1, D2, D3 Pages Replaced: 1-7, 10-11, 13, 16, 19-23 Total pages of calculation hard copy for Revision 2= 101

NPG CALCULATION TABLE OF CONTENTS

Calculation Identifier: CDQ00020080012	Revision:	2

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Appendix D	Hydrostatic Loads on Spillway Tainter Gates	D1

Note: N/A indicates electronically attached file(s).

NPG CALCULATION VERIFICATION FORM

Calculation Identifier CDQ000020080012 Revision 2

Method of verification used:

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

Verifier Andrew Murr Date 12/22/2009

Comments:

This calculation entitled, "Dam Rating Curve, Hiwassee," 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.

The methodology used to justify the operability of the gates is based solely on the conclusions of the "Watts Bar Dam – Flood and Earthquake Analysis on Radial Spillway Gates." Appendix D uses the same assumptions, methodology, and approach developed in the Watts Bar radial gate analysis to determine the forces on the radial gates in a closed position with the forces on the gates in the maximum open position. This appendix does not assert that a structural analysis has been performed beyond that found in the Watts Bar radial gate calculation.

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

NPG CALCULATION VERIFICATION FORM

Calculation Identifier CDQ000020080012 Revision 0

Method of verification used:

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

Verifier R.B. Williston / Andrew Muir Date 12/22/08

Russell B. Williston Andrew Muir

Comments:

Revision 0 Verification Form Included for Reference Only

NPG COMPUTER INPUT FILE
STORAGE INFORMATION SHEET

Document CDQ000020080012	Rev. 2	Plant: GEN	

Subject:
Dam Rating Curve, Hiwassee

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

There are no electronic input or output files associated with this calculation.

☒ 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.)

These files 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.

Attachment 19: Complete PDF copy of TVA Water Control Project Manual (Blue Book) for Hiwassee Dam, TVA River Operations, October, 1999 (Ref. 2)
Attachment 20: Complete PDF copy of "Hiwassee Dam Spillway Discharge Tables" (Refs. 7 & A1)
Attachment 21: Complete PDF copy of "Rating Curves for Flow over Drum Gates," Joseph N. Bradley, Paper No. 2677, Transactions of the American Society of Civil Engineers, vol. 119, pp. 403-433, 1954 (Ref. 11)
Attachment 22: Spreadsheet, Hiwassee Rating Curves.xls
Attachment 23: Spreadsheet, Hiwassee Model Data For Headwater Ratings.xls
Attachments 24-33 and 35-38: High Resolution copies of Refs. 1, 3-5, 9, 12, 14-17, and 18-21
Attachments A16-A17: High Resolution copies of Refs A5 and A6

☐ Microfiche/eFiche

1. Purpose

Headwater rating curves for twenty dams geographically located on the Tennessee River and its tributaries above the existing Bellefonte Nuclear facility are required as inputs to TVA's SOCH and TRBROUTE models, which perform flood-routing calculations. The headwater rating curves for each dam provide total dam discharge as a function of headwater elevation. This calculation presents headwater rating curves for Hiwassee Dam.

TVA developed methods of analysis, procedures, and computer programs for determining design basis flood levels for nuclear plant sites in the 1970's. Determination of maximum flood levels included consideration of the most severe flood conditions that may be reasonably predicted to occur at a site as a result of both severe hydrometerological conditions and seismic activity. This process was followed to meet Nuclear Regulatory Guide 1.59. At that time, there were no computer programs available that would handle unsteady flow and dam failure analysis. As a result of this early work and method development, TVA developed a runoff and stream course modeling process for the TVA reservoir system. This process provided a basis for currently licensed plants (Sequoyah Nuclear Plant, Watts Bar Nuclear Plant, and Browns Ferry Nuclear Plant). The Bellefonte Nuclear Plant (BLN) Units 1 & 2 Final Safety Analysis Report (FSAR) was also based on this process.

BLN Unit 3 & 4 Combined Operating License Application (COLA) was submitted using data and analysis that was determined for the original BLN FSAR (Unit 1 and Unit 2) and was documented in a 1998 reassessment. In 1998, the analysis process and documentation was brought under the nuclear quality assurance process for the first time. A quality assurance audit conducted by NRC staff in early 2007 raised several questions related to past work regarding design basis flood level determinations. This calculation supports a portion of the effort to improve this design basis documentation.

Preparation of all calculations supporting nuclear development and licensing are subject to TVA Standard Department Procedure NEDP-2. This standard dictates the process in which calculations are prepared, checked, verified, stored, and cross referenced in a goal to provide the highest quality nuclear design input and output possible.

Figure 1 is the plan and elevation views (Ref. 1) of Hiwassee Dam. A photograph is included as Attachment 2. For headwaters in the normal operating range, discharge is passed through the turbines, spillway, and spillway regulating conduits. The spillway consists of seven spillway bays, each with a radial, or tainter, gate to control discharge. If, as during a probable maximum flood (PMF) event, headwater rises above the normal operating range, discharge may pass also over the tops of the open spillway gates. Discharge is not expected to pass over any portion of the dam, however, because the top elevation of the dam is equal to or greater than the headwater elevation during a PMF event. Consequently, the rating curves developed in this calculation do not include headwater elevations above the top of the dam.

Rating curves are presented for the following two cases

Case 1 – Valid for rising headwaters and for falling headwaters as long as the tailwater elevation does not flood the powerhouse (TW<1305.2').

Case 2 – Valid for falling headwaters after the powerhouse has been flooded.

These headwater rating curves are based on the configuration of the Hiwassee Dam as defined on the current design drawings. The purpose of this calculation does not evaluate the design loading conditions for the dam.

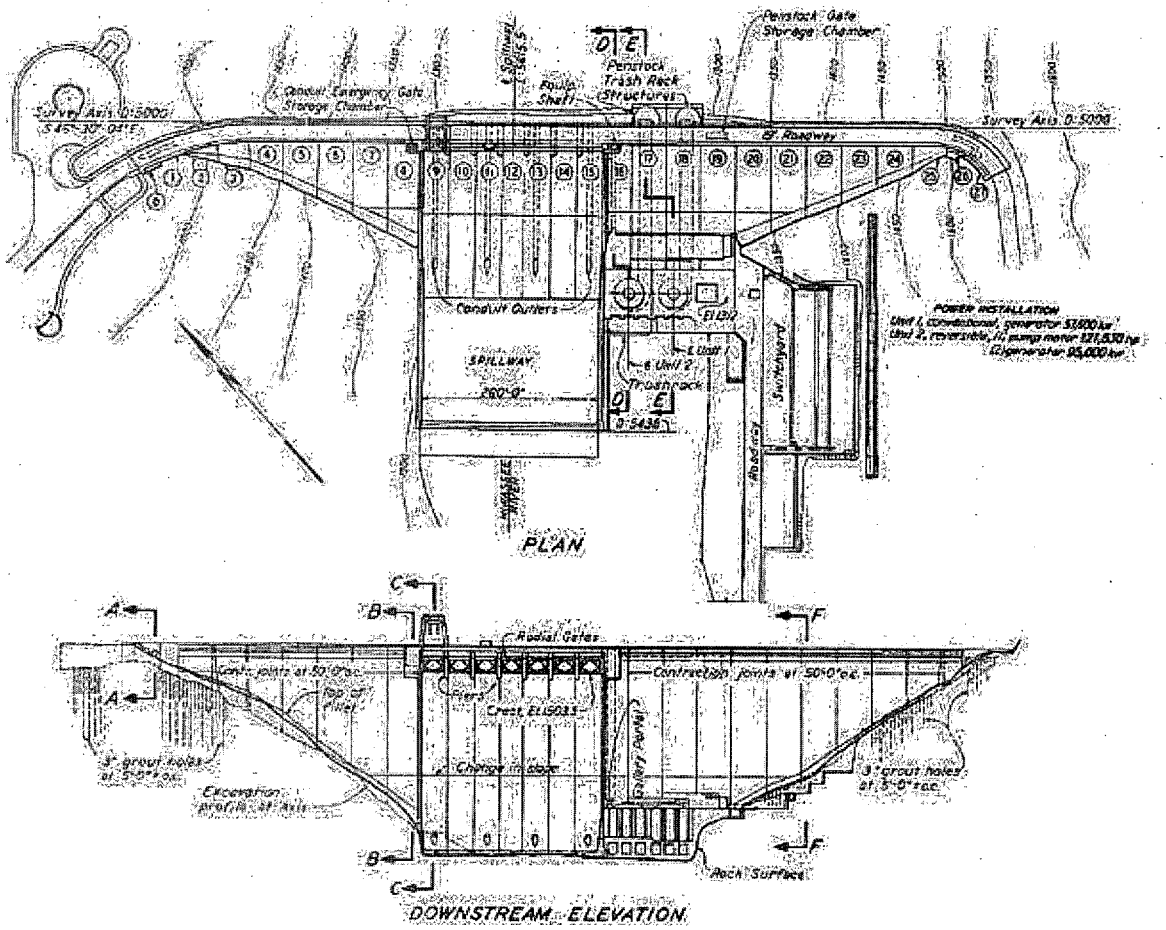


Figure 1 – Hiwassee Dam, General Plan and Elevation (Ref. 1).

2. References

1. TVA drawing no: 10L203, R7 (Attachments 1 & 24)
2. TVA Water Control Project Manual (Blue Book) for Hiwassee Dam, TVA River Operations, October, 1999 (Attachment 19)
3. TVA drawing no: 21N206, R5 (Attachments 4 & 25)
4. TVA drawing no: 21N217, R4 (Attachments 5 & 26)
5. TVA drawing no: 10M201, R5 (Attachments 6 & 27)
6. TVA files, binder "River Scheduling: Tailwater Rating Curves by Projects." (Relevant Pages included in Attachment 8)
7. "Hiwassee Dam Spillway Discharge Tables", River Operations, Tennessee Valley Authority, 2004, EDMS # L58 081212 804 (Attachment 20)
8. "Hydraulic Design Criteria," USACE (U. S. Army Engineer Waterways Experiment Station), Eighteenth issue, Vicksburg, MS, 1988.
9. TVA drawing no: 51N587, R7 (Attachments 9 & 28)
10. Handbook of Hydraulics, E. F. Brater and H. W. King, Sixth Ed., McGraw Hill, 1976.
11. "Rating Curves for Flow over Drum Gates," Joseph N. Bradley, Paper No. 2677, Transactions of the American Society of Civil Engineers, vol. 119, pp. 403-433, 1954. (Attachment 21)
12. TVA drawing no: 14W372, R8 (Attachments 11 & 29)
13. Intentionally Left Blank
14. TVA drawing no: 21N213, R5 (Attachments 15 & 30)
15. TVA drawing no: 45K326, R1 (Attachments 12-1 & 31)
16. TVA drawing no: 47K2864, R0 (Attachments 12-2 & 32)
17. TVA drawing no: 46N218, R0 (Attachments 33 and 34)
18. TVA drawing no: 51N228, R3 (Attachments B1 and 35)
19. TVA drawing no: 31N221, R0 (Attachments B2 and 36)
20. TVA drawing no: 10M200, R5 (Attachments B3 and 37)
21. TVA drawing no: 21N218, R7 (Attachments B4 and 38)
22. TVA 2009: "Basis for Dam Spillway Gate/Outlet Open Configuration for Flood Analyses", May 29, 2009 (EDMS No. L58090529800)

3. Assumptions & Methodology

The headwater rating curves developed in these calculations will be used in simulations of probable maximum flood events. Consequently, the rating curves have been calculated well above the normal operating range of the dam.

3.1 Assumptions

3.1.1 Assumption: Power generation will continue during the PMF event until the powerhouse is flooded.
Technical Justification: Power generation is assumed to stop when the addition of turbine discharge would lead to the tailwater reaching an elevation of 1305.2 feet, at which point the tailwater will enter the powerhouse via the powerhouse air inlet grille (Attachment 34 Ref. 17). Accordingly, turbine discharge will be considered for rising headwaters until the addition of discharge through the turbines would cause the tailwater to reach an elevation of 1305.2 feet. After the powerhouse has been flooded, the generator will not be restarted as electrical components will be wet. Therefore, turbine discharge is not included as headwaters fall after flooding of the powerhouse.

3.1.2 Assumption: The attached tailwater rating curve (Attachment 8 from Reference 6) is sufficient for computing submergence effects on the headwater rating curves.
Technical Justification: The tailwater rating curve attached to this calculation was generated by the TVA Flood Risk group. This tailwater rating curve is used by TVA during actual flooding events to drive river management decisions and is therefore considered the best available source of tailwater elevation data. Regardless, tailwater will only affect sluice flow, as tailwater needs to rise another 167.5 feet from its maximum before impacting flow through the spillway (See Section 7, 1503.5'-1336'=167.5'). Tailwater will reduce the flow through the sluices, however the impacts tailwater has on the overall headwater rating curves are negligible (Appendix C).

3.1.3 Assumption: Tailwater effects will be calculated as if headwater elevation at Apalachia Dam is 1297.0 feet.
Technical Justification: According to past TVA experience, headwater at Apalachia Dam is not expected to rise past 1297.0 feet. Regardless, the impact the tailwater rating curve has on the overall headwater rating curves are minimal (See 3.1.2 and Appendix C).

3.1.4 Assumption: Spillway and sluice gates are considered fully operable and open to the maximum gate opening as specified in Reference 7.
Technical Justification: For justification of this assumption, see Reference 22 and Appendix D. The radial gates will remain operable in the maximum opened position based on the findings of the "Watts Bar Dam – Flood and Earthquake Analysis on Radial Spillway Gates" (Reference D1). Appendix D uses the same assumptions, methodology, and approach as the Watts Bar radial gate analysis to compare forces on the gates in a closed position with forces on the gates in the maximum open position to provide technical justification for the gates to remain operable in the maximum open position during a PMF.

3.1.5 Assumption: Headwaters will not rise beyond 1545 feet in elevation.
Technical Justification: The upper limit on the headwater elevation is assumed appropriate for the Bellefonte PMF (although different from the project PMF). The SOCH/TRBROUTE analyst will identify if a revision to this calculation is required to accommodate higher elevations.

3.2 Unverified Assumptions

None.

3.3 Methodology -- Discharge Equations

Discharges past the dam are computed as either "free" discharge or "orifice" discharge. Free discharge refers to free surface overflow and is computed using a weir-type equation as follows. Reference 8 shows weir flow equations for overflow discharges:

$$Q_f = C_f L H_c^{1.5} \tag{1}$$

in which Q_f = free discharge (cfs), C_f = free discharge coefficient ($ft^{0.5}$/sec), L = length of overflowing section (ft), H_c = head on crest (ft) = HW - Z_c, HW = headwater elevation (ft), and Z_c = top, or crest, elevation of overflowing section (ft). This equation need not be modified to account for tailwater submergence, as no portion of the dam which has free surface overflow will be submerged by tailwater.

Flows over the nonoverflow section, abutments, dam piers, and north end of the road are treated as free discharge. Flow over the spillway crest is treated as free discharge for headwater elevations below $H_c = H_{Lmin}$, the head at which the overflowing nappe first touches the bottoms of the open gates (see Attachment A10). H_{Lmin} varies with gate opening, V, defined as the vertical distance between the bottom of the gate and the spillway crest.

For headwater elevations above $H_c = H_{Lmin}$ flow through the spillway gates is treated as orifice discharge. Orifice discharge refers to flow passing through a contracted opening and is computed using an orifice-type equation as follows (e.g., Reference 8, Hydraulic Design Chart 311-1):

$$Q_g = C_g G_n L \sqrt{2g(H_c - H_{mp})} \tag{2}$$

in which Q_g = orifice discharge (cfs), C_g = orifice discharge coefficient (dimensionless -- varies with gate opening and H_c), G_n = effective gate opening = minimum distance between the gate lip and the crest (ft), g = acceleration of gravity, and H_{mp} = vertical distance between the mid-point of G_n and the crest. This equation need not be modified to account for tailwater submergence as the tailwater will never reach the crest elevation and influence discharge.

Sluice (spillway regulating conduit) discharge is also treated as orifice flow and computed using a simplified form of the orifice equation as follows:

$$Q_S = 4K\sqrt{HW - Z_{Ref}} \tag{3}$$

The coefficient K (in $ft^{2.5}$/sec) lumps the constant quantities effecting orifice flow into one parameter. It may be thought of as equal to $CA\sqrt{2g}$ in which C = discharge coefficient and A equals area for flow under the sluice gate. Because the discharge is through a closed conduit, both C and A, and consequently K, are constant at a given gate opening. In Equation (3), the head differential term is defined as HW – Z_{ref}., with Z_{Ref} = the centerline elevation of the sluice outlet nozzle (1265.29 feet, Ref. 9, Att. 9). Also, Equation (3) contains the multiplier 4 to reflect the number of sluices. The K - values for all sluice openings were determined in Attachment 17 from prototype data (for a single sluice) in Reference 7.

Equation 3 assumes no tailwater effects. Under the conditions for which this headwater rating is developed, the tailwater may affect the sluice discharge. For the fully opened Hiwassee sluices, tailwater submergence effects will be computed for tailwater elevations, TW (in feet), which result in a fully submerged sluice. The following equation will be used:

$$Q_{sl} = 4K\sqrt{HW - TW + 3.485} \qquad (4)$$

where Q_{sl} = discharge affected by submergence. By adding 3.485 feet (1268.775 – 1265.29) to the head difference term (HW-TW), the desirable result that $Q_{sl} = Q_s$ at TW = 1268.775 feet, the elevation at which the tailwater first submerges the entire sluice outlet, is obtained (Ref. 9, Att. 9). Because the tailwater level varies with total dam discharge, an iterative process is used to determine submerged sluice discharge.

3.4 Methodology -- Spillway Discharge Calculations

The discharge coefficient, C_f, for free discharge over a spillway crest varies with head, H_c (References 8 and 10). For the Hiwassee spillway crest, the relationship $C_f(H_c)$ is available from model test data (Appendix A). The discharge coefficient, C_g, for orifice discharge varies with H_c and vertical gate opening, V. The relationships $H_{Lmin}(V)$ and $C_g(H_c,V)$ are available from model test data (Appendix A). The crest length, L, and crest elevation, Z_c, are shown on TVA drawings (e.g., Ref. 5). The parameters G_n and H_{mp} are determined from geometry (Appendix A).

The physical model used to measure spillway discharge included several bays and the piers between them. Consequently, pier contraction effects are implicitly included in the discharge coefficients derived from the model test data.

Under the assumption that all spillway gates are fully open (3.1.4), the two end bays (first and last) are the only spillway bays subject to end contraction effects. These effects, which may reduce discharge through these two bays by a few percent, are neglected in this calculation.: According to Hydraulic Design Chart 111-3/2 (Attachment 3), end contraction losses effectively reduce the length of the overflowing spillway crest, L=224'(see Section 4), by K_a*H_e, in which K_a = abutment contraction coefficient (dimensionless), and $H_e = H_c$ =Energy head on the crest (in ft.). The maximum possible value for K_a = 0.2 (Att. 3), which means the maximum possible impact of abutment effects (calculated at maximum H_c , 26.5 ft, See Section 7, maximum elevation for free discharge) is equal to:

$$\left[1 - \frac{L - 2K_a(H_c)}{L}\right] * 100\% = \left[1 - \frac{224' - 2(0.2)(26.5')}{224'}\right] * 100\% = 4.7\%$$

3.5 Methodology -- Discharge Coefficients for Overflow Sections

Values of the discharge coefficient, C_f, for flows over the nonoverflow sections and the tops of the open spillway gates are estimated using Hydraulic Design Chart 711 (Available in Reference 8) which is included as Attachment B5. Length, L, and crest elevation, Z_c, in each case is determined from TVA drawings (all relevant drawings are defined as References). Appendix B contains calculations which determine the values of C_f for each section which is expected to overflow.

The upper plot of HDC 711 (Attachment B5) shows that C_f is about 2.65 for very broad crests ($H_1/B < 0.4$ where $H_1 = H_c$ and B = streamwise length of the crest) and gradually increases to 3.1, the maximum value for a "broad-crested" weir, as H_1/B increases to about 1.2. As H_1/B increases above 1.2, C_f continues to increase as the weir transitions from broad-crested to sharp-crested at about $H_1/B = 2.0$. Since the estimation of discharge over the top of various sections of a dam and its embankments is an approximation, small variations in C_f with H_c are not modeled and the effects of end contractions are neglected. A single representative value for C_f within the range of its variation is used for all headwater elevations included in the rating. Neglecting minor variations in C_f values and end contractions has negligible impact on the dam rating curve.

3.6 Methodology—Sluice Gates Discharge Coefficient

Hiwassee Dam has four 8.5 foot diameter sluice tunnels fitted with 7.83 foot diameter nozzles. Reference 9 (Att. 9) shows a cross-section through a sluice tunnel. All sluice tunnels will be considered fully open. Attachment 16 states that table "discharges are based on coefficients of discharge obtained from prototype measurements." Therefore, the K value from Equation (3) can be back-calculated from the information in the sluice discharge tables. Attachment 18 indicates that spillway discharge tables have not been corrected for tailwater effects. However, Reference 7 is unclear as to whether or not the sluice discharge tables reflect tailwater effects. Justification that sluice discharge does not include tailwater effects is contained in paragraph 4.11.

4. Design Input

Sect.	Input Parameter	Source	Symbol	Value
4.1	**Acceleration of gravity**	Common knowledge, Ref. 8, sheet. 000-1 for example	g	32.2 ft/sec^2
4.2	**Spillway crest parameters**			
4.2.1	Crest length	7 32-foot wide bays; Ref. 5	L	224 feet
4.2.2	Crest elevation	Ref. 5 or Ref. 12	Z_c	1503.5 feet
4.2.3	Free discharge coefficient	Polynomial fit to model data given in Att. A12 and discussed in Appendix A	$C_f(H_c)$	Equation A3
4.3	**Spillway gate parameters**			
4.3.1	Vertical opening	Extrapolation of field measurements given in Att. A3 and discussed in Appendix A	V	20.44 feet
4.3.2	Effective gate opening	Computed in Appendix A	G_n	21.065 feet
4.3.3	Mid-point elevation of opening relative to crest	Computed in Appendix A	H_{mp}	10.029 feet
4.3.4	Distance from spillway crest to point at which nappe touches gates	Estimated in Appendix A from data in Reference A2	H_{Lmin}	29.11 feet
4.3.5	Headwater elevation at which nappe touches gates	H_{Lmin} estimated in Appendix A	$H_{Lmin} + Z_c$	1532.61 feet
4.3.6	Orifice discharge coefficient	Extrapolated curve given in Att. A13 and discussed in Appendix A	$C_g(H_c)$	Equations A4.1- A4.3
4.4	**Spillway Gate Overflow**			
4.4.1	Discharge coefficient	Justification in Appendix B	C_o	3.1
4.4.2	Overflow elevation	Computed in Appendix A	Z_o	1533.5 feet
4.4.3	Overflow length	Same as spillway crest, Ref.5	L_o	224 feet
4.4A	**Non Overflow Section (Including Spillway Piers)**			
4.4A.1	Discharge coefficient	Justification in Appendix B	C_f	2.65
4.4A.2	Overflow elevation	Justification in Appendix B	Z_c	1540.42 feet
4.4A.3	Overflow length	Calculated in Appendix B	L	921 feet
4.4B	**Abutment Overflow**			
4.4B.1	Discharge coefficient	Justification in Appendix B	C_f	2.65
4.4B.2	Overflow elevation	Justification in Appendix B	Z_c	1542.57 feet
4.4B.3	Overflow length	Calculated in Appendix B	L	109.75 feet
4.4C	**North End Overflow**			
4.4C.1	Discharge coefficient	Justification in Appendix B	C_f	2.65
4.4C.2	Overflow elevation	Justification in Appendix B	Z_c	1538.57 feet
4.4C.3	Overflow length	Calculated in Appendix B	L	34 feet
4.5	**Sluice gates**			
4.5.0	Number of Sluice Gates	Ref. 5	N	4
4.5.1	Discharge coefficient with or without tailwater effects	Paragraph 4.11	K	342.8982
4.5.2	Elevation at which tailwater effects flow	Ref. 9, Att. 9	Z_{ref} + 3.485	1268.775 feet
4.5.3	Elevation of outlet nozzle centerline	Ref. 9, Att. 9	Z_{ref}	1265.29 feet
4.6	**Turbine Discharges**			
4.6.1	Q_t v/s Gross Head, H_t	Paragraph 4.8	$Q_t(H_t)$	Equations (5.1) and (5.2)
4.7	**Tailwater Curve**			
4.7.1	TW v/s Total Discharge, Q	Paragraph 4.9	TW(Q)	Equations (6.1) and (6.2)

4.7	**Tailwater Curve**			
4.7.1	TW v/s Total Discharge, Q	Paragraph 4.9	TW(Q)	Equations (6.1) and (6.2)

4.8 Discharge through Turbines

Discharges through both the Unit 1and Unit 2 turbines, Q_{t1} and Q_{t2}, were determined from Attachments 12-1 and 12-2 (Refs. 15 and 16) at 100% gate opening. Points were scaled from References 15 and 16 (100% gate curve) and curve fits to turbine discharge versus gross head were developed in Attachment 13. The resulting polynomials are presented in Attachment 13 and repeated below.

$$Q_{t1} = 13.055(H_t) + 2091.8 \quad (5.1)$$

$$Q_{t2} = -0.0479(H_t)^2 + 33.673(H_t) - 190.96 \quad (5.2)$$

in which Q_t = turbine discharge in cfs and H_t = gross head on the turbine (HW-TW) in feet. Because sluice discharge (Equation (4)) and turbine discharge (Equation (6)) are functions of tailwater elevation, which itself is a function of all discharges past the dam (Equation (5)), an iterative process will be used to calculate tailwater elevation, sluice discharge, and turbine discharge for Case 1.

4.9 Tailwater Rating Curve

The tailwater rating curve used in this calculation was developed from data contained in Attachment 8. Tailwater elevation at Hiwassee was calculated as if headwater elevation at Apalachia has reached 1297.0 feet. The Hiwassee tailwater rating curve (Attachment 14) was generated by plotting the tailwater elevations given in Attachment 8 versus the Hiwassee discharge (at an Apalachia headwater elevation of 1297.0). The polynomial listed in Attachment 14 and listed below was used for headwater rating curve calculations.

$$TW = 1294.2668 + 0.3557Q - 1.3744\times10^{-3}Q^2 + 2.80\times10^{-6}Q^3 \quad \text{for } Q \geq 7.75 \quad (6.1)$$

$$TW = 1297 \quad \text{for } Q < 7.75 \quad (6.2)$$

in which Q = total discharge past the dam in cfs divided by 1000 ("1000 cfs").

Because tailwater elevations never reach the crest elevation at Hiwassee dam, tailwater does not affect spillway flow. However, tailwater does affect sluice flow (See Section 3.3).

4.10 Upper Limit on Headwater Elevation Included in Rating Curves

From past simulation experience, during a PMF event the headwater at Hiwassee Dam is not expected to rise past 1545 feet and therefore the dam rating curve generated by this calculation ends at this headwater elevation [3.1.5]. Although the headwater rating curve provided in this calculation extends to the elevation noted, Section 5.0 of this calculation limits the applicability of this curve to the headwater elevation defined in Section 5.0.

4.11 Sluice Gate K Value

The sluice gate K value is determined from Attachment 16. As evident from Equation (3), if the sluice discharge, Q, is plotted versus $4\sqrt{HW - 1265.29}$ the resulting slope (when the y-intercept is forced to 0) will be the K value (as y = mx) as long as the sluice data in Attachment 16 were determined without tailwater interactions. If, however, the sluice data was affected by tailwater, plotting Q versus $4K\sqrt{HW - TW + 3.485}$ would result in a straight line with slope equal to K (see Equation (4)).

Q is plotted versus $4\sqrt{HW - 1265.29}$ in Attachment 17. The slope of the linear fit to the data is included on the plot in Attachment 17. Because the resulting fit to the data provides a perfect linear fit ($R^2 = 1.0$), it can be concluded that the data in the sluice discharge table was not corrected for tailwater effects. K is determined by the slope of the linear fit and is used in conjunction with Equation (4) to calculate sluice flow when it is affected by tailwater.

The K value used for calculation is K = 342.8982 (Attachment 17)

5.0 Special Requirements/Limiting Conditions

Calculations performed in Appendix D demonstrate that the spillway gate PMF hydrostatic loads in the expected fully open position are comparable to the normal spillway gate design loads in the fully closed position. Although a detailed gate analysis could potentially demonstrate the capability of the gate to withstand higher headwater elevations, the applicability of this calculation is limited to headwaters no greater than 1542.00. If PMF headwater elevations at the Hiwassee Dam exceed 1542.00, a revision of this calculation will be required.

6. Calculations

Case 1

The calculations consist of computing spillway, sluice, turbine and overflow discharges (from Equations 1 through 5) for a list of headwater elevations ranging from just below the crest elevation up to 1537.5 feet [4.10], the top of the dam. The headwater rating curve is a plot of headwater elevation versus total dam discharge.

Discharge passes through the sluices and turbines first and then the spillway as headwater rises above the crest elevation. As headwater elevations continue to rise, discharge may also pass over the tops of the open tainter gates. Total discharge, given in "1000 cfs", is the sum of all discharges in cfs past the dam divided by 1000.

Figure 2 shows the spreadsheet calculations for the headwater rating curve (spreadsheet included as Attachment 22). The final result, the rating curve, is defined by the first two columns, HW vs. Total Discharge. The third column (TW) gives the tailwater elevation associated with the "Total Discharge" from the tailwater rating curve polynomial fit [4.9].

Because tailwater is sufficiently high to affect the sluice discharge at all headwater elevations, the corrected sluice discharge is given in the fourth column. The corrected discharge is calculated from Equation (4). Because the tailwater level varies with total dam discharge, an iterative process is used to determine submerged sluice discharge. For the iterative process TW is assumed (red text column in Attachment 22), Q_{total} is calculated (using Q_{s1}, Q_{t1} and Q_{t2} calculated from $TW_{assumed}$), and $TW_{calculated}$ is calculated from Q_{total}. Iteration is accomplished by varying $TW_{assumed}$ until the difference between $TW_{assumed}$ and $TW_{calculated}$ is equal to 0, within convergence tolerances. The convergence tolerance was set to $1*10^{-6}$. The average difference for converged solutions is $2*10^{-8}$ feet (Attachment 22).

Spillway discharge is computed in the seventh column. H_c, and $C_f|C_g$ are the parameters used to determine the spillway discharge, $Q_f|Q_g$. Free discharge occurs for elevations below 1532.61 feet [4.3.5] and orifice discharge occurs for headwaters above this elevation. The transition point is indicated by a horizontal line. Above the transition line, the listed discharge coefficient is C_f [4.2.3] and below the transition line the listed discharge coefficient is C_g [4.3.6]. Column $Q_f|Q_g$ is the spillway discharge computed from Equation (1) for free discharge and from Equation (2) for orifice discharge.

The column following the spillway discharge column shows "C_f=", "Z_c=", and "L=" in three rows to indicate the meaning of the values included in those rows in the "Overflow Discharge" columns.

The next four columns are overflow discharges in cfs for overflow of the spillway gates, nonoverflow dam, abutments, and overflow around the north end of the dam. The overflow discharge coefficient C_f ([4.4.1], [4.4A.1], [4.4B.1], [4.4C.1]), elevation Z_c ([4.4.2], [4.4A.2], [4.4B.2], [4.4C.2]), and length L ([4.4.3], [4.4A.3], [4.4B.3], [4.4C.3]) are indicated in the three rows above the computed discharges. All overflow discharges are computed using Equation (1). Since the tailwater elevation is below the overflow crest elevations for all headwater elevations included in the ratings, there are no tailwater effects on these discharges.

Turbine discharge in cfs is computed by Equations (5.1) and (5.2) in the final two columns.

Case 2

The calculations consist of computing spillway, sluice and overflow discharges (from Equations 1 through 4) for a list of headwater elevations ranging from the top of the dam, 1537.5 feet [4.10], to just below the crest elevation. The headwater rating curve is a plot of headwater elevation versus total dam discharge.

Figure 2 shows the spreadsheet calculations for the headwater rating curve (spreadsheet included as Attachment 22). The final result, the rating curve, is defined by the first two columns, HW vs. Total Discharge. The third column (TW) gives the tailwater elevation associated with the "Total Discharge" from the tailwater rating curve polynomial fit [4.9].

Because tailwater is sufficiently high to affect the sluice discharge at all headwater elevations, the corrected sluice discharge is given in the fourth column. The corrected discharge is calculated from Equation (4). Because the tailwater level varies with total dam discharge, an iterative process is used to determine submerged sluice discharge. For the iterative process TW is assumed (red text column in Attachment 22), Q_{total} is calculated (using Q_{s1} calculated from $TW_{assumed}$), and $TW_{calculated}$ is calculated from Q_{total}. Iteration is accomplished by varying $TW_{assumed}$ until the difference between $TW_{assumed}$ and $TW_{calculated}$ is equal to 0, within convergence tolerances. The convergence tolerance was set to $1*10^{-6}$. The average difference for converged solutions is $2.7*10^{-8}$ feet (Attachment 22).

Spillway discharge is computed in the seventh column. H_c, and $C_f|C_g$ are the parameters used to determine the spillway discharge, $Q_f|Q_g$. Free discharge occurs for elevations below 1532.61 feet [4.3.5] and orifice discharge occurs for headwaters above this elevation. The transition point is indicated by a horizontal line. Above the transition line, the listed discharge coefficient is C_f [4.2.3] and below the transition line the listed discharge coefficient is C_g [4.3.6]. Column $Q_f|Q_g$ is the spillway discharge computed from Equation (1) for free discharge and from Equation (2) for orifice discharge.

The column following the spillway discharge column shows "C_f=", "Z_c=", and "L=" in three rows to indicate the meaning of the values included in those rows in the "Overflow Discharge" columns.

The next four columns are overflow discharges in cfs for overflow of the spillway gates, nonoverflow dam, abutments, and overflow around the north end of the dam. The overflow discharge coefficient C_f ([4.4.1], [4.4A.1], [4.4B.1], [4.4C.1]), elevation Z_c ([4.4.2], [4.4A.2], [4.4B.2], [4.4C.2]), and length L ([4.4.3], [4.4A.3], [4.4B.3], [4.4C.3]) are indicated in the three rows above the computed discharges. All overflow discharges are computed using Equation (1). Since the tailwater elevation is below the overflow crest elevations for all headwater elevations included in the ratings, there are no tailwater effects on these discharges.

7. Results/Conclusions

For convenience, the headwater rating results, separate from the calculation details provided above, are tabulated as total discharge in cfs vs. headwater elevation in feet in Figure 3. The headwater rating curves are plotted in Figure 4.

The headwater rating curves developed in this calculation provide Hiwassee total dam discharge vs. headwater elevation for use in TVA's SOCH and TRBROUTE models for simulation conditions satisfying the assumptions in Section 3. In particular, all of the spillway gates must all be fully raised, all sluices must by fully open, and the maximum sustainable discharge must be passing through the turbines.

As discussed in Section 5.0, the dam rating curves provided in Figures 2a and 2b are limited in applicability to headwater elevations no greater than 1542.

Hiwassee - Dam Rating Curve, Case 1

g = 32.2 ft/s²

Sluice Parameters
K= 342.898 ft²
Z_{ref} = 1265.29 ft
N = 4 sluices

Spillway Parameters
L = 224 ft
Z_c = 1503.5 ft
G_n = 21.065 ft
H_{mp} = 10.029 ft

HW feet	Q Total Discharge 1000 cfs	TW	Sluice cfs Q_{s1}	Spillway ft H_c	C_f | C_g	cfs Q_f | Q_g	Overflow Discharge Qf in cfs: Spill Gate Overflow	Non-over Overflow	Abutment Overflow	North End Overflow	Gross Head ft H_t	Turbine Discharge 100% Gate Opening Unit 1 cfs Q_{t1}	Unit 2 cfs Q_{t2}
							C_f = 3.1	2.65	2.65	2.65			
							Z_c = 1533.5	1540.42	1542.57	1538.57			
							L = 224	921	109.75	34			
1305	4.85	1296.0	4854	0.00	0.00	0	0	0	0	0			
1310	5.69	1296.2	5694	0.00	0.00	0	0	0	0	0			
1320	7.10	1296.7	7096	0.00	0.00	0	0	0	0	0			
1330	8.27	1297.1	8272	0.00	0.00	0	0	0	0	0			
1340	9.31	1297.5	9305	0.00	0.00	0	0	0	0	0			
1350	10.24	1297.8	10238	0.00	0.00	0	0	0	0	0			
1360	11.10	1298.0	11095	0.00	0.00	0	0	0	0	0			
1370	11.89	1298.3	11892	0.00	0.00	0	0	0	0	0			
1380	12.64	1298.5	12641	0.00	0.00	0	0	0	0	0			
1390	13.35	1298.8	13348	0.00	0.00	0	0	0	0	0			
1400	14.02	1299.0	14021	0.00	0.00	0	0	0	0	0			
1410	14.66	1299.2	14663	0.00	0.00	0	0	0	0	0			
1420	15.28	1299.4	15279	0.00	0.00	0	0	0	0	0			
1430	15.87	1299.6	15872	0.00	0.00	0	0	0	0	0			
1440	23.75	1302.0	16316	0.00	0.00	0	0	0	0	0	138	3894	3544
1450	24.63	1302.2	16868	0.00	0.00	0	0	0	0	0	148	4021	3739
1460	25.48	1302.5	17404	0.00	0.00	0	0	0	0	0	158	4148	3925
1470	26.30	1302.7	17923	0.00	0.00	0	0	0	0	0	167	4276	4101
1480	27.10	1303.0	18429	0.00	0.00	0	0	0	0	0	177	4403	4269
1490	27.88	1303.2	18921	0.00	0.00	0	0	0	0	0	187	4531	4428
1500	28.64	1303.4	19402	0.00	0.00	0	0	0	0	0	197	4659	4578
1503.5	28.90	1303.5	19567	0.00	0.00	0	0	0	0	0	200	4703	4628
1504	29.16	1303.5	19588	0.50	2.86	227	0	0	0	0	200	4709	4634
1505	30.19	1303.8	19622	1.50	2.94	1210	0	0	0	0	201	4718	4645
1506	31.69	1304.2	19650	2.50	3.01	2666	0	0	0	0	202	4726	4653
1507	33.57	1304.8	19673	3.50	3.07	4508	0	0	0	0	202	4732	4660
1508	26.51	1302.8	19815	4.50	3.13	6693	0	0	0	0			
1510	31.81	1304.3	19839	6.50	3.23	11973	0	0	0	0			
1512	38.17	1306.0	19852	8.50	3.30	18321	0	0	0	0			
1514	45.46	1307.9	19859	10.50	3.36	25598	0	0	0	0			
1516	53.56	1309.8	19861	12.50	3.40	33698	0	0	0	0			
1518	62.41	1311.8	19862	14.50	3.44	42545	0	0	0	0			
1520	71.96	1313.8	19862	16.50	3.47	52095	0	0	0	0			
1522	82.21	1315.8	19863	18.50	3.50	62347	0	0	0	0			
1524	93.20	1317.7	19864	20.50	3.53	73338	0	0	0	0			
1526	105.02	1319.7	19866	22.50	3.56	85156	0	0	0	0			
1528	117.80	1321.7	19867	24.50	3.61	97937	0	0	0	0			
1529	124.62	1322.7	19868	25.50	3.63	104748	0	0	0	0			
1530	131.74	1323.7	19867	26.50	3.66	111877	0	0	0	0			
1532.61	150.74	1326.2	19869	29.11	0.791	130870	0	0	0	0			
1533.5	150.34	1326.2	19914	30.00	0.771	130423	0	0	0	0			
1534	150.26	1326.2	19938	30.50	0.759	130075	246	0	0	0			
1535	150.44	1326.2	19984	31.50	0.736	129179	1276	0	0	0			
1536	151.51	1326.3	20024	32.50	0.717	128737	2745	0	0	0			
1537	153.42	1326.6	20059	33.50	0.702	128819	4547	0	0	0			
1538.57	160.03	1327.5	20092	35.070	0.697	132015	7927	0	0	0			
1539	162.23	1327.8	20099	35.500	0.697	133144	8957	0	0	25			
1540.42	169.79	1328.7	20119	36.920	0.697	136805	12641	0	0	227			
1541	174.07	1329.3	20120	37.500	0.697	138272	14263	1078	0	341			
1542.57	189.65	1331.4	20096	39.070	0.697	142169	18968	7694	0	721			
1543	194.67	1332.1	20084	39.500	0.697	143217	20333	10114	82	840			
1544	207.47	1333.9	20045	40.500	0.697	145627	23626	16532	497	1140			
1545	221.56	1336.1	19991	41.500	0.697	147997	27080	23922	1102	1469			

Figure 2a – Calculations for Headwater Rating Curve, Case 1

Hiwassee - Dam Rating Curve, Case 2

g = 32.2 ft/s^2

Sluice Parameters

K= 342.898 ft^2

Z_{ref} = 1265.29 ft

N = 4 sluices

Spillway Parameters

L = 224 ft

Z_c = 1503.5 ft

G_n = 21.065 ft

H_{mp} = 10.029 ft

HW feet	Q Total Discharge 1000 cfs	TW	Sluice cfs Q_{s1}	Spillway ft H_c	$C_f \mid C_g$	cfs $Q_f \mid Q_g$	Overflow Discharge Qf in cfs: Spill Gate Overflow	Non-over Overflow	Abutment Overflow	North End Overflow
						C_f =	3.1	2.65	2.65	2.65
						Z_c =	1533.5	1540.42	1542.57	1538.57
						L =	224	921	109.75	34
1305	4.85	1296.0	4854	0.00	0.00	0	0	0	0	0
1310	5.69	1296.2	5694	0.00	0.00	0	0	0	0	0
1320	7.10	1296.7	7096	0.00	0.00	0	0	0	0	0
1330	8.27	1297.1	8272	0.00	0.00	0	0	0	0	0
1340	9.31	1297.5	9305	0.00	0.00	0	0	0	0	0
1350	10.24	1297.8	10238	0.00	0.00	0	0	0	0	0
1360	11.10	1298.0	11095	0.00	0.00	0	0	0	0	0
1370	11.89	1298.3	11892	0.00	0.00	0	0	0	0	0
1380	12.64	1298.5	12641	0.00	0.00	0	0	0	0	0
1390	13.35	1298.8	13348	0.00	0.00	0	0	0	0	0
1400	14.02	1299.0	14021	0.00	0.00	0	0	0	0	0
1410	14.66	1299.2	14663	0.00	0.00	0	0	0	0	0
1420	15.28	1299.4	15279	0.00	0.00	0	0	0	0	0
1430	15.87	1299.6	15872	0.00	0.00	0	0	0	0	0
1440	16.44	1299.8	16444	0.00	0.00	0	0	0	0	0
1450	17.00	1299.9	16996	0.00	0.00	0	0	0	0	0
1460	17.53	1300.1	17532	0.00	0.00	0	0	0	0	0
1470	18.05	1300.3	18052	0.00	0.00	0	0	0	0	0
1480	18.56	1300.4	18558	0.00	0.00	0	0	0	0	0
1490	19.05	1300.6	19051	0.00	0.00	0	0	0	0	0
1500	19.53	1300.7	19531	0.00	0.00	0	0	0	0	0
1503.5	19.70	1300.8	19697	0.00	0.00	0	0	0	0	0
1504	19.94	1300.8	19717	0.50	2.86	227	0	0	0	0
1505	20.96	1301.1	19750	1.50	2.94	1210	0	0	0	0
1506	22.44	1301.6	19776	2.50	3.01	2666	0	0	0	0
1507	24.31	1302.1	19798	3.50	3.07	4508	0	0	0	0
1508	26.51	1302.8	19815	4.50	3.13	6693	0	0	0	0
1510	31.81	1304.3	19839	6.50	3.23	11973	0	0	0	0
1512	38.17	1306.0	19852	8.50	3.30	18321	0	0	0	0
1514	45.46	1307.9	19859	10.50	3.36	25598	0	0	0	0
1516	53.56	1309.8	19861	12.50	3.40	33698	0	0	0	0
1518	62.41	1311.8	19862	14.50	3.44	42545	0	0	0	0
1520	71.96	1313.8	19862	16.50	3.47	52095	0	0	0	0
1522	82.21	1315.8	19863	18.50	3.50	62347	0	0	0	0
1524	93.20	1317.7	19864	20.50	3.53	73338	0	0	0	0
1526	105.02	1319.7	19866	22.50	3.56	85156	0	0	0	0
1528	117.80	1321.7	19867	24.50	3.61	97937	0	0	0	0
1529	124.62	1322.7	19868	25.50	3.63	104748	0	0	0	0
1530	131.74	1323.7	19867	26.50	3.66	111877	0	0	0	0
1532.61	150.74	1326.2	19869	29.11	0.791	130870	0	0	0	0
1533.5	150.34	1326.2	19914	30.00	0.771	130423	0	0	0	0
1534	150.26	1326.2	19938	30.50	0.759	130075	246	0	0	0
1535	150.44	1326.2	19984	31.50	0.736	129179	1276	0	0	0
1536	151.51	1326.3	20024	32.50	0.717	128737	2745	0	0	0
1537	153.42	1326.6	20059	33.50	0.702	128819	4547	0	0	0
1538.57	160.03	1327.5	20092	35.070	0.697	132015	7927	0	0	0
1539	162.23	1327.8	20099	35.500	0.697	133144	8957	0	0	25
1540.42	169.79	1328.7	20119	36.920	0.697	136805	12641	0	0	227
1541	174.07	1329.3	20120	37.500	0.697	138272	14263	1078	0	341
1542.57	189.65	1331.4	20096	39.070	0.697	142169	18968	7694	0	721
1543	194.67	1332.1	20084	39.500	0.697	143217	20333	10114	82	840
1544	207.47	1333.9	20045	40.500	0.697	145627	23626	16532	497	1140
1545	221.56	1336.1	19991	41.500	0.697	147997	27080	23922	1102	1469

Figure 2b – Calculations for Headwater Rating Curve, Case 2

Hiwassee Headwater Curves

Case 1 2008 Rating		Case 2 2008 Rating	
HW feet	Total Discharge 1000 cfs	HW feet	Total Discharge 1000 cfs
1305	4.85	1305	4.85
1310	5.69	1310	5.69
1320	7.10	1320	7.10
1330	8.27	1330	8.27
1340	9.31	1340	9.31
1350	10.24	1350	10.24
1360	11.10	1360	11.10
1370	11.89	1370	11.89
1380	12.64	1380	12.64
1390	13.35	1390	13.35
1400	14.02	1400	14.02
1410	14.66	1410	14.66
1420	15.28	1420	15.28
1430	15.87	1430	15.87
1440	23.75	1440	16.44
1450	24.63	1450	17.00
1460	25.48	1460	17.53
1470	26.30	1470	18.05
1480	27.10	1480	18.56
1490	27.88	1490	19.05
1500	28.64	1500	19.53
1503.5	28.90	1503.5	19.70
1504	29.16	1504	19.94
1505	30.19	1505	20.96
1506	31.69	1506	22.44
1507	33.57	1507	24.31
1508	26.51	1508	26.51
1510	31.81	1510	31.81
1512	38.17	1512	38.17
1514	45.46	1514	45.46
1516	53.56	1516	53.56
1518	62.41	1518	62.41
1520	71.96	1520	71.96
1522	82.21	1522	82.21
1524	93.20	1524	93.20
1526	105.02	1526	105.02
1528	117.80	1528	117.80
1529	124.62	1529	124.62
1530	131.74	1530	131.74
1532.61	150.74	1532.61	150.74
1533.5	150.34	1533.5	150.34
1534	150.26	1534	150.26
1535	150.44	1535	150.44
1536	151.51	1536	151.51
1537	153.42	1537	153.42
1538.57	160.03	1538.57	160.03
1539	162.23	1539	162.23
1540.42	169.79	1540.42	169.79
1541	174.07	1541	174.07
1542.57	189.65	1542.57	189.65

Figure 3 – Headwater Rating Results

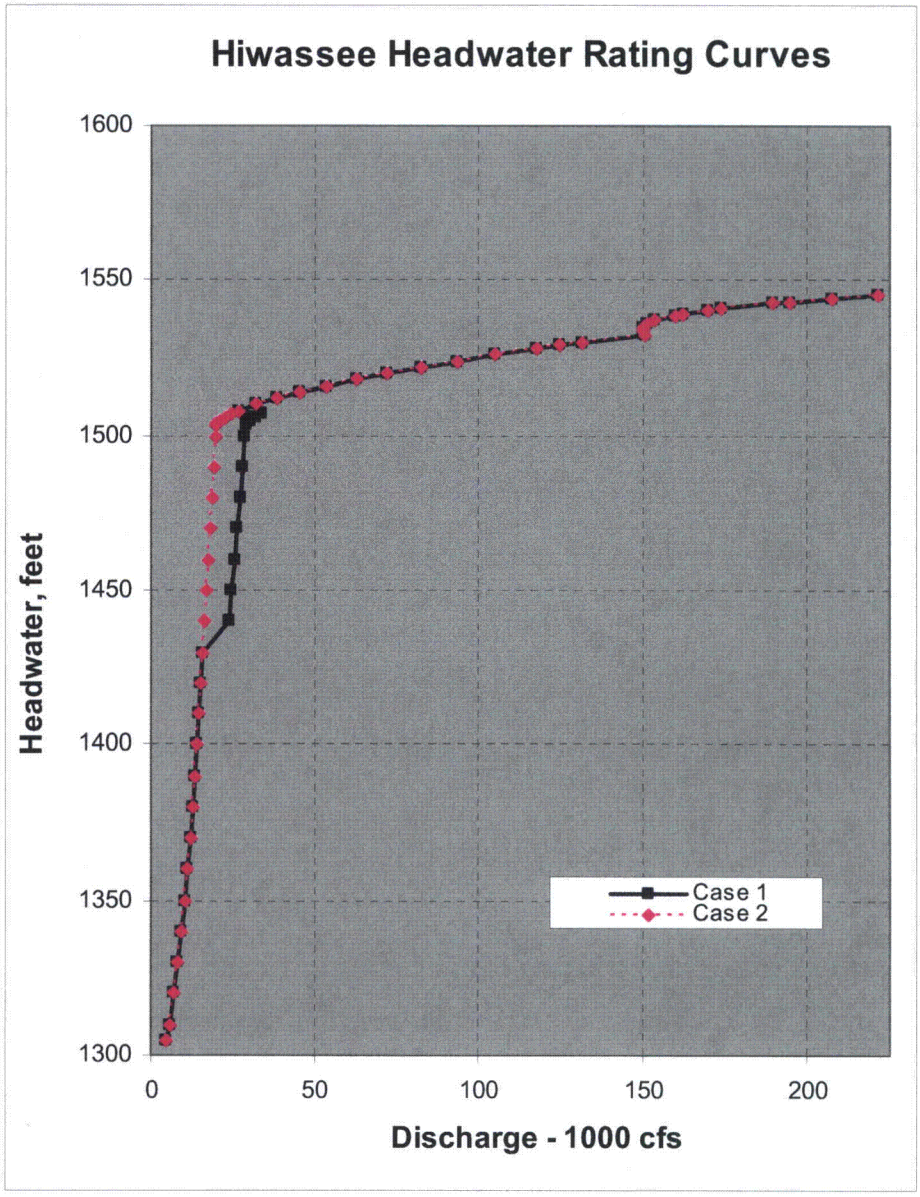
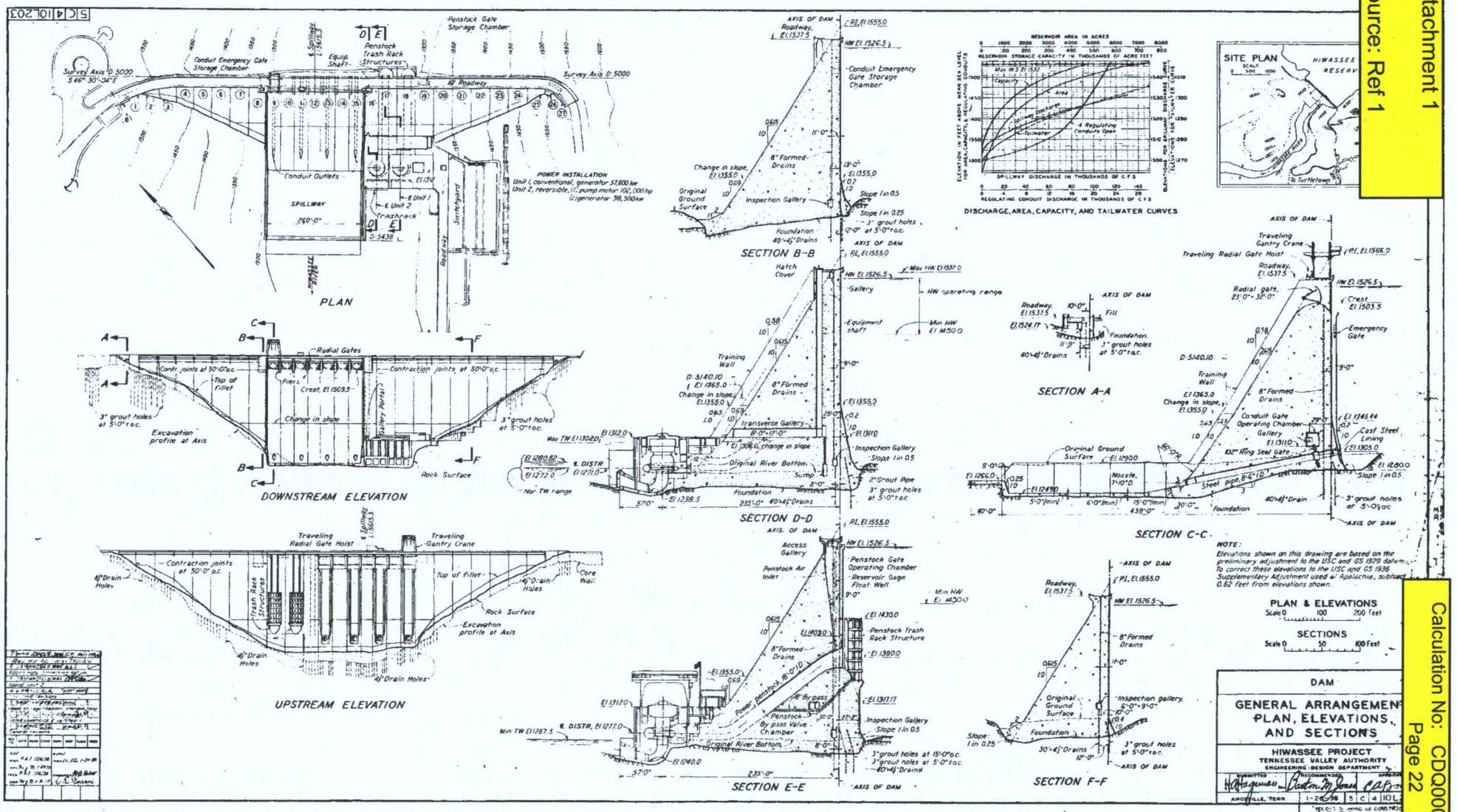


Figure 4 – Headwater Rating Curves

Attachment 1
Source: Ref 1

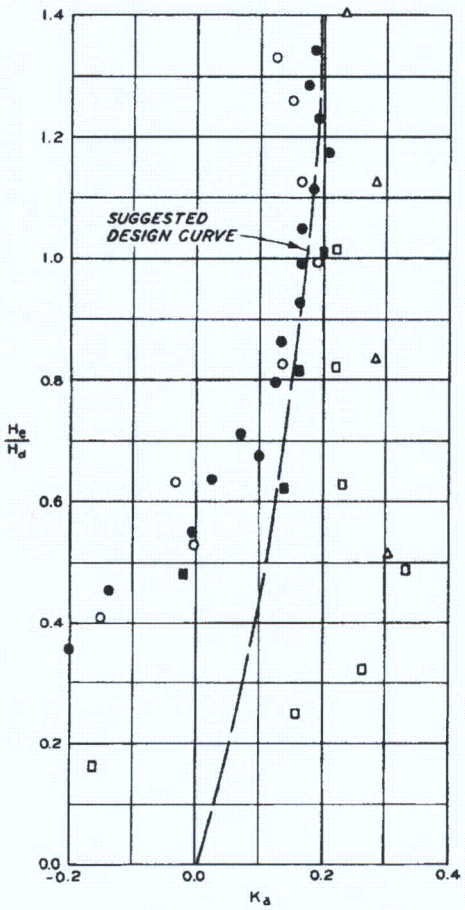


Calculation No: CDQ00002008001 2
Page 22

HIWASSEE DAM

Attachment 2
Source: Reference 2

October 1999



BASIC EQUATION

$$Q = C[L' - 2(NK_p + K_a)H_e]H_e^{3/2}$$

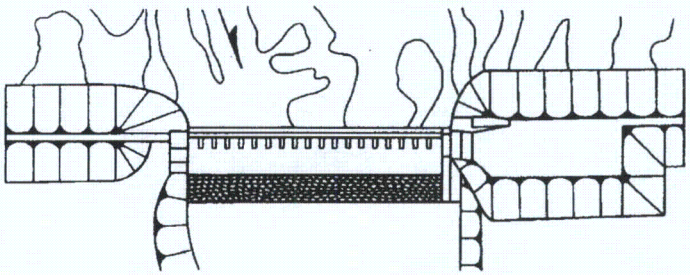
WHERE:
- Q = DISCHARGE, CFS
- C = DISCHARGE COEFFICIENT
- L' = NET LENGTH OF CREST, FT
- N = NUMBER OF PIERS
- K_p = PIER CONTRACTION COEFFICIENT
- K_a = ABUTMENT CONTRACTION COEFFICIENT
- H_e = ENERGY HEAD ON CREST, FT

LEGEND

SYMBOL	PROJECT	R	W/L	W/H
□	DORENA	2	5.60	10.7
■	DORENA	4	5.60	10.7
○	RED ROCK*	7.8	3.42	16.5
●	CARLYLE*	9	8.44	75.5
△	WALTER F. GEORGE*	4	5.44	55.3

*GATED SPILLWAY WITH PIERS

NOTE: R = RADIUS OF ABUTMENT, FT
W = WIDTH OF APPROACH REPRODUCED IN MODEL, FT
L = GROSS WIDTH OF SPILLWAY, FT
H = DEPTH OF APPROACH IN MODEL, FT
H_d = DESIGN HEAD ON CREST, FT



OVERFLOW SPILLWAY CREST WITH ADJACENT EMBANKMENT SECTIONS

ABUTMENT CONTRACTION COEFFICIENT

HYDRAULIC DESIGN CHART III-3/2

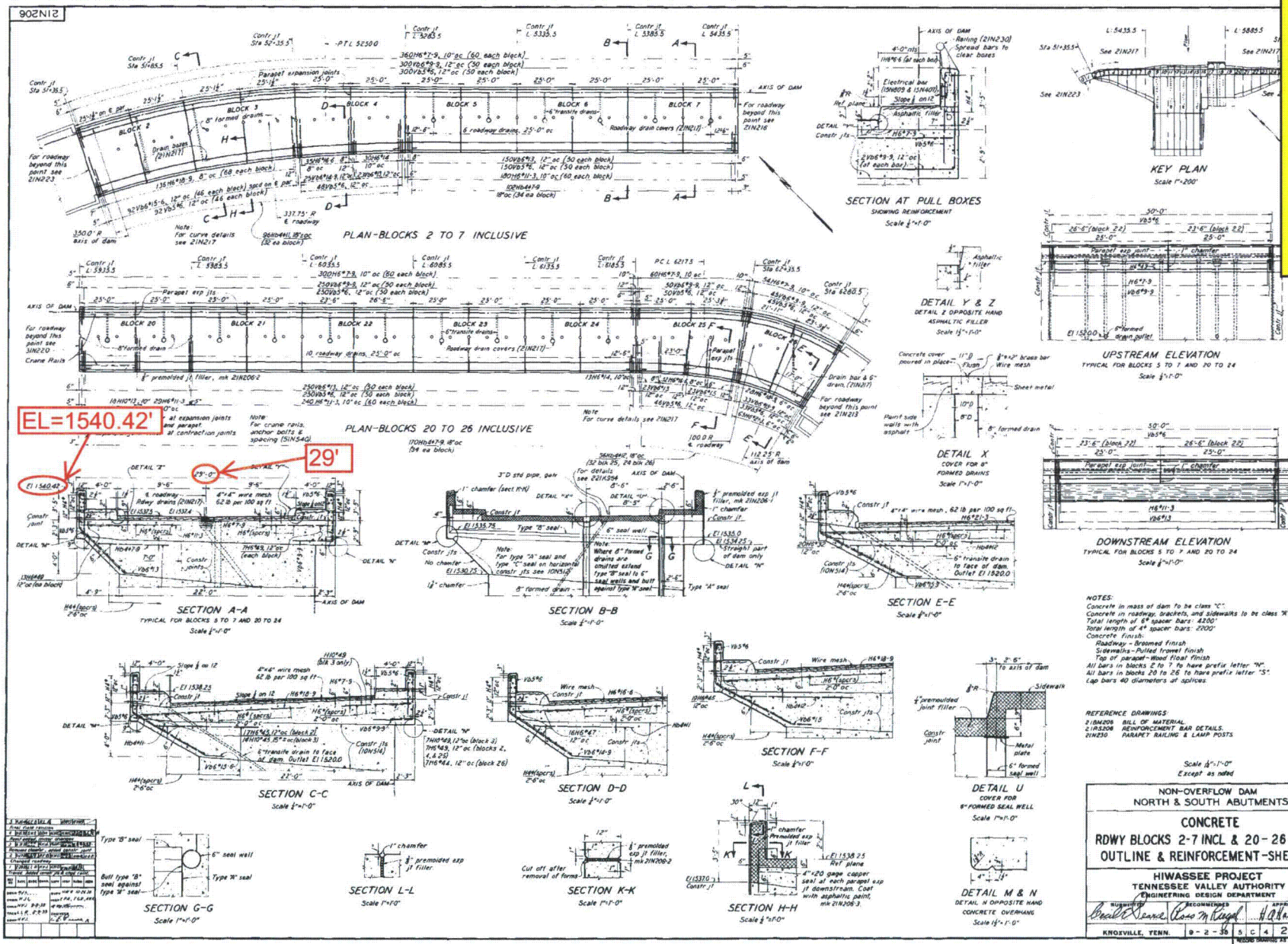
PREPARED BY U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION, VICKSBURG, MISSISSIPPI

REV 1-64

WES 8-60

Attachment 4

Source: Reference 3



Calculation No: CDQ00002008012

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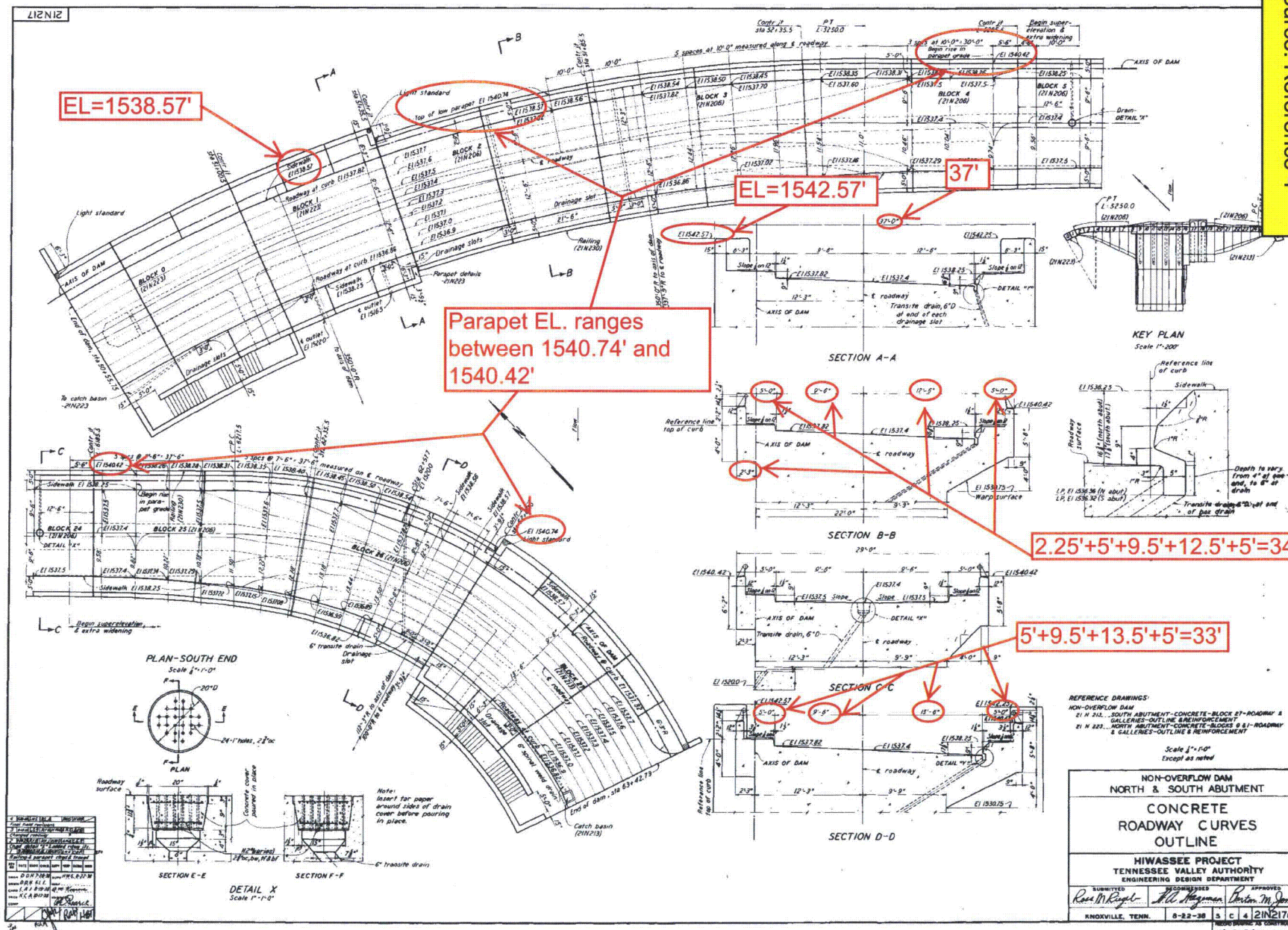
Attachment 5

Source: Reference 4

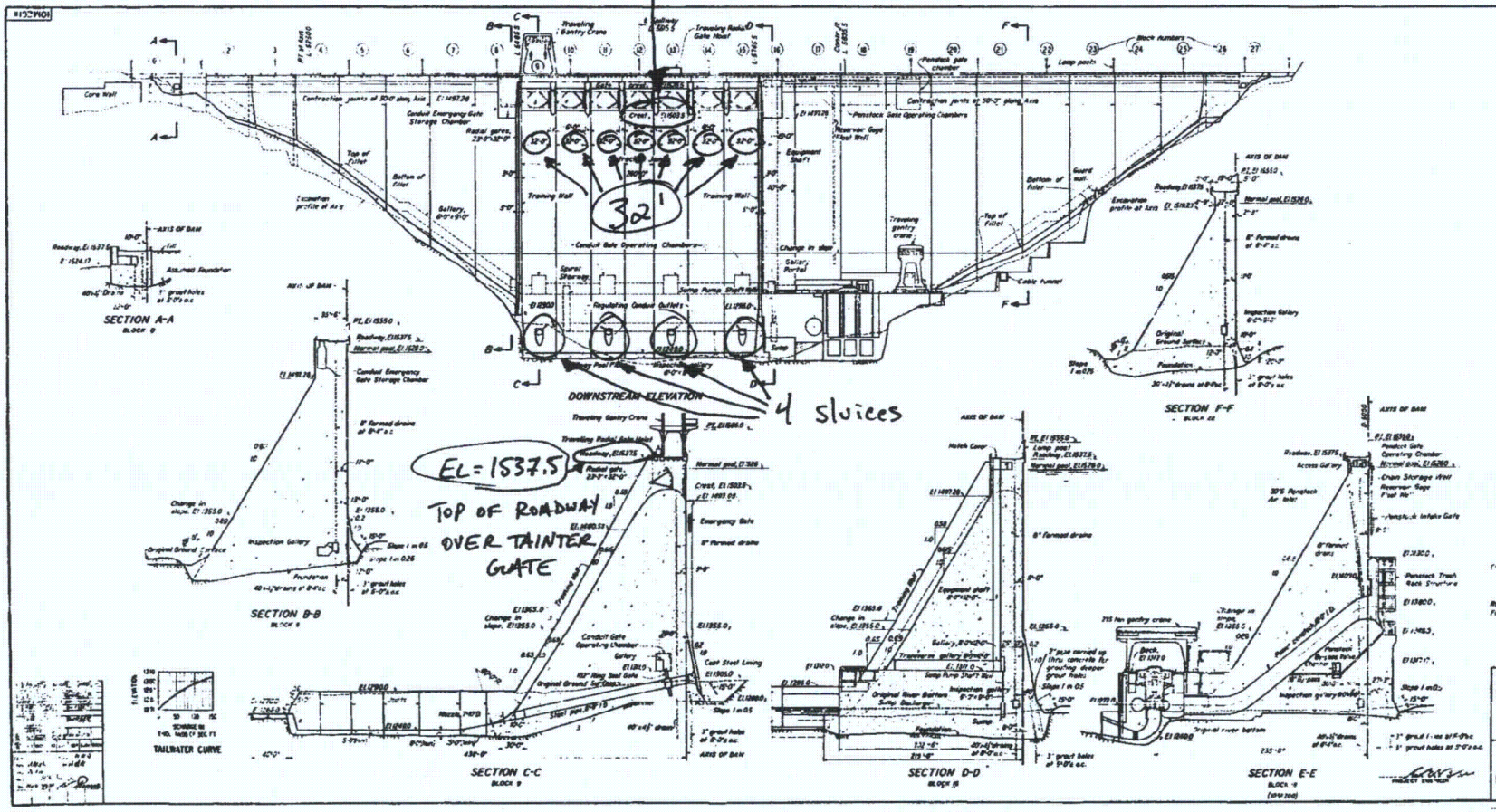


Calculation No: CDQ00002008001 2

Page 26

CREST = 1503.5'

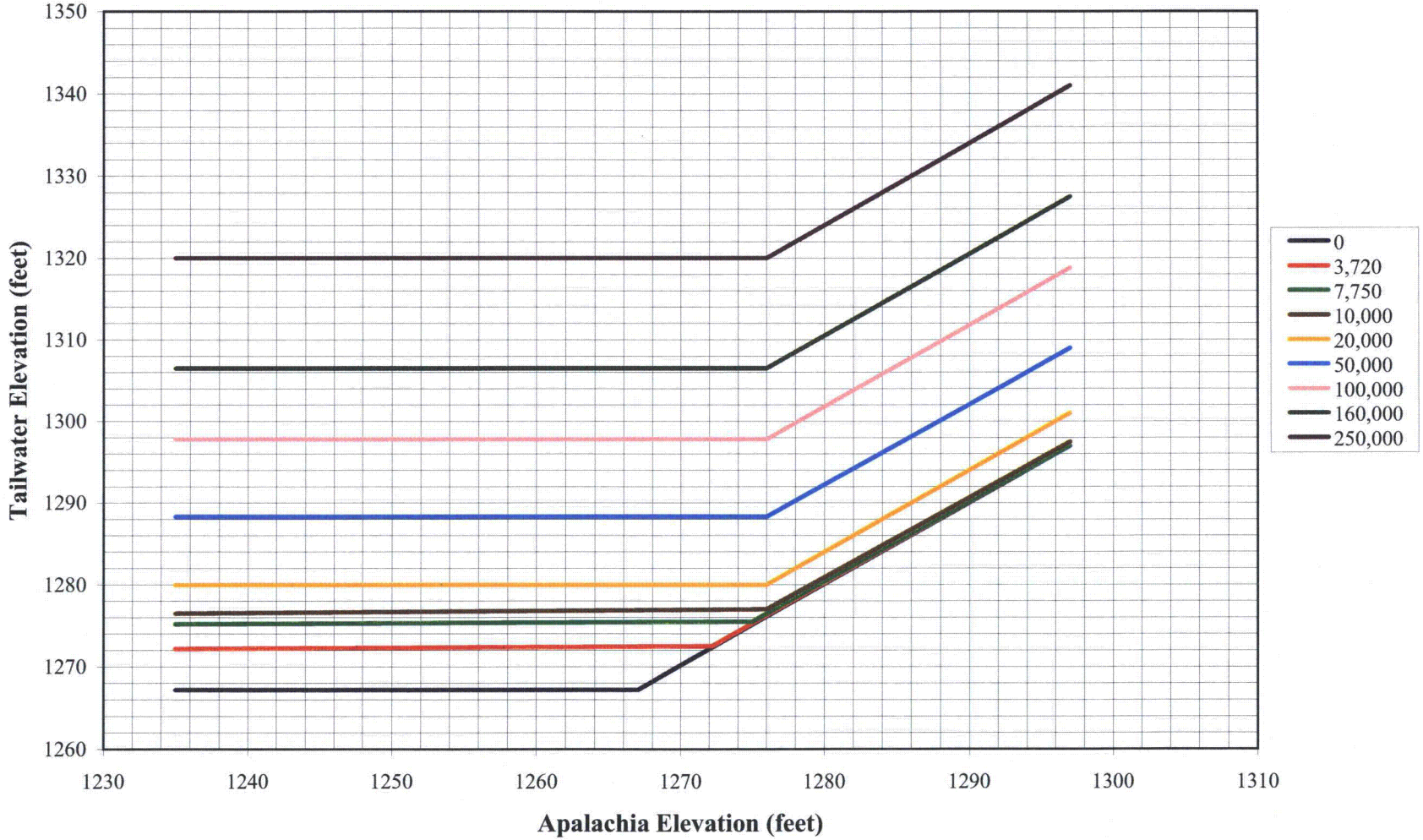
CREST L = 32' / BAY × 7 BAYS = 224'



Attachment 6

Source: Reference 5

Hiwassee Tailwater Rating



Hiwassee Tailwater Rating

Q*1000	Q	Apalachia Elev.	TW
0	0	1235	1267.2
0	0	1267	1267.2
0	0	1297	1297

Q*1000	Q	Apalachia Elev.	TW
3.72	3,720	1235	1272.2
3.72	3,720	1272.2	1272.5
3.72	3,720	1297	1297

Q*1000	Q	Apalachia Elev.	TW
7.75	7,750	1235	1275.2
7.75	7,750	1275	1275.5
7.75	7,750	1297	1297

Q*1000	Q	Apalachia Elev.	TW
10	10,000	1235	1276.5
10	10,000	1276	1277
10	10,000	1297	1297.5

Q*1000	Q	Apalachia Elev.	TW
20	20,000	1235	1280
20	20,000	1276	1280
20	20,000	1297	1301

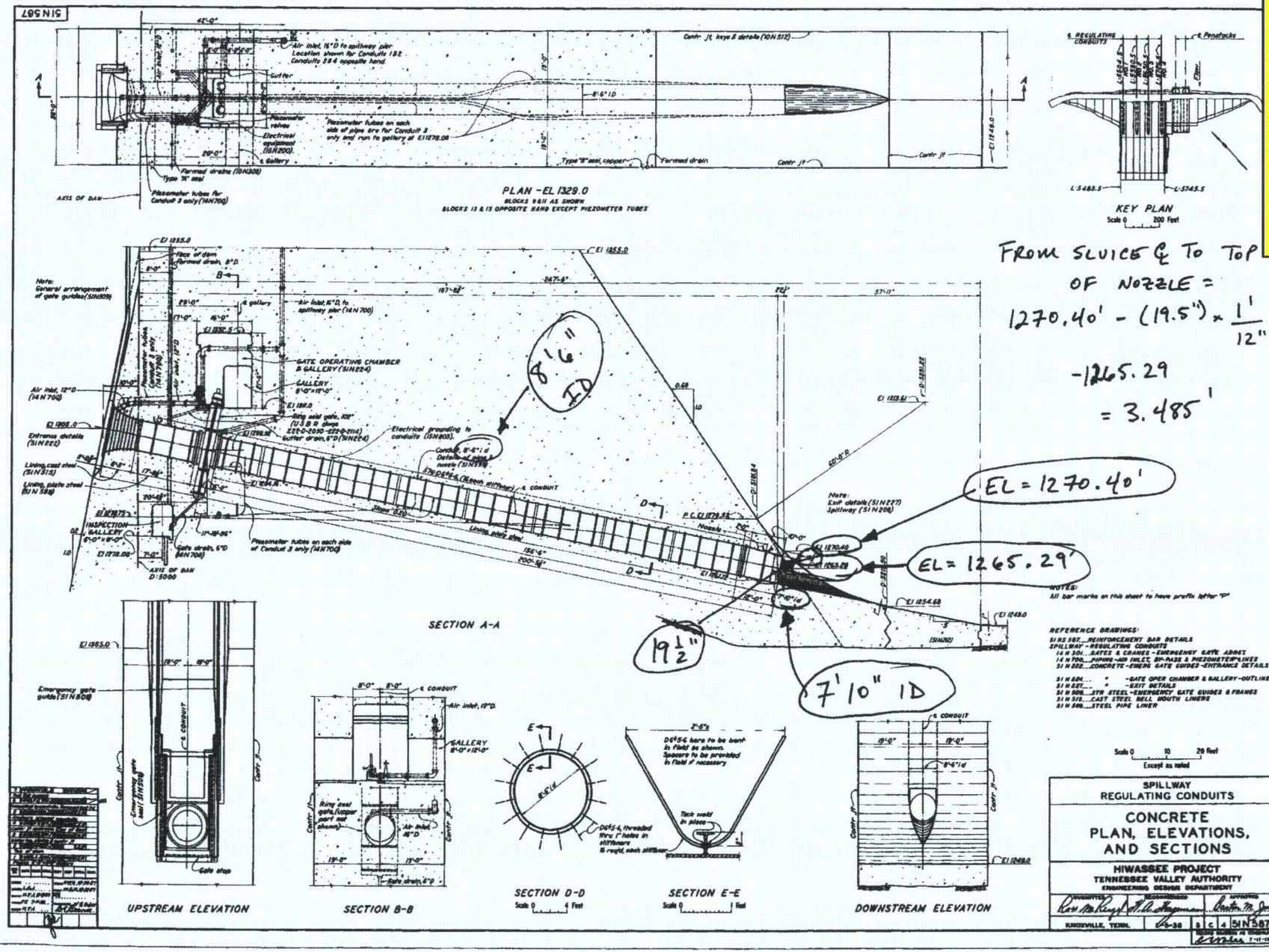
Q*1000	Q	Apalachia Elev.	TW
50	50,000	1235	1288.3
50	50,000	1276	1288.3
50	50,000	1297	1309

Q*1000	Q	Apalachia Elev.	TW
100	100,000	1235	1297.8
100	100,000	1276	1297.8
100	100,000	1297	1318.8

Q*1000	Q	Apalachia Elev.	TW
160	160,000	1235	1306.5
160	160,000	1276	1306.5
160	160,000	1297	1327.5

Q*1000	Q	Apalachia Elev.	TW
250	250,000	1235	1320
250	250,000	1276	1320
250	250,000	1297	1341

Attachment 9
Source: Reference 9



Calculation No: CDQ00002008012

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Attachment 10

Source: Reference 11

been able to check the discharge measurements of Bazin. However, the actual values are not so important for the case at hand as is the significance of the trend.

Method of Combining Test Results

The method for combining results from the eleven drum gates tested (Table 2) consisted of first plotting the coefficient of discharge data separately

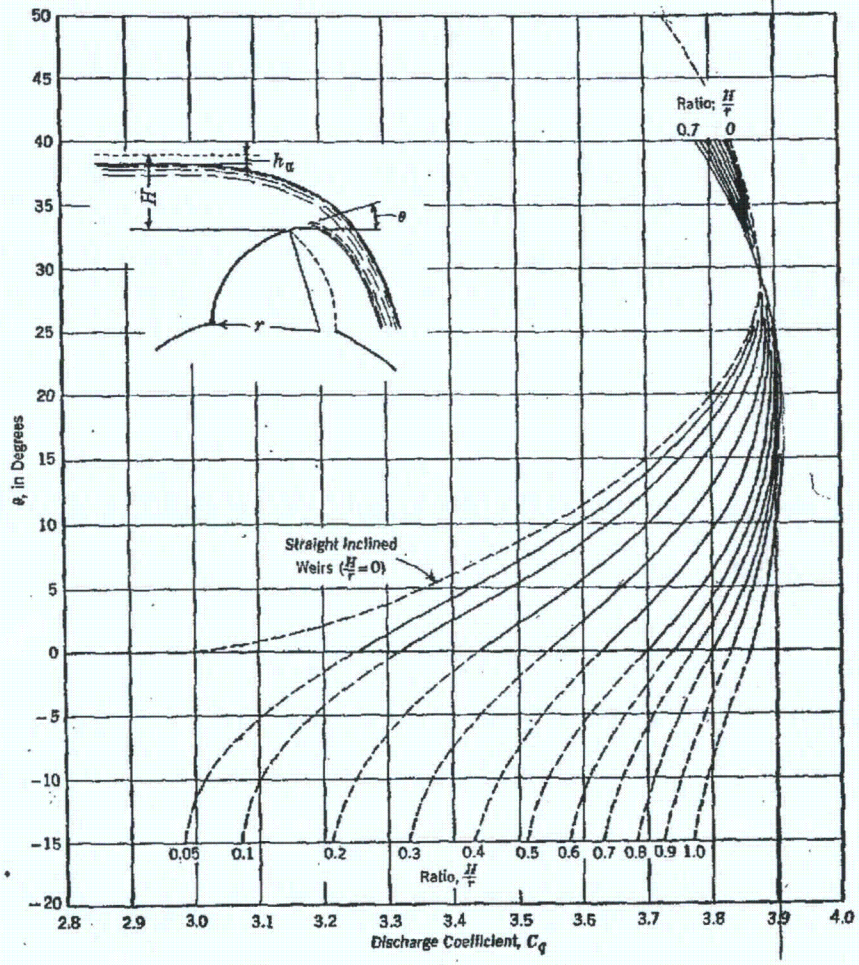

Fig. 6.—General Curves for the Determination of Discharge Coefficients

for each gate as illustrated by the sheet for the Shasta Dam gate (Fig. 5). With the coefficient of discharge as the abscissa and H/r as the ordinate, each curve in Fig. 5 represents a different gate angle θ, which the tangent to the downstre lip of the gate makes with the horizontal. In all cases, H is the

Calculation No: CDQ000020080012
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total head, including the velocity head of approach, measured above the high point of the gate, and r is the radius of the gate. In Fig. 5, C_q is based on the relationship, $Q = C_q L H^{\frac{3}{2}}$. For positive values of θ, the head was measured above the lip of the gate, whereas for negative angles it was observed above the high point, or crest, of the gate proper. The method of measuring the head is illustrated in Fig. 2.

Upon completion of a similar set of curves for each gate tested, the eleven sets of curves were replotted and combined into the chart exhibited as Fig. 6. The results from the various gates showed good general agreement; and the curves in Fig. 6 constitute the general experimental information needed for determining the discharge coefficients for gates in raised or partly raised positions. The supporting points are not shown in Fig. 6, but the individual information for each gate is listed in Table 2.

Analysis of Test Results

The curves in Fig. 6 show a tendency toward reversal, similar to that exhibited by the Bazin curve in Fig. 4, but the points of inflection vary from $\theta = 20°$ to $\theta = 30°$, depending on the value of H/r. Fig. 4 showed the coefficients to vary only slightly with the head, but in this case the coefficients definitely vary with the head.

A matter of significance is the reversal of the (H/r)-order which occurs at 29° (Fig. 6). The coefficient of discharge has but one value, 3.88, when θ approximates 29°; thus, it is insensitive to both the radius and the head on the gate for this angle. The curve for $H/r = 0$ approximates a drum gate of infinite radius and was obtained from the data of Bazin (Fig. 4) by applying a uniform adjustment.

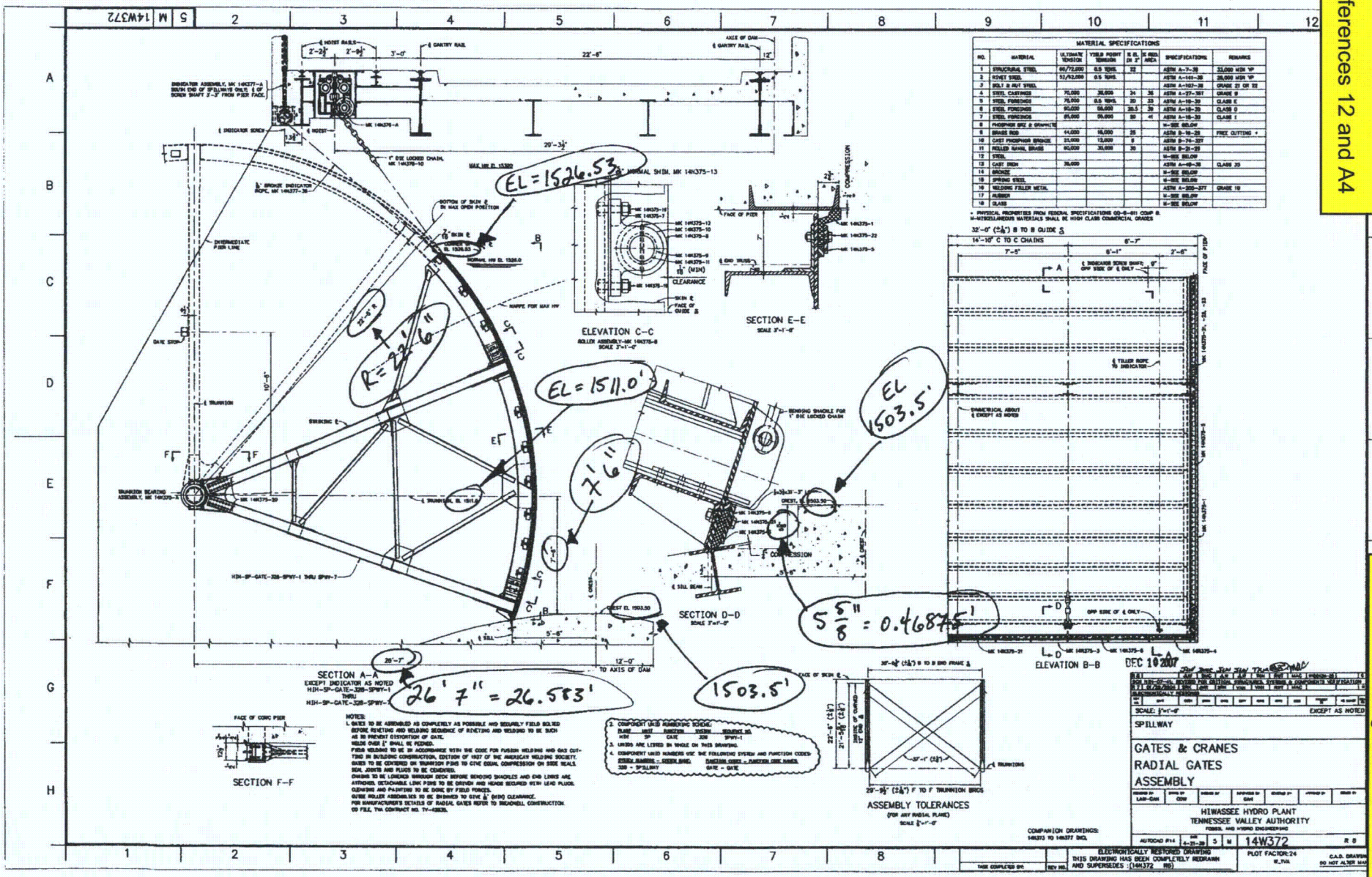
As stated previously, similitude is valid for small negative angles of θ, as well as for positive angles up to 90°; thus, the curves in Fig. 6 are shown and recommended for use down to $\theta = -15°$. As the gate is lowered beyond this angle, the curves double back and converge, finally terminating in the free flow coefficient.

The discharge coefficients in the region between $\theta = -15°$ and the gate completely down are determined by graphical interpolation. Interpolation is accomplished by plotting head-discharge curves for several gate angles between $-15°$ and the maximum positive angle. Also the head-discharge curve is plotted for the free crest. This information is then cross-plotted to obtain values in the transition zone. The method will be explained in the example that follows. It will be discovered that negative angles greater than $-15°$ (with the exception of the free crest) are not particularly important from an operator's standpoint, as a change in gate position has little effect on the discharge in this range.

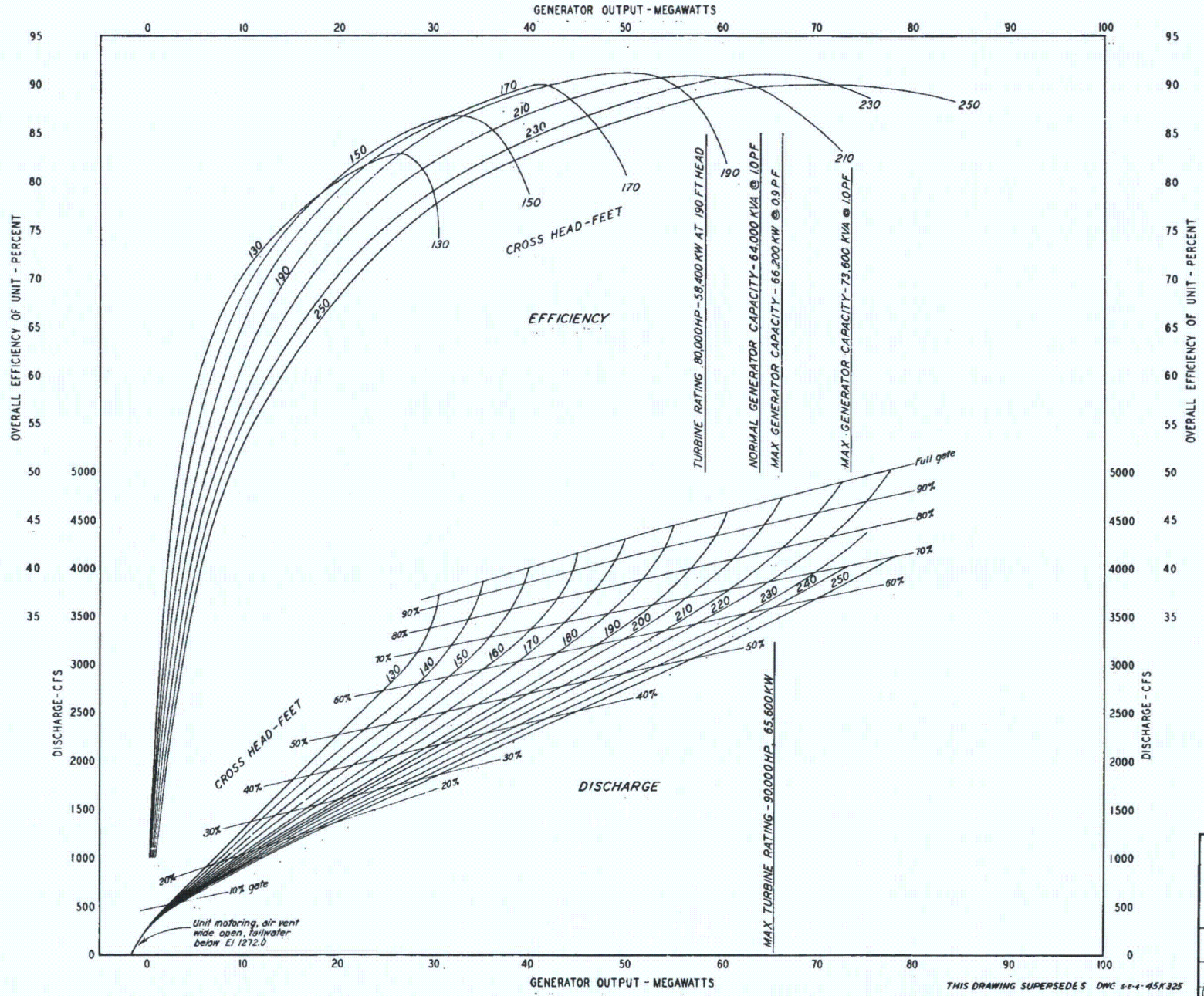
It must be assumed that the coefficient of discharge is known for at least one value of the head on the free crest (gate completely down) for the particular spillway under consideration. With the coefficient known for one or more heads, the complete coefficient curve for the free crest can be plotted by consulting Fig. 7, in which H_o and C_o are the designed head and the coefficient

Attachment 11

Source: References 12 and A4



Calculation No: CDQ00002008001 2
Page 32



THIS DRAWING SUPERSEDES DWG s-e-4-45K325

TURBINE:
80,000 HP - 190 ft head, 120 rpm.
Newport News Shipbuilding and Drydock Co.

GENERATOR:
64,000 kva - 3 phase - 60 cycles - 13,000 volts
0.9 power factor - 120 rpm.
Westinghouse Electric and Manufacturing Co.

NOTES:
Curves for 180 ft head are based on index tests conducted 11-24-40.
Other curves adjusted from model test No 280 on 16 9/16" dia test runner and adjusted to correspond with Gibson tests on Norris Dam u
This turbine is practically a duplicate of those at Norris Dam.
Air vent wide open at 6/10 gate and below.
Operating Dept to make record of full gate out at each 10 ft head and forward to Design Dept check values shown on this curve.
This curve will be revised as additional data is ab

POWERHOUSE
UNIT I

OPERATING CHARACTERIS

64,000 KVA UNIT

HIWASSEE PROJECT
TENNESSEE VALLEY AUTHORITY
DESIGN DEPARTMENT

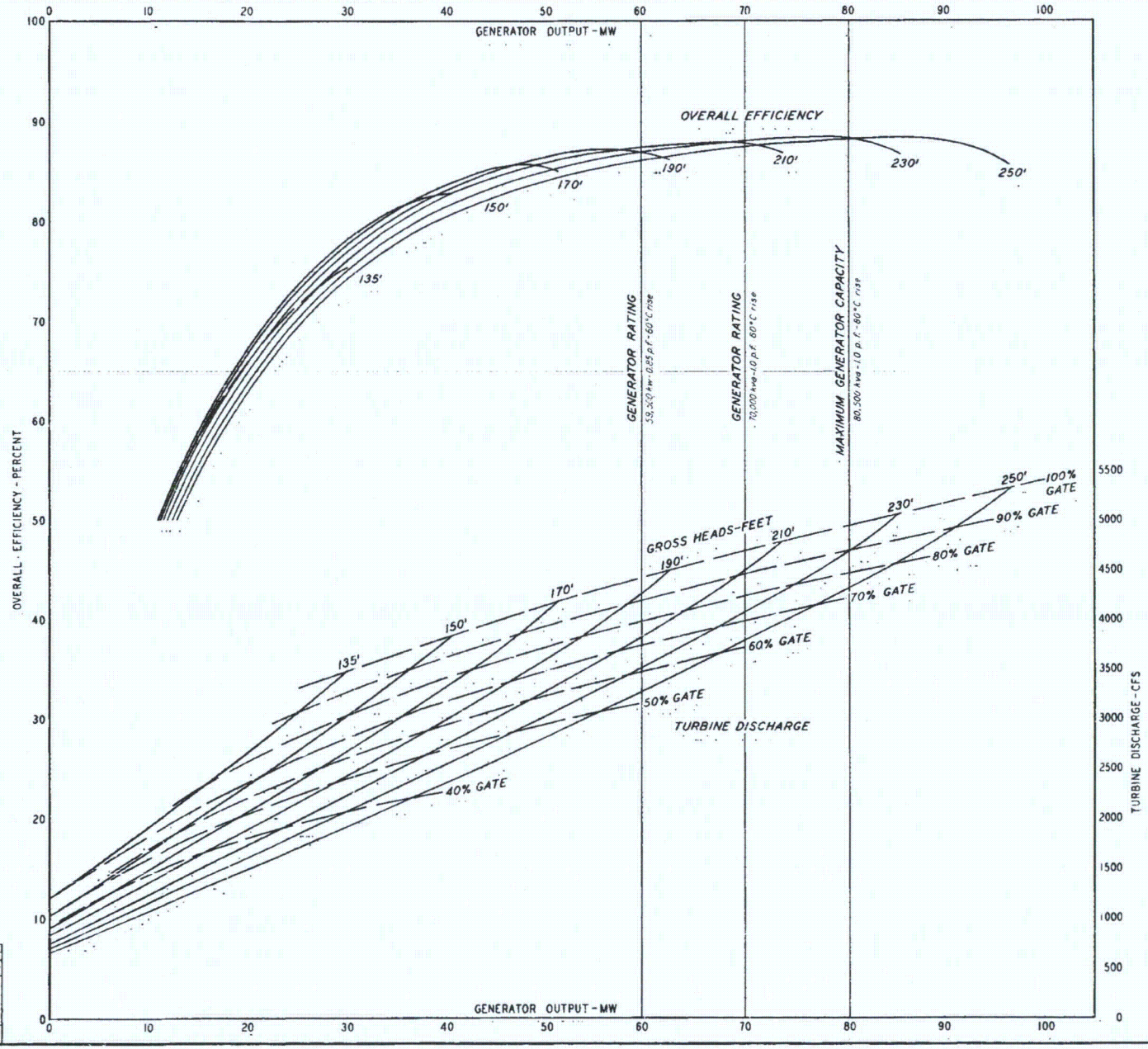
SUBMITTED	RECOMMENDED	APPR
J. F. Roberts	George Lick	H. H. Hag

KNOXVILLE 12-9-40 5 E 4 45K

Revision 1 5/1/54. Unit number added to title

Attachment 12-1
Source: Reference 15

Calculation No: CDQ0000020080012
Page 33.1



NOTES:

This curve is based on model test No. 39112 of the Allis-Chalmers Co. and is modified in accordance with the salt-velocity test conducted on this unit on 4-2-57 at approximately 195-foot gross head. Generator test efficiencies and measured penstock losses were used in the computations. Test should be made at other heads to check the accuracy of this curve.

TURBINE: 82,000 hp-190-foot net head-105.9 rpm manufactured by The Allis-Chalmers Co, Milwaukee, Wisconsin.

GENERATOR: 70,000 kva-3 phase-60 cycle-0.85 p.f. 60°C rise manufactured by The Allis-Chalmers Co, Milwaukee, Wisconsin.

POWERHOUSE
UNIT 2

OPERATING CHARACTERISTI OF PUMP-TURBINE UNIT GENERATING

HIWASSEE PROJECT
TENNESSEE VALLEY AUTHORITY
"DIVISION OF DESIGN"

SUBMITTED	RECOMMENDED	APPROVED
K		

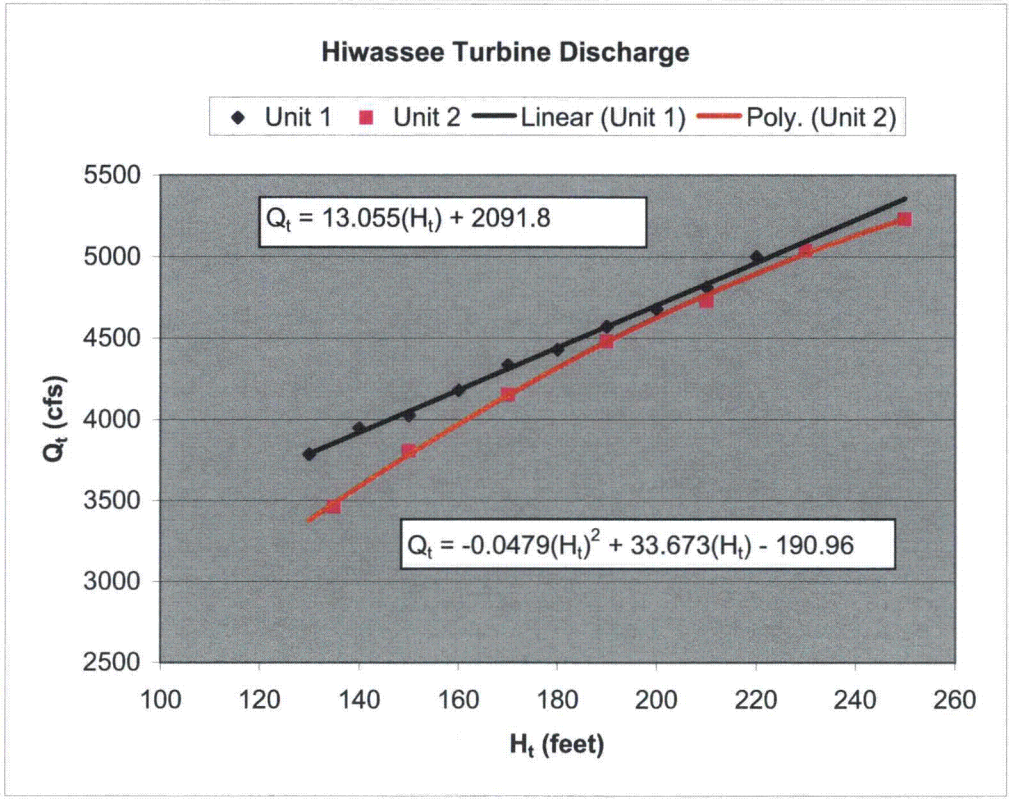
KNOXVILLE	4-10-58	S I M	4	47 K 28

Attachment 12-2
Source: Reference 16

Calculation No: CDQ000020080012
Page 33.2

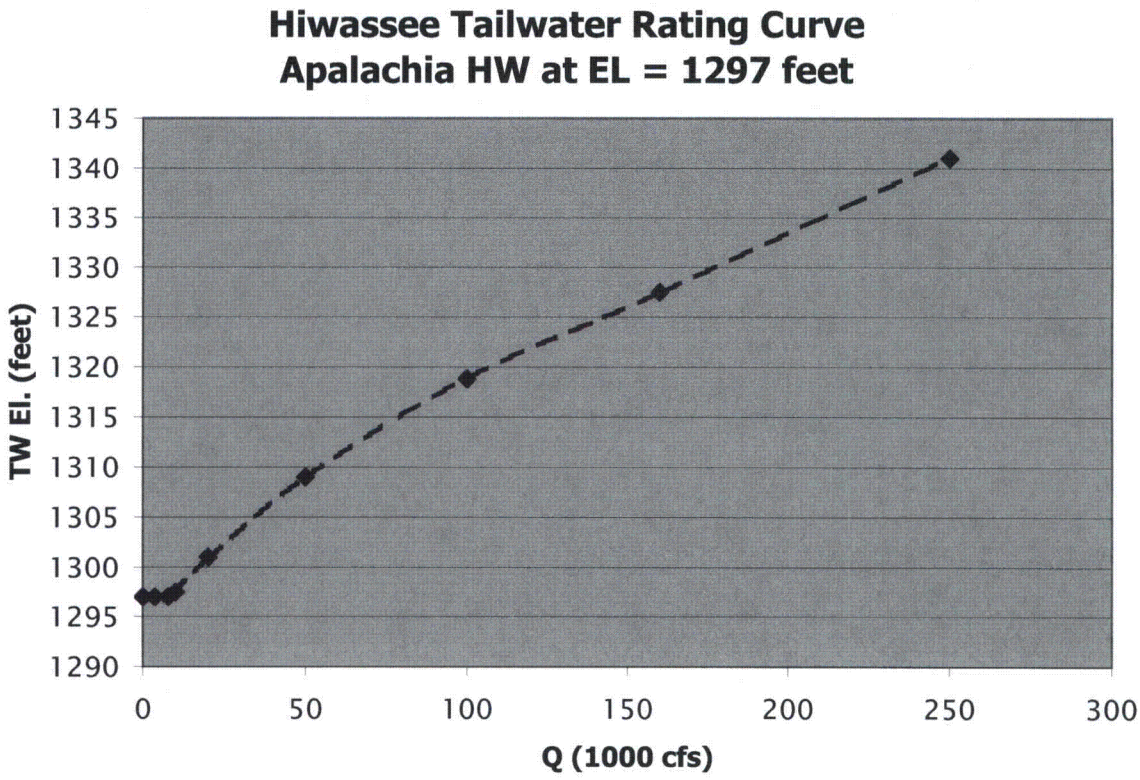
Fit to Turbine Discharge
Data from Drawing 45K326 (Unit 1) & 47K2864 (Unit 2)

Gross Head ft	Flow Unit 1 cfs	Fit to Unit 1 cfs	Flow Unit 2 cfs	Fit to Unit 2 cfs
130	3786	3789		3377
135		3854	3462	3482
140	3946	3920		3584
150	4025	4050	3807	3782
160	4179	4181		3970
170	4336	4311	4154	4149
180	4429	4442		4318
190	4571	4572	4481	4478
200	4679	4703		4628
210	4814	4833	4731	4768
220	5000	4964		4899
230		5094	5039	5020
250		5356	5231	5234



Hiwassee Tailwater Rating Curve
Apalachia HW = 1297 feet
(Apalachia PMF = 1296 ft)

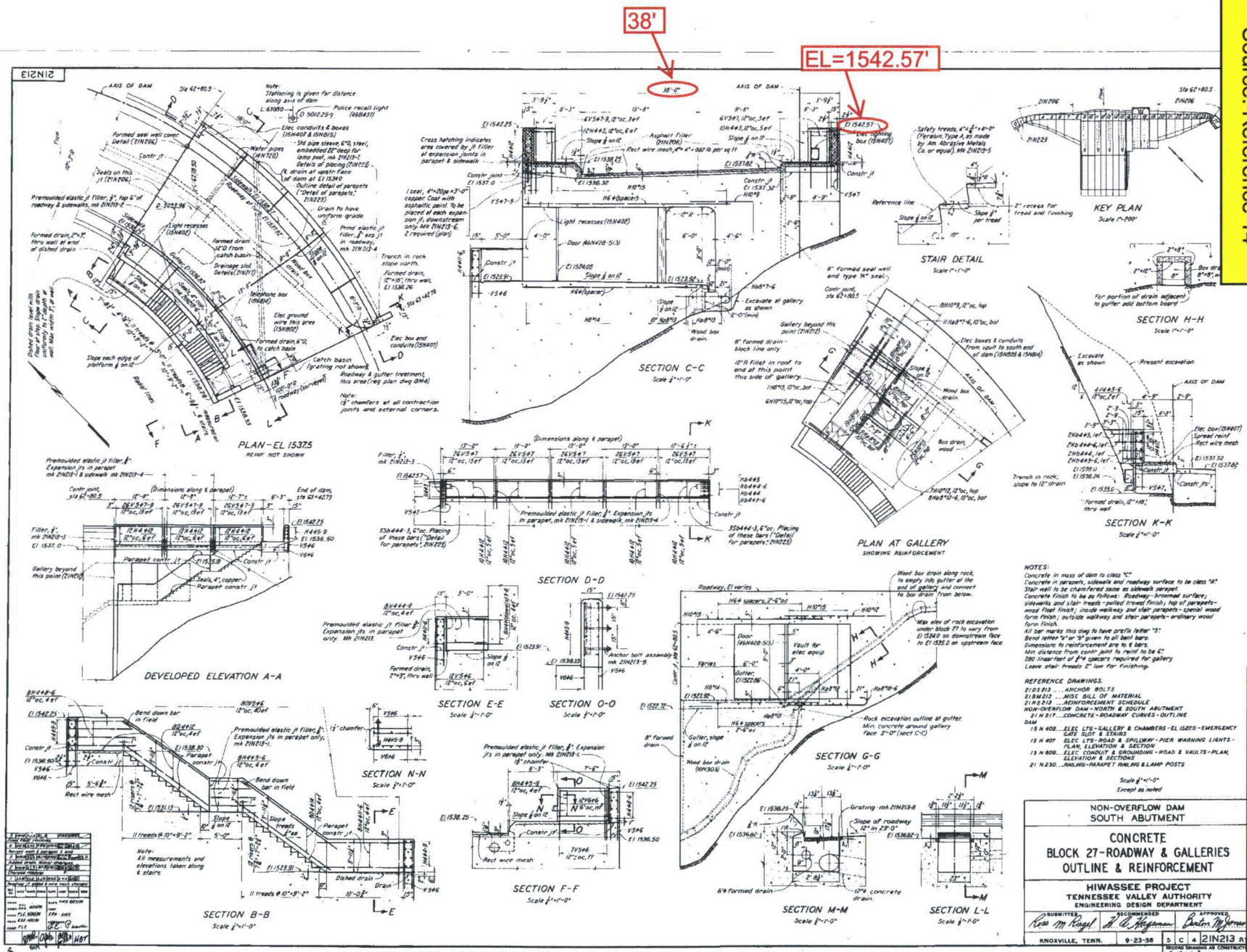
HW Elev.	Q	TW	TW (fit)
1297	0	1297	1297
1297	3.72	1297	1297
1297	7.75	1297	1296.94
1297	10	1297.5	1297.69
1297	20	1301	1300.85
1297	50	1309	1308.97
1297	100	1318.8	1318.89
1297	160	1327.5	1327.46
1297	250	1341	1341.04



$TW = 2.8*10^{-6}Q^3 - 1.3744*10^{-3}Q^2 + 0.3557Q + 1294.2668$
for Q>=7.75
TW = 1297 for Q<7.75

Attachment 15
Source: Reference 14

Calculation No: CDQ00002008012
Page 36



Attachment 16-1

Source: Reference 7

INSTRUCTIONS FOR USE OF TABLES

1. Tables Update

These tables supersede the tables dated September 1996. They differ from those tables only in a few minor details. The September 1996 tables superseded the tables dated March 1991. Those tables were revised to reflect the discharge values obtained from SPILLQ, which is a computer code used in TVA software for monitoring spill discharges and determining gate arrangements.

2. Purpose of Tables

These tables provide a means of setting up or determining the discharge through the four spillway sluices in Hiwassee Dam. They give the total discharge in cubic feet per second when the headwater elevation and operating sluices are known. . The discharges are based on coefficients of discharge obtained from prototype measurements.

The combination of sluices operated at any one time was determined to minimize scour on the spillway apron and to reduce the tailwater level below the powerhouse.

3. Arrangement of Tables

The tables give the total discharge of sluice 3; sluices 2 and 4; sluices 1, 3, and 4; and sluices 1, 2, 3, and 4 at full gate openings. Only these combinations of sluices should be used. The locations of the sluices are shown on page 4.

The discharge for each combination of sluices is tabulated for each 1-foot of headwater elevation between elevations 1410 feet and 1532 feet.

The interval between tabulated discharges caused by a change of 1-foot in headwater elevation is so small that it is unnecessary to interpolate between values given in these tables.

HIWASSEE DAM

SLUICE DISCHARGE IN CUBIC FEET PER SECOND

Headwater Elevation	SLUICES OPERATING			
	3	2 & 4	1, 3, & 4	1, 2, 3, & 4
1410	4120	8250	12370	16500
1411	4140	8280	12420	16560
1412	4150	8310	12460	16610
1413	4170	8330	12500	16670
1414	4180	8360	12540	16730
1415	4200	8390	12590	16780
1416	4210	8420	12630	16840
1417	4220	8450	12670	16890
1418	4240	8470	12710	16950
1419	4250	8500	12750	17010
1420	4270	8530	12800	17060
1421	4280	8560	12840	17120
1422	4290	8590	12880	17170
1423	4310	8610	12920	17220
1424	4320	8640	12960	17280
1425	4330	8670	13000	17330
1426	4350	8690	13040	17390
1427	4360	8720	13080	17440
1428	4370	8750	13120	17500
1429	4390	8770	13160	17550
1430	4400	8800	13200	17600
1431	4410	8830	13240	17660
1432	4430	8850	13280	17710
1433	4440	8880	13320	17760
1434	4450	8910	13360	17820

Attachment 16-2

Source: Reference 7

HIWASSEE DAM

SLUICE DISCHARGE IN CUBIC FEET PER SECOND

Headwater Elevation	SLUICES OPERATING			
	3	2 & 4	1, 3, & 4	1, 2, 3, & 4
1435	4470	8930	13400	17870
1436	4480	8960	13440	17920
1437	4490	8990	13480	17970
1438	4510	9010	13520	18030
1439	4520	9040	13560	18080
1440	4530	9060	13600	18130
1441	4550	9090	13640	18180
1442	4560	9120	13670	18230
1443	4570	9140	13710	18280
1444	4580	9170	13750	18340
1445	4600	9190	13790	18390
1446	4610	9220	13830	18440
1447	4620	9240	13870	18490
1448	4630	9270	13900	18540
1449	4650	9300	13940	18590
1450	4660	9320	13980	18640
1451	4670	9350	14020	18690
1452	4690	9370	14060	18740
1453	4700	9400	14090	18790
1454	4710	9420	14130	18840
1455	4720	9450	14170	18890
1456	4740	9470	14210	18940
1457	4750	9500	14240	18990
1458	4760	9520	14280	19040
1459	4770	9540	14320	19090

HIWASSEE DAM

SLUICE DISCHARGE IN CUBIC FEET PER SECOND

Headwater Elevation	SLUICES OPERATING			
	3	2 & 4	1, 3, & 4	1, 2, 3, & 4
1460	4780	9570	14350	19140
1461	4800	9590	14390	19190
1462	4810	9620	14430	19240
1463	4820	9640	14460	19290
1464	4830	9670	14500	19330
1465	4850	9690	14540	19380
1466	4860	9720	14570	19430
1467	4870	9740	14610	19480
1468	4880	9760	14650	19530
1469	4890	9790	14680	19580
1470	4910	9810	14720	19620
1471	4920	9840	14750	19670
1472	4930	9860	14790	19720
1473	4940	9880	14830	19770
1474	4950	9910	14860	19820
1475	4970	9930	14900	19860
1476	4980	9950	14930	19910
1477	4990	9980	14970	19960
1478	5000	10000	15000	20000
1479	5010	10030	15040	20050
1480	5020	10050	15070	20100
1481	5040	10070	15110	20140
1482	5050	10100	15140	20190
1483	5060	10120	15180	20240
1484	5070	10140	15210	20280

Attachment 16-3

Source: Reference 7

HIWASSEE DAM

SLUICE DISCHARGE IN CUBIC FEET PER SECOND

Headwater Elevation	SLUICES OPERATING			
	3	2 & 4	1, 3, & 4	1, 2, 3, & 4
1485	5080	10170	15250	20330
1486	5090	10190	15280	20380
1487	5110	10210	15320	20420
1488	5120	10230	15350	20470
1489	5130	10260	15390	20510
1490	5140	10280	15420	20560
1491	5150	10300	15450	20610
1492	5160	10330	15490	20650
1493	5170	10350	15520	20700
1494	5190	10370	15560	20740
1495	5200	10390	15590	20790
1496	5210	10420	15630	20830
1497	5220	10440	15660	20880
1498	5230	10460	15690	20920
1499	5240	10480	15730	20970
1500	5250	10510	15760	21010
1501	5260	10530	15790	21060
1502	5280	10550	15830	21100
1503	5290	10570	15860	21150
1504	5300	10600	15890	21190
1505	5310	10620	15930	21240
1506	5320	10640	15960	21280
1507	5330	10660	15990	21320
1508	5340	10680	16030	21370
1509	5350	10710	16060	21410

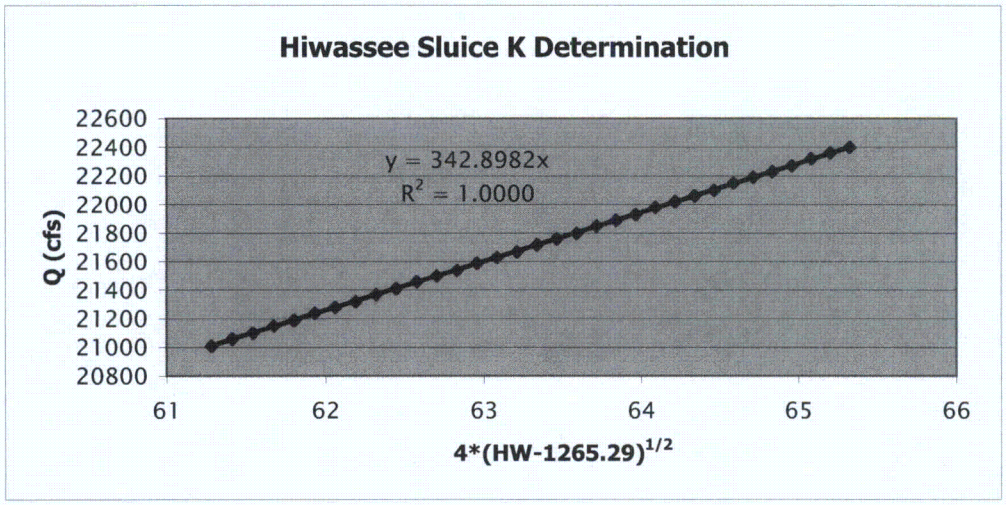
HIWASSEE DAM

SLUICE DISCHARGE IN CUBIC FEET PER SECOND

Headwater Elevation	SLUICES OPERATING			
	3	2 & 4	1, 3, & 4	1, 2, 3, & 4
1510	5360	10730	16090	21460
1511	5380	10750	16130	21500
1512	5390	10770	16160	21540
1513	5400	10790	16190	21590
1514	5410	10820	16220	21630
1515	5420	10840	16260	21670
1516	5430	10860	16290	21720
1517	5440	10880	16320	21760
1518	5450	10900	16350	21800
1519	5460	10920	16390	21850
1520	5470	10950	16420	21890
1521	5480	10970	16450	21930
1522	5490	10990	16480	21980
1523	5500	11010	16510	22020
1524	5520	11030	16550	22060
1525	5530	11050	16580	22100
1526	5540	11070	16610	22150
1527	5550	11090	16640	22190
1528	5560	11120	16670	22230
1529	5570	11140	16710	22270
1530	5580	11160	16740	22320
1531	5590	11180	16770	22360
1532	5600	11200	16800	22400

Determination of Sluice K Value
Data From Hiwassee
Discharge Tables, 2004

HW ft	Q cfs	y Q	x $4*(HW-1265.29)^{1/2}$
1500	21010	21010	61.28099216
1501	21060	21060	61.41139959
1502	21100	21100	61.54153069
1503	21150	21150	61.67138721
1504	21190	21190	61.80097087
1505	21240	21240	61.93028338
1506	21280	21280	62.05932645
1507	21320	21320	62.18810176
1508	21370	21370	62.31661095
1509	21410	21410	62.44485567
1510	21460	21460	62.57283756
1511	21500	21500	62.70055821
1512	21540	21540	62.82801923
1513	21590	21590	62.95522218
1514	21630	21630	63.08216864
1515	21670	21670	63.20886014
1516	21720	21720	63.33529822
1517	21760	21760	63.46148438
1518	21800	21800	63.58742014
1519	21850	21850	63.71310697
1520	21890	21890	63.83854635
1521	21930	21930	63.96373973
1522	21980	21980	64.08868855
1523	22020	22020	64.21339424
1524	22060	22060	64.33785822
1525	22100	22100	64.46208188
1526	22150	22150	64.58606661
1527	22190	22190	64.70981378
1528	22230	22230	64.83332476
1529	22270	22270	64.9566009
1530	22320	22320	65.07964351
1531	22360	22360	65.20245394
1532	22400	22400	65.32503349



INSTRUCTIONS FOR USE OF TABLES

1. Tables Update

These tables supersede the tables dated September 1996. They differ from those tables only in a few minor details. The September 1996 tables superseded the tables dated March 1991. Those tables were revised to include Gate 1 in the spillway gate arrangements. Gate 1 was previously out of service. The computer code SPILLQ generated the tabulated discharges.

2. Purpose of Tables

These tables provide a means for setting required spillway discharges and for determining the discharge when a specific arrangement of gates is in use. The tabulated discharges are based on test results from scale models.

The specific gate arrangements in the tables were determined by considering erosion data obtained from spillway model studies together with incremental discharge values required for satisfactory spillway operation.

3. Range of Tables

The tables cover a discharge range from 0 to 126,500 cubic feet per second. Headwater elevations range from 1503.5 feet to 1532 feet. The tailwater does not affect the discharge from this spillway.

4. Arrangement of Tables

The discharge tables show spillway discharges in cubic feet per second. Headwater elevations in 0.1-foot increments are shown at the top of each column. The headwater range is indicated at the bottom of each page.

The discharge is tabulated under the headwater elevations for specific arrangements of gate openings, which are indicated by number in the left and right columns of each page. The numbered arrangements are defined in the table of Spillway Gate Arrangements on page 5. Reference to this table and to the drawing showing the location of the gates on page 4 determines the gate opening to which each gate is to be set for any particular discharge given in the tables.

5. Discharge Intervals

The tables have been prepared so that the incremental discharge between the tabulated values for consecutive gate arrangements is generally less than 5 percent of the tabulated discharge. The incremental discharge between tabulated values of consecutive headwater elevations is generally less than 1 percent. These increments are exceeded at low headwater elevations where operation is relatively infrequent. In general, it is possible to set any required discharge within 2-1/2 percent and to know the actual discharge for any given set of conditions within 1 percent. These tolerances are considered acceptable and therefore <u>it will not be necessary to interpolate between values given in these tables</u>.

When the exact headwater elevation does not appear in the tables, the discharge for the headwater elevation closest to it is used. For example, the column headed 1512.2 is used for actual headwater elevations between 1512.15 feet and 1512.24 feet inclusive. When the actual headwater elevation is exactly halfway between tabular values, the larger value is used.

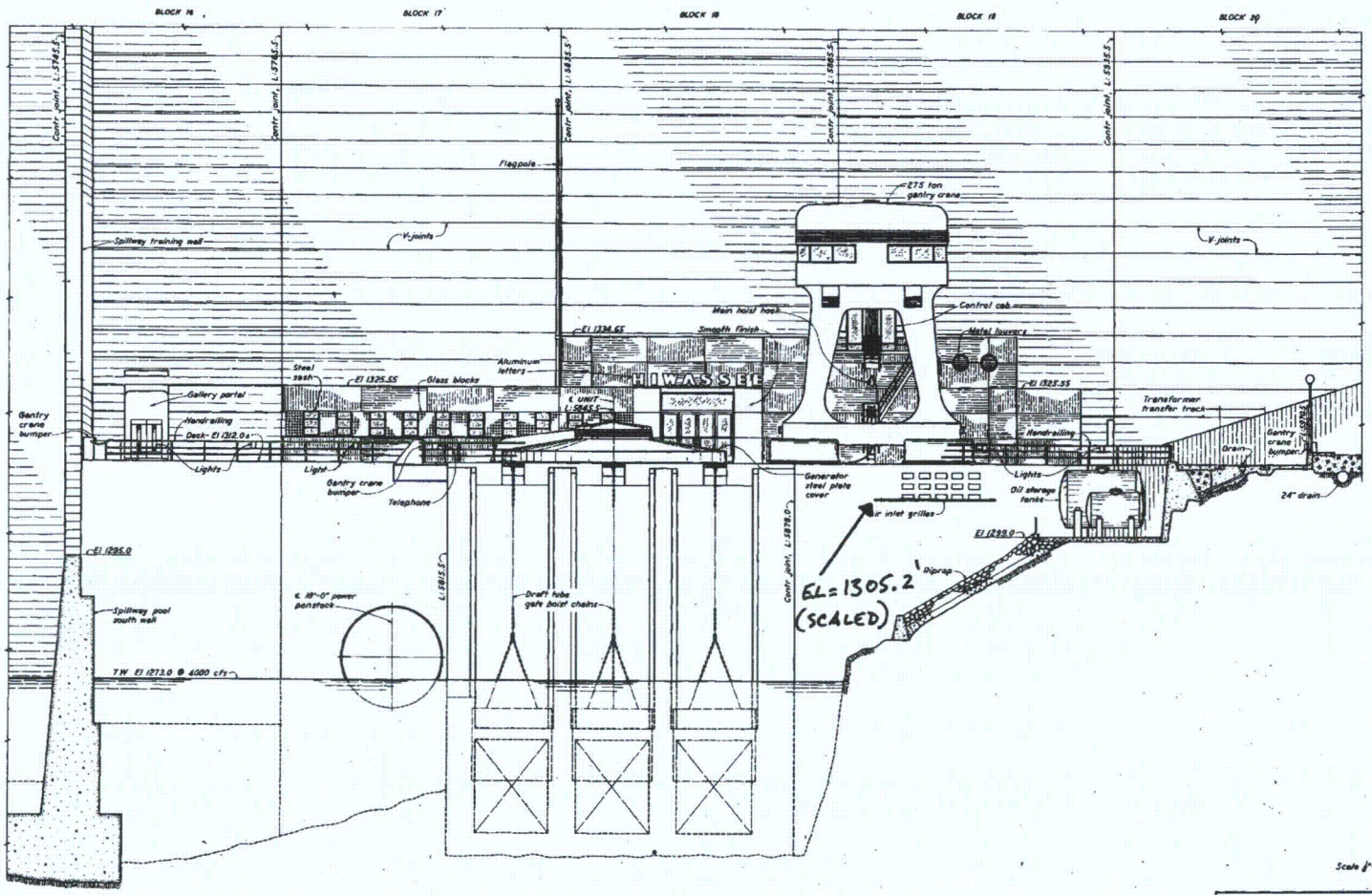
6. Raising and Lowering Gates

A traveling gantry crane raises and lowers the gates using chains attached to the ends of each gate. Gate openings are set by dogging each chain using a dogging arrangement located just below the deck of the dam.

The gate opening positions are defined by the chain link numbers (number of links past the zero links) referenced in the Table of Spillway Gate Arrangements, page 5. The zero links for each gate are identified by wires wrapped around their centers, and the zero positions are indicated in the Table of Spillway Gate Arrangements by a dash (-). To set a gate, it is necessary to count the number of links past the zero link to dog the required link. Gate opening positions are not interchangeable between gates because a given link on one gate will not give the same discharge as the same link on another gate (the actual gate openings are not the same).

An emergency travel hoist powered by a gasoline engine is available for lifting the gates in the event of a power failure.

Attachment 34
Source: Reference 17



POWERHOUSE

EQUIPMENT
DOWNSTREAM ELEVATION

HIWASSEE PROJECT
TENNESSEE VALLEY AUTHORITY
ENGINEERING DESIGN DEPARTMENT

SUBMITTED	RECOMMENDED	APPROVED			
H.H. Knoxville	A.B. Hagyman	T.V.B. Parker			
KNOXVILLE, TENN.	7-30-40	5	A	4	46N218A

PROJECT ENGINEER

46N218

Calculation No: CDQ00002008012
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Appendix A: Spillway Discharge Coefficients and Submergence Factors for Hiwassee Dam from Scale Model Test Data

TVA has model test data describing the relationships between discharge, headwater, tailwater, and gate opening for most of its spillways. These data are used in the headwater rating curve calculations. Use of reference book discharge coefficients for standard crests would result in inferior results because TVA's spillway crests are not standard.

Hiwassee dam has seven spillway bays, each controlled by a radial (tainter) gate as illustrated in Attachment A1. For headwater rating curve calculations the gates are assumed to be open to their maximum opening position, V, as specified in the Spillway Gate Arrangements table in Reference A1 and included as Attachment A2. As shown in this table the maximum opening corresponds to gate arrangement 84 (corresponding to an opening to chain link "68"). 1971 Field measurements (Attachment A3) relate gate opening (referenced from the crest elevation) to the chain link number on the gate hoist. Data was not collected for chain link numbers as high as 68, so the available data for each of the seven gates were averaged and extrapolated. The relationship between chain link and gate opening is linear for low gate openings, but becomes non-linear as V increases. Because of this, only the field data from the six largest openings were curve fit for the extrapolation. Extrapolation estimates V = 20.44 for chain link 68 (Attachment A4).

Test data from a 1:55 scale model are available for free discharge conditions (Ref. A2, relevant pages included as Attachment A5) and for orifice discharge conditions for nine different gate openings varying from V = 1.17 feet to V = 16.17 feet (Prototype Dimensions, Attachment A5). Orifice discharge data were not collected for gate openings as large as V = 20.44 feet, however, because under normal operating conditions the overflowing nappe will never touch the bottom of a gate open this far. But under the PMF conditions considered for the headwater rating curves the nappe will touch the gate in this position. Consequently, the data for gate openings V = 16.17, 13.09, 10.28, 7.16, and 4.22 feet are used here to estimate orifice flow discharge characteristics for V = 20.44 feet

A.1 References

A1. "Hiwassee Dam Spillway and Sluice Discharge Tables," River Operations, Tennessee Valley Authority, 2004 (Attachment 20).
A2. "Tainter Gate Rating Data Determined from Eight TVA Model Studies," Tennessee Valley Authority, Division of Water Control Planning, Engineering Laboratory, Norris, TN, 1962, RIMS No. L58 080821 001 (Relevant pages as Attachment A5)
A3. "Hydraulic Design Criteria," USACE (U. S. Army Engineer Waterways Experiment Station), Eighteenth issue, Vicksburg, MS, 1988
A4. TVA drawing no: 14W372, R8 (Attachments 11 & 29)
A5. TVA drawing no: 51W206, R5 (Attachment A8 & A16)
A6. TVA drawing no: 10K214, R1 (Attachment A15 & A17)

A.2 Discharge Equations

Attachment A6 is a definition sketch for flow over the Hiwassee Dam spillway. Free discharge occurs for headwater elevations below the elevation at which the overflowing nappe first touches the bottom lip of the gate, or $H_c <= H_{Lmin}$, and is computed using a weir equation (e.g., Reference A3):

$$Q_f = C_f L H_c^{1.5} \tag{A1}$$

in which Q_f = free discharge (cfs), C_f = free discharge coefficient ($ft^{0.5}$/sec), L = length of overflowing section (ft), H_c = head on crest (ft) = HW - Z_c, HW = headwater elevation (ft), and Z_c = top, or crest, elevation of overflowing section (ft). This equation need not be modified to account for tailwater submergence.

For headwater elevations above the elevation at which the nappe touches the gate lip, or $H_c > H_{Lmin}$, orifice flow occurs and is computed from (e.g., Reference A3)

$$Q_g = C_g G_n L \sqrt{2g(H_c - H_{mp})} \tag{A2}$$

in which Q_g = orifice discharge (cfs), C_g = orifice discharge coefficient (dimensionless -- varies with gate opening and H_c), G_n = effective gate opening = minimum distance between the gate lip and the crest (ft), g = acceleration of gravity (32.2 ft/s^2 -- common knowledge, Reference A3, sheet. 000-1 for example), and H_{mp} = vertical distance between the mid-point of G_n and the crest (ft). This equation need not be modified to account for tailwater submergence.

A.3 Model Test Data

The 1:55 scale Hiwassee model test data (Reference A2) are used to determine

- $C_f(H_c)$
- H_{Lmin} and $C_g(H_c)$ for V = 20.44 ft.

The Hiwassee model test results for $C_f(H_c)$ were published in Reference A2. Reference A2 also includes results for orifice discharge but in terms of a different discharge coefficient than the coefficient C_g used here, and Reference A2 includes no information on the relationship between H_{Lmin} and gate opening. However, the model test data for both orifice and free discharge are tabulated in Reference A2 and these data are used below to estimate H_{Lmin} and $C_g(H_c)$ for V = 20.44 feet and to establish a curve fit for $C_f(H_c)$.

Attachment A5 provides the pages from Reference A2 that are relevant to these calculations.

A.4 Geometry

Parameters G_n, H_{mp}, $Z_c = Z_o$ (gate overflow elevation), and β (angle plotted against discharge coefficient in Reference A3) are computed from crest and gate geometry as described in Attachment A7. Table A1 gives the values of these parameters for V = 4.22, 7.16, 10.28, 13.09, 16.17and 20.44 feet.

Table A1: Geometrical Parameters for Relevant Gate Openings

V, feet	G_n, feet	H_{mp}, feet	Z_o, feet	β, deg.
4.22	4.473	1.999	1529.655	74.9
7.16	7.369	3.495	1531.140	83.3
10.28	10.491	5.060	1532.336	91.4
13.09	13.340	6.456	1533.070	98.4
16.17	16.516	7.970	1533.470	105.9
20.44	21.065	10.029	1533.5	116.4

As an example, the procedure for computing the geometrical parameters for V = 20.44 feet is given here. From Attachment 11 (Reference A4):

- R = 22.5 feet
- Z_c = 1503.5 feet
- Z_{tr} = 1511 feet
- z_1 = 1511 – (1503.5 - .46875) = 7.97 feet
- z_2 = 1526.53 - 1511 = 15.53 feet

where the parameters are defined in Attachment A7. Referring to Attachment A7:

Angle θ:
$$\theta = \sin^{-1}\left(\frac{7.97}{22.5}\right) + \sin^{-1}\left(\frac{15.53}{22.5}\right) = 64.393°$$

Angle α:
$$\alpha = \tan^{-1}\left(\frac{1511 - 1503.5 - 20.44}{\sqrt{22.5^2 - (1511 - 1503.5 - 20.44)^2}}\right) = -35.107°$$

Overflow elevation Z_o:
$$Z_o = 1511 + 22.5\sin[64.393 - (-35.107)] = 1533.191 \ \ feet$$

Analysis of Table A1 indicates the maximum value of Z_o would not occur at the maximum gate opening if the above value is used for subsequent calculation. This means that the gate is open past vertical and that the highest elevation at which gate overflow occurs is directly above the trunnion. In this case Z_o is calculated as follows:

$$Z_o = Z_{tr} + R = 1511 + 22.5 = 1533.5 \ \ feet$$

Gate lip y-coordinate:
$$y_\ell = 1511 - 1503.5 - 20.44 = -12.940 \ \ feet$$

Gate lip x-coordinate:
$$x_\ell = \sqrt{22.5^2 - (-12.94)^2} = 18.407 \ \ feet$$

From Attachment A8 (Reference A5), where y^*_s and x^*_s are coordinates relative to crest centerline at the maximum crest elevation:

$$y_s^* = f(x_s^*) = 0.01538(x_s^*)^2 \quad for\ 0 \le x_s^* \le 52.8542$$

in which $y_s^* = y_s - 7.5 \quad and \quad x_s^* = 26.583 - x_s$ (See Reference A4). In terms of y_s and x_s:

$$y_s = f(x_s) = 0.01538(26.583 - x_s)^2 + 7.5 \quad for \quad -26.27 \le x_s \le 26.583\ feet$$

and

$$\frac{dy_s}{dx_s} = -.03076(26.583 - x_s)$$

To get effective gate opening, G_n, solve the following equation for x_{sn}:

$$x_{sn} - 18.407 + \left(0.01538(26.583 - x_s)^2 + 7.5 - (-12.940)\right)\left(-.03076(26.583 - x_{sn})\right) = 0$$

Solution:

- x_{sn} = 21.599 feet (by iteration)
- y_{sn} = 0.01538*(26.583-21.60)^2 + 7.5 = 7.882 feet
- $G_n = \sqrt{(21.599 - 18.407)^2 + (7.882 - (-12.940))^2} = 21.065\ feet$

and

- H_{mp} = 20.44'-[7.882' - (-12.940')]/2 = 10.029 feet
- $\beta = 90^o - \tan^{-1}\left(\frac{-12.940}{18.407}\right) - \tan^{-1}\left(\frac{21.599 - 18.407}{7.882 - (-12.940)}\right) = 90^o - (-35.107^o) - 8.716^o = 116.4°$

A.5 Determination of $H_{Lmin}(V)$

Attachment A9 shows the model test data for H_{Lmin} (Data from Ref. A2). The test data for both free and gated discharge were plotted together to form a family of curves. The intersection point between the extrapolated gated flow curves and the curve fit free discharge curve were used to determine H_{Lmin} at V = 1.17, 2.32, 4.22, 7.16, 10.28, 13.09, and 16.17. An example of this procedure is contained below for V = 2.32 feet.

Assume that curves intersect at $H_c < 10.94$, so that

$$Q_f = 144.96 * H_c^2 + 1019.45 * H_c - 820.51$$ (Attachment A9-1)

For V = 2.32 feet,

$$Q_g = -5.446 * H_c^2 + 596.24 * H_c + 3872.1$$ (Attachment A9-2)

Q_f is equal to Q_g at the intersection point, therefore;

$$0 = 150.406 * H_c^2 + 423.21 * H_c - 4692.61$$

Solving this quadratic equation yields solutions at H_c = -7.17 and 4.35, therefore H_c = 4.35 at V = 2.32 feet. Because the solution falls in the correct range for the free discharge flow (i.e. $H_c < 10.94$), the solution is correct. If the solution fell outside of this range, the procedure would have to be corrected to use the fit to the free discharge flow for $H_c > 10.94$.

From these calculated intersection points, H_{Lmin} as a function of V is determined and the resulting curve extrapolated to determine H_{Lmin} for V = 20.44 (Attachment A10). The following is used for the headwater rating curve calculations:

H_{Lmin} = 29.11 feet for V = 20.44 feet.

A.6 Determination of $C_f(H_c)$

Attachments A5, A9-1, and A11 show the model test data for free discharge and a polynomial curve fit to the data. The polynomial indicated in Attachment A12 is used to calculate C_f for the headwater rating curve calculations:

$$C_f = 2.8223 + 0.08495H_c - 0.004021H_c^2 + 7.5847\times10^{-5}H_c^3 \quad \text{(A3)}$$

A.7 Determination of $C_g(H_c)$ for V = 20.44 feet

Attachment A13 shows the calculations and results for extrapolating $C_g(H_c)$ for V = 20.44 feet from the model data for other gate openings. The first column in Attachment A13-1 denotes the data for which $H_c = H_{Lmin}$, at which H_c is just high enough to touch the bottom of the gate. Some of these values are available from model data, while others were determined by the intersection of the extrapolated gated discharge curve with the free discharge curve. The discharge indicated for V = 20.44 feet at $H_c = H_{Lmin}$ is the free discharge computed by extrapolating the $Q_f(H_c)$ curve (available from model data) to H_c = 29.11 feet (H_{Lmin} at V = 20.44) (Attachments A9-1 and A11). The first two numerical columns list the model data (scaled to prototype dimensions) or extrapolated data (estimated from model data) for V = 4.22, 7.16, 10.28, 13.09, and 16.17 feet as listed in Attachment A5. The rows that do not include values of discharge, Q, were added to extrapolate the C_g data. The next three columns after the model data list prototype geometrical parameters. The last numerical column lists the C_g values back-calculated from the discharge data via Equation (A2). Values that were "estimated" for extrapolation purposes are labeled as such to the right of the C_g column.

Attachment A13-2 shows C_g plotted against H_c for all gate openings. The curves include extrapolated segments. The estimated curve for V = 20.44 feet starts with the value for $H_c = H_{Lmin}$ and runs parallel to the curve for V = 16.17 feet. Given the absence of data, this extrapolated line segment fit for $C_g(H_c)$ at V = 20.44 feet is used for the headwater rating calculations. $C_g(H_c)$ can be calculated from the following equations:

$$C_g = 0.7912 + 0.023(29.11 - H_C) \quad for\ 29.11 \le H_c \le 32 \qquad \text{(A4.1)}$$

$$C_g = 0.7247 + 0.015(32 - H_C) \quad for\ 32 < H_c \le 33.5 \qquad \text{(A4.2)}$$

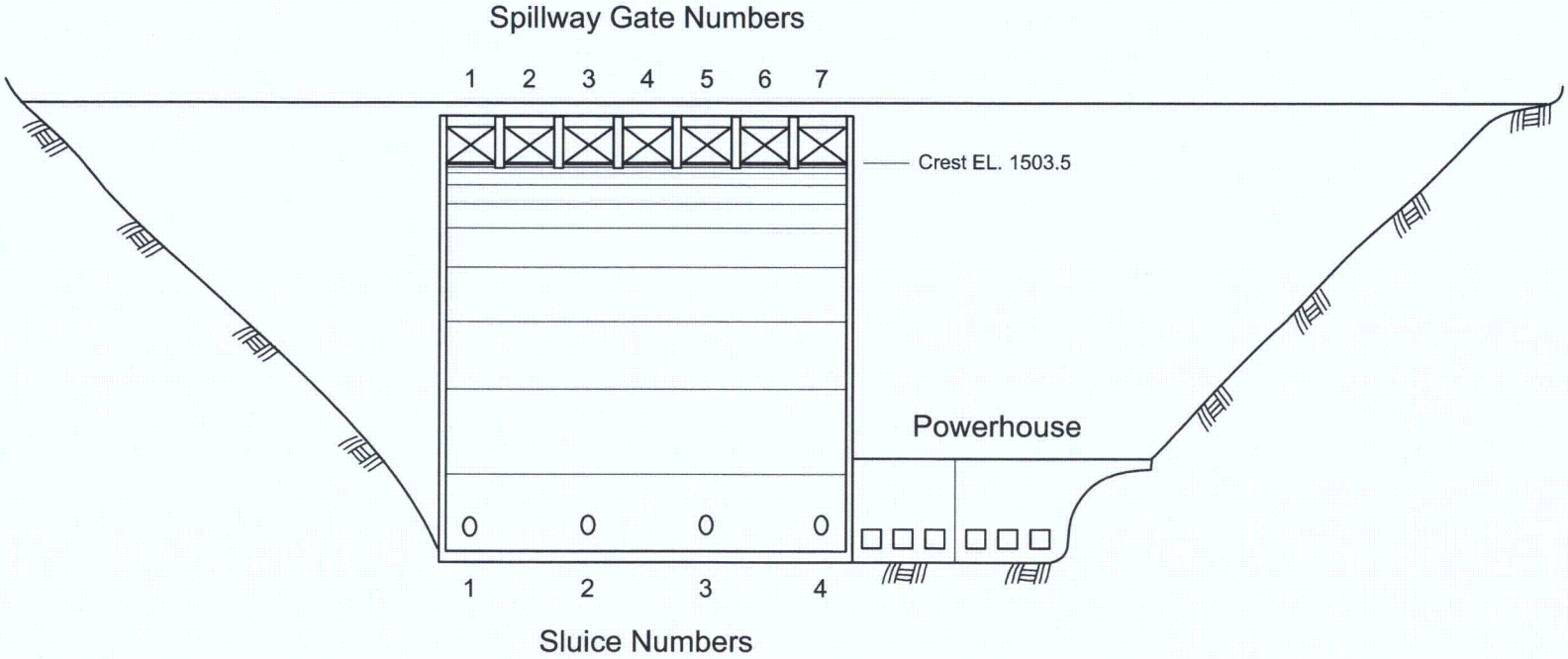
$$C_g = 0.7022 + 0.00556(33.5 - H_C) \quad for\ 33.5 < H_c \le 34.5 \qquad \text{(A4.3)}$$

$$C_g = 0.6967 \quad for\ H_c > 34.5 \qquad \text{(A4.4)}$$

As further justification for the extrapolation, Attachment A14 shows the Hiwassee C_g values at large H_c (specifically H_c = 41.5 feet) plotted against angle β on Hydraulic Design Chart 311-1 from Reference A3 showing U.S. Army Corps of Engineers data for tainter gates on standard crests. The value of X/H_d for Hiwassee is 0.19 (X = 5.5 feet, Attachment A11, and Hd = 28.5, Attachment A15). Presumably because TVA's spillway crests are not standard, TVA data always lie to the left of the suggested design curves on this chart. Note that C_g = 0.6967 at H_c = 41.5 feet and V = 20.44 feet (β = 116.4 degrees) is a very reasonable extrapolation of the Hiwassee data curve and appears reasonable compared with the suggested design curves on the chart.

HIWASSEE DAM

LOCATION OF SPILLWAY GATES AND SLUICE GATES



DOWNSTREAM ELEVATION

Attachment A2

Source: Reference A1

Calculation No: CDQ000020080012

Page A8

HIWASSEE DAM

SPILLWAY GATE ARRANGEMENTS

Arrangement Number	Gate Number 1	2	3	4	5	6	7
1	-	-	-	-	4	-	-
2	-	-	4	-	4	-	-
3	-	-	4	-	4	-	4
4	4	-	4	-	4	-	4
5	4	-	4	-	4	4	4
6	4	4	4	-	4	4	4
7	4	4	4	4	4	4	4
8	4	4	4	4	6	4	4
9	4	4	6	4	6	4	4
10	4	4	6	4	6	4	6
11	6	4	6	4	6	4	6
12	6	4	6	4	6	6	6
13	6	6	6	4	6	6	6
14	6	6	6	6	6	6	6
15	6	6	6	6	10	6	6
16	6	6	10	6	10	6	6
17	6	6	10	6	10	6	10
18	10	6	10	6	10	6	10
19	10	6	10	6	10	10	10
20	10	10	10	6	10	10	10
21	10	10	10	10	10	10	10
22	10	10	10	10	14	10	10
23	10	10	14	10	14	10	10
24	10	10	14	10	14	10	14
25	14	10	14	10	14	10	14
26	14	10	14	10	14	14	14
27	14	14	14	10	14	14	14
28	14	14	14	14	14	14	14
29	14	14	14	14	18	14	14
30	14	14	18	14	18	14	14

Arrangement Number	Gate Number 1	2	3	4	5	6	7
31	14	14	18	14	18	14	18
32	18	14	18	14	18	14	18
33	18	14	18	14	18	18	18
34	18	18	18	14	18	18	18
35	18	18	18	18	18	18	18
36	18	18	18	18	22	18	18
37	18	18	22	18	22	18	18
38	18	18	22	18	22	18	22
39	22	18	22	18	22	18	22
40	22	18	22	18	22	22	22
41	22	22	22	18	22	22	22
42	22	22	22	22	22	22	22
43	22	22	22	22	26	22	22
44	22	22	26	22	26	22	22
45	22	22	26	22	26	22	26
46	26	22	26	22	26	22	26
47	26	22	26	22	26	26	26
48	26	26	26	22	26	26	26
49	26	26	26	26	26	26	26
50	26	26	26	26	30	26	26
51	26	26	30	26	30	26	26
52	26	26	30	26	30	26	30
53	30	26	30	26	30	26	30
54	30	26	30	26	30	30	30
55	30	30	30	26	30	30	30
56	30	30	30	30	30	30	30
57	30	30	30	30	38	30	30
58	30	30	38	30	38	30	30
59	30	30	38	30	38	30	38
60	38	30	38	30	38	30	38

Arrangement Number	Gate Number 1	2	3	4	5	6	7
61	38	30	38	30	38	38	38
62	38	38	38	30	38	38	38
63	38	38	38	38	38	38	38
64	38	38	38	38	46	38	38
65	38	38	46	38	46	38	38
66	38	38	46	38	46	38	46
67	46	38	46	38	46	38	46
68	46	38	46	38	46	46	46
69	46	46	46	38	46	46	46
70	46	46	46	46	46	46	46
71	46	46	46	46	54	46	46
72	46	46	54	46	54	46	46
73	46	46	54	46	54	46	54
74	54	46	54	46	54	46	54
75	54	46	54	46	54	54	54
76	54	54	54	46	54	54	54
77	54	54	54	54	54	54	54
78	54	54	54	54	68	54	54
79	54	54	68	54	68	54	54
80	54	54	68	54	68	54	68
81	68	54	68	54	68	54	68
82	68	54	68	54	68	68	68
83	68	68	68	54	68	68	68
84	68	68	68	68	68	68	68

GATE OPENINGS

Figures in columns under each gate number refer to gate chain link number
dash (-) indicates closed gate

Link No. US Gate Opening above crest

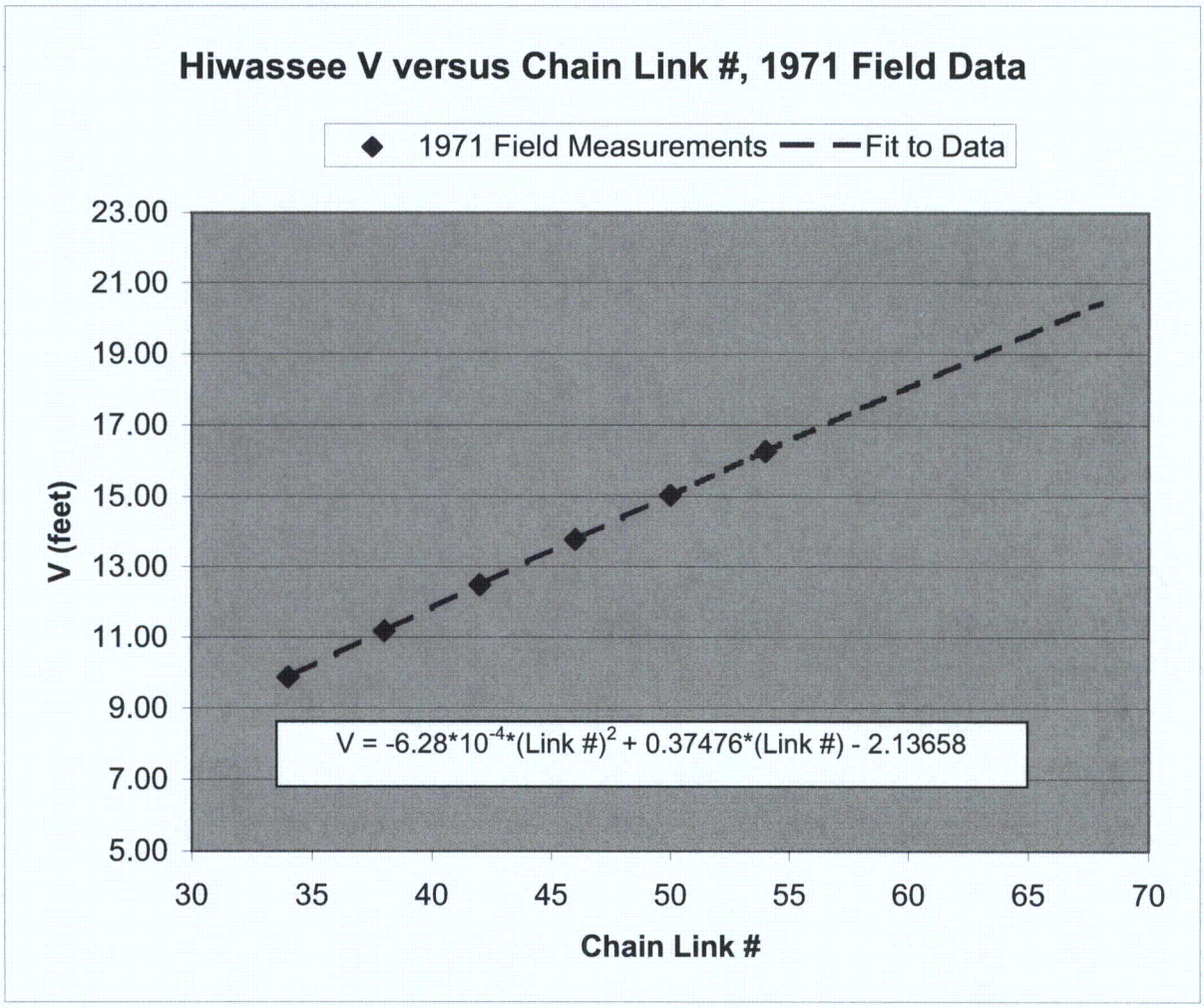
HIWASSEE

COMPUTED BJC DATE 2-22-71
JNB 2-22-71
CHECKED BJC DATE 2-23-71

Link No.	1	2	3	4	5	6	7
	+	✓	+	+	✓	+	✓
4	.078	.13	.09	.050	.140	.080	.15
6	.71	.74	.71	.68	.76	.68	.76
8	1.34	1.36	1.34	1.30	1.40	1.31	1.41
10	1.97	2.00	1.98	1.95	2.03	1.95	2.07
12	2.63	2.65	2.63	2.60	2.68	2.60	2.72
14	3.28	3.30	3.27	3.24	3.32	~~3.25~~ 3.25	3.38
18	4.59	4.61	4.58	4.55	4.62	4.56	4.69
22	5.91	5.92	5.91	5.86	5.94	5.86	6.01
26	7.24	7.24	7.23	7.18	7.26	7.19	7.34
30	8.56	8.57	8.55	8.50	8.58	8.52	8.66
34	9.88	9.89	9.86	9.82	9.90	9.84	9.99
38	11.20	11.19	11.16	11.14	11.20	11.14	11.31
42	12.50	12.48	12.48	12.44	12.50	12.44	12.61
46	13.78	13.78	13.76	13.72	13.78	13.73	13.89
50	15.04	15.03	15.01	14.98	15.04	14.99	15.15
54	16.27	16.27	16.25	16.21	16.26	16.22	16.38
58	17.48						

	1,3,4,6	2,5,7
4	.074	.14
6	.78	.75
8	1.32	1.39
10	1.96	2.03
12	2.61	2.68
14	3.26	3.33
18	4.57	4.64
22	5.88	5.96
26	7.21	7.28
30	8.53	8.60
34	9.85	9.93
38	11.16	11.23
42	12.46	12.53
46	13.75	13.82
50	15.00	15.07
54	16.24	16.30
58		

	Gate (1971 Field Data)								
Link	1	2	3	4	5	6	7	Avg of all Gates	Fit to Data
4	0.078	0.13	0.09	0.05	0.14	0.08	0.15		
6	0.71	0.74	0.71	0.68	0.76	0.68	0.76		
8	1.34	1.36	1.34	1.3	1.4	1.31	1.41		
10	1.97	2	1.98	1.95	2.03	1.95	2.07		
12	2.63	2.65	2.63	2.6	2.68	2.6	2.72		
14	3.28	3.3	3.27	3.24	3.32	3.25	3.38		
18	4.59	4.61	4.58	4.55	4.62	4.56	4.69		
22	5.91	5.92	5.91	5.86	5.94	5.86	6.01		
26	7.24	7.24	7.23	7.18	7.26	7.19	7.34		
30	8.56	8.57	8.55	8.5	8.58	8.52	8.66		
34	9.88	9.89	9.86	9.82	9.9	9.84	9.99	9.88	9.88
38	11.2	11.19	11.16	11.14	11.2	11.14	11.31	11.19	11.20
42	12.5	12.48	12.48	12.44	12.5	12.44	12.61	12.49	12.50
46	13.78	13.78	13.76	13.72	13.78	13.73	13.89	13.78	13.77
50	15.04	15.03	15.01	14.98	15.04	14.99	15.15	15.03	15.03
54	16.27	16.27	16.25	16.21	16.26	16.22	16.38	16.27	16.27
68				Extrapolated					20.44



Tennessee Valley Authority

Tainter Gate Ratings

Basic Model and Prototype Data

	MODEL					PROTOTYPE		
Project	Model Scale	No. of Spill-way Bays	Crest Length L	Approach Width W	Up-stream Depth P	Crest Elev.	Design Head H_o	Pier Nose Radius R
Apalachia	1:28.72	6	6.684	8.00	3.38	1257.0	23.0	3.00
Boone	1:50	5	3.480	(1)	(1)	1350.0	35.0	12.75(2) 11.25(3) 3.50(4)
Ft. Patrick Henry	1:15	1	2.333(5)	2.77(5)	2.29	1228.0	35.0	3.25
Hales Bar	1:34.76	6	6.908(6) 6.905(7)	7.94	0.921	616.0	18.0	3.00
Hiwassee	1:55	7	4.050	8.00	6.35	1503.5		3.00
Watts Bar	1:35	6	6.866	8.00	1.5	713.0	23.5	3.25
Wheeler	1:34.35	6	6.984	7.97	1.253	541.3	16.5	2.50

(1) Variable because approach was reproduced in model.

(2) Right end pier.

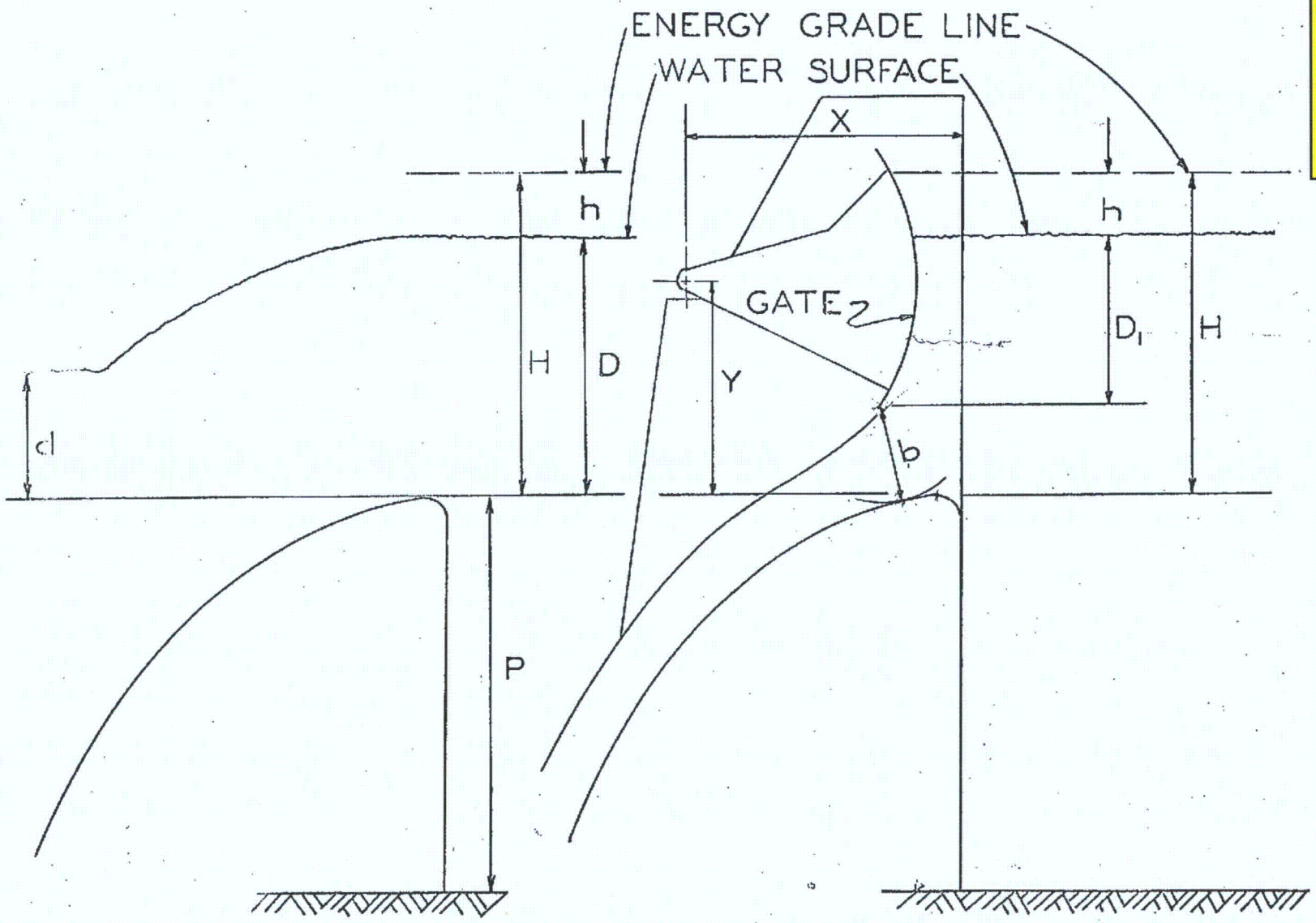
(3) Left end pier.

(4) Intermediate piers.

(5) Except as noted on data tabulations.

(6) Gates partially opened.

(7) Gates raised above water surface.



[a] FIGURE 1 [b]

Tennessee Valley Authority

Hiwassee Project

Tainter Gates Raised Above Water Surface

MODEL TEST DATA			EQUIVALENT PROTOTYPE		
D	Q	h	H	Q	C
ft.	cfs	ft.	ft.	cfs	
0.199	1.224	Negligible	10.94	27,460	3.40
0.238	1.616		13.09	36,250	3.44
0.303	2.348		16.66	52,680	3.48
0.353	3.002		19.42	67,350	3.54
0.463	4.673		25.46	104,800	3.66
0.083	0.3053		4.56	6,849	3.15
0.081	0.2932		4.46	6,578	3.13
0.150	0.7790		8.25	17,480	3.31
0.113	0.4982		6.22	11,180	3.24
0.147	0.7553		8.08	16,940	3.31
0.157	0.8340		8.64	18,710	3.31
0.217	1.404		11.94	31,500	3.43
0.252	1.769		13.86	39,690	3.45
0.283	2.116		15.56	47,470	3.47
0.293	2.244		16.12	50,340	3.49
0.319	2.548		17.54	57,160	3.49
0.371	3.254		20.40	73,000	3.56
0.289	2.200		15.90	49,350	3.50
0.498	5.274		27.39	118,300	3.71
0.314	2.498		17.27	56,040	3.50
0.426	4.059		23.43	91,060	3.60
0.054	0.1572		2.97	3,527	3.11
0.120	0.5475		6.60	12,280	3.25
0.347	2.893		19.08	64,900	3.49
0.347	2.911		19.08	65,310	3.52
0.422	3.993		23.21	89,580	3.60
0.280	2.082		15.40	46,710	3.47
0.048	0.1296		2.64	2,907	3.05
0.081	0.2886		4.46	6,474	3.08

Tennessee Valley Authority

Hiwassee Project

Tainter Gates Partially Opened

MODEL TEST DATA				EQUIVALENT PROTOTYPE			
G.O. ft.	D ft.	Q cfs	h ft.	G.O. ft.	H ft.	Q cfs	C
0.1302	0.229	1.222		7.16	12.60	27,410	3.85
	0.277	1.344			15.24	30,150	3.71
	0.389	1.612			21.40	36,160	3.59
	0.447	1.751			24.59	39,280	3.59
	0.483	1.833			26.57	41,120	3.59
	0.425	1.703			23.38	38,210	3.60
	0.346	1.512			19.03	33,920	3.62
0.1293	0.300	1.382		7.11	16.50	31,000	3.65
	0.347	1.505			19.08	33,760	3.62
	0.477	1.817			26.24	40,760	3.62
	0.237	1.229			13.04	27,570	3.80
	0.248	1.255			13.64	28,150	3.76
0.187	0.402	2.282	Negligible	10.28	22.11	51,190	3.63
	0.350	2.130			19.25	47,780	3.72
	0.320	2.057			17.60	46,150	3.83
	0.452	2.438			24.86	54,690	3.59
	0.491	2.563			27.00	57,500	3.59
0.186	0.317	2.041		10.23	17.44	45,790	3.84
	0.320	2.037			17.60	45,700	3.81
0.238	0.445	3.051		13.09	24.48	68,450	3.72
	0.491	3.213			27.00	72,080	3.66
	0.381	2.908			20.96	65,240	3.96
	0.388	2.909			21.34	65,260	4.04
0.294	0.501	4.033		16.17	27.56	90,480	3.82
	0.422	3.993			23.21	89,580	4.32
	0.422	3.989			23.21	89,490	4.31
	0.460	3.989			25.30	89,490	4.03
	0.465	3.989			25.58	89,490	4.00

Tennessee Valley Authority

Hiwassee Project

Tainter Gates Partially Opened

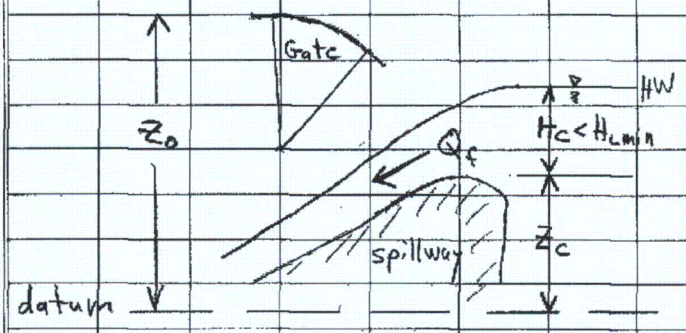
MODEL TEST DATA				EQUIVALENT PROTOTYPE			
G.O. ft.	D ft.	Q cfs	h ft.	G.O. ft.	H ft.	Q cfs	C
0.0213	0.280	0.3292	Negligible	1.17	15.40	7,385	4.96
	0.185	0.2692			10.18	6,039	5.03
	0.070	0.1636			3.85	3,670	5.24
	0.310	0.3456			17.05 ~~1.71~~	7,753	4.96
	0.449	0.4161			24.70	9,335	4.92
	0.385	0.3849			21.18	8,635	4.92
	0.048	0.1296			2.64	2,907	5.25
	0.051	0.1372			2.80	3,078	5.38
	0.052	0.1415			2.86	3.174	5.46
	0.051	0.1404			2.80	3,150	5.51
	0.056	0.1520			3.08	3,410	5.61
	0.063	0.1568			3.46	3,518	5.37
	0.077	0.1725			4.24	3,870	5.20
	0.084	0.1812			4.62	4,065	5.27
	0.124	0.2188			6.82	4,909	5.15
	0.229	0.3010			12.60	6,753	5.06
	0.322	0.3555			17.71	7,975	5.01
0.0421	0.142	0.3687		2.32	7.81	8,271	4.16
	0.100	0.3133			5.50	7,029	4.39
	0.196	0.4123			10.78	9,250	3.86
	0.277	0.5273			15.24	11,830	4.08
	0.385	0.6276			21.18	14,080	4.08
	0.473	0.6983			26.02	15,670	4.08
	0.203	0.4465			11.16	10,020	4.10
0.0767	0.120	0.5475		4.22	6.60	12,280	4.13
	0.188	0.6886			10.34	15,450	3.82
	0.261	0.8201			14.36	18,400	3.72
	0.318	0.9188			17.49	20,610	3.72
	0.374	1.003			20.57	22,500	3.71
	0.440	1.094			24.20	24,540	3.69
0.0762	0.172	0.6546		4.19	9.46	14,690	3.88
	0.203	0.7079			11.16	15,880	3.78

Definition Sketch for Spillway Discharge

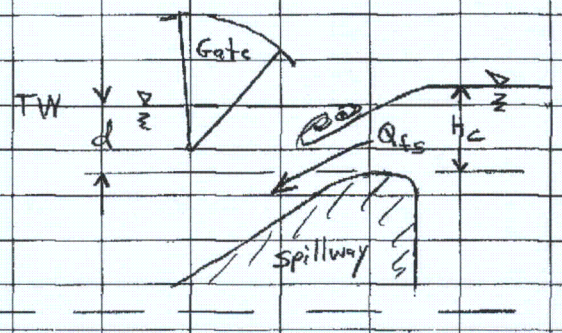
COMPUTED GAS DATE 8/12/2008

CHECKED ____ DATE ____

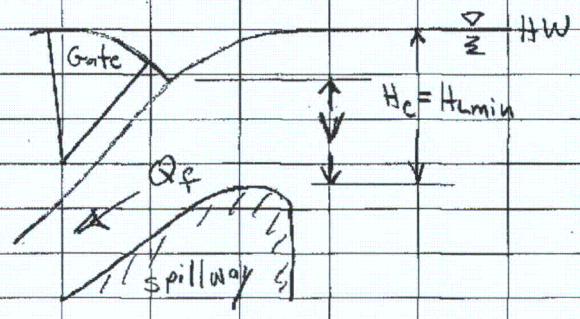
Free Discharge - No Tailwater effect



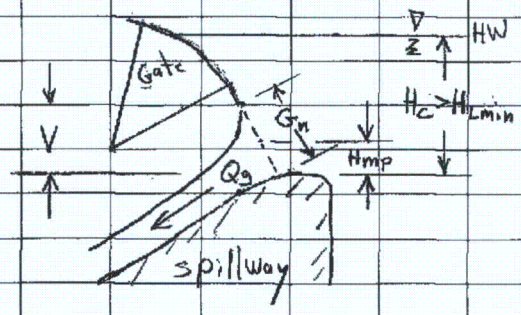
Free Discharge affected by Tailwater



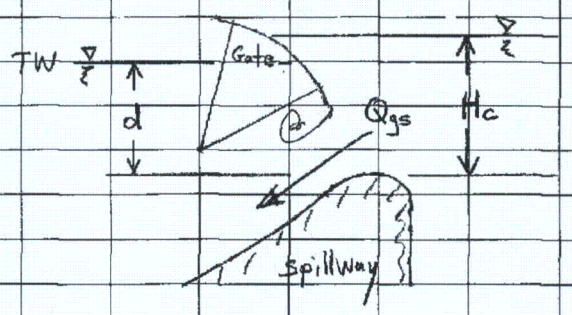
Nappe Touches Gate



Orifice Discharge - No Tailwater Effect



Orifice Discharge affected by Tailwater

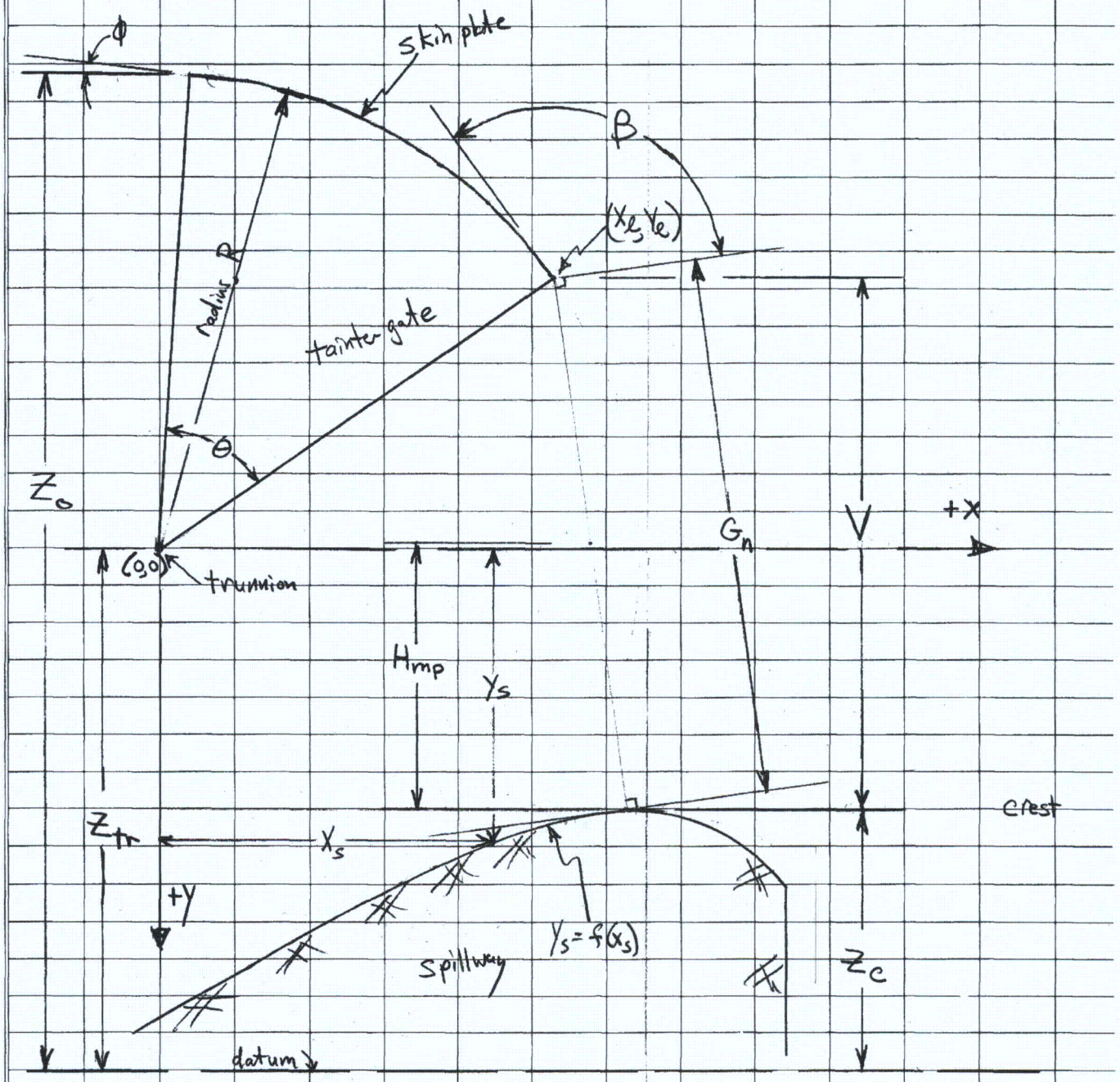


Spillway Discharge Calculations
Geometry for Flow Under an Open Tainter Gate

COMPUTED CAS DATE 8/11/2008

CHECKED _____ DATE _____

Definition Sketch



Spillway Gate Geometry

COMPUTED GAS DATE 8/11/2008

CHECKED _____ DATE _____

Variables

V = vertical distance between the bottom of the open gate and the crest

Z_c = crest elevation

Z_{tr} = trunnion elevation

Z_o = overflow elevation

R = radius of the tainter gate

G_n = minimum distance between the gate lip and the crest

H_{mp} = vertical distance between the mid-point of G_n and the crest

β = angle formed by the tangent to the gate lip and the tangent to the crest curve at the nearest point of the crest curve

Θ = angle of the sector of a circle formed by two lines connecting the trunnion axis to the bottom and top of the radial gate.

X, Y = coordinates relative to trunnion axis (Y positive downward)

X_s, Y_s = coordinates of spillway surface defined by $Y_s = f(X_s)$

X_ℓ, Y_ℓ = coordinates of the gate lip relative to trunnion axis

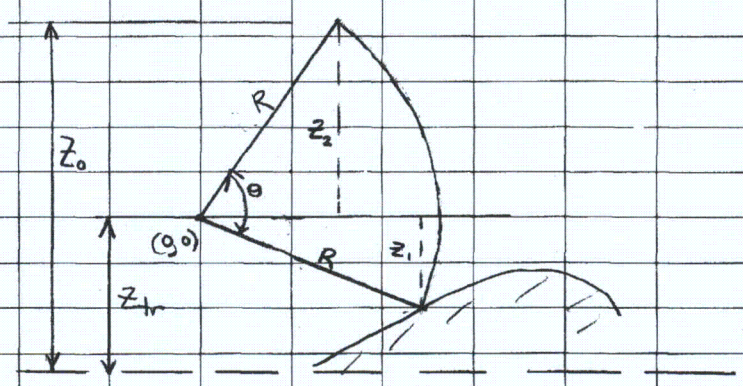
notes: $\begin{cases} Y \text{ positive downward for all coordinates} \\ \text{all coordinates relative to trunnion axis} \end{cases}$

Φ = angle formed by the tangent to the gate top and horizontal

Angle, Θ

$$\Theta = \sin^{-1}\left(\frac{Z_2}{R}\right) + \sin^{-1}\left(\frac{Z_1}{R}\right)$$

Z_1 & Z_2 are determined from drawings



Closed Gate

Spillway Gate Geometry

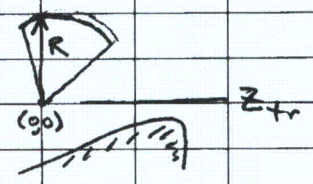
COMPUTED GAS DATE 8/11/2008

CHECKED _____ DATE _____

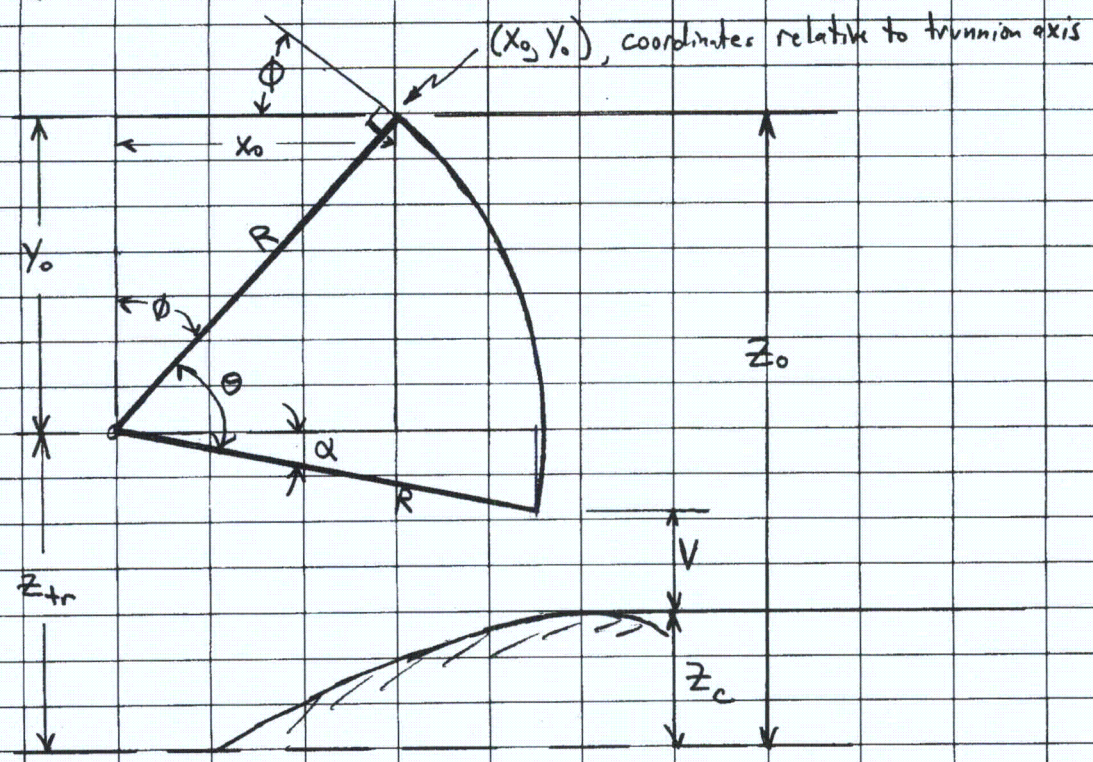
Overflow Elevation, Z_o and Angle, Φ

For a gate opened so far that its upper edge is downstream of the trunnion:

$$Z_o = Z_{tr} + R$$



For a gate opened less:



$$\alpha = \tan^{-1}\left(\frac{Z_{tr} - (Z_{cr} + V)}{\sqrt{R^2 - (Z_{tr} - Z_{cr} - V)^2}}\right)$$

V given

$$\boxed{Z_o = Z_{tr} + R\sin(\theta - \alpha)}$$

and $\boxed{\Phi = \tan^{-1}\left(\frac{X_o}{Y_o}\right)}$ with $\begin{cases} Y_o = Z_o - Z_{tr} \\ X_o = R\cos(\theta - \alpha) \end{cases}$

Spillway Gate Geometry

COMPUTED GAS DATE 8/11/2008

CHECKED _____ DATE _____

Gate Opening, G_n

Gate lip coordinates:
$$\begin{cases} Y_\ell = Z_{tr} - Z_{cr} - V \\ X_\ell = \sqrt{R^2 - Y_\ell^2} \end{cases}$$

Distance between gate lip and any point on spillway surface is

$$\ell = \sqrt{(X_s - X_\ell)^2 + (Y_s - Y_\ell)^2} \equiv \sqrt{(X_s - X_\ell)^2 + [f(X_s) - Y_\ell]^2}$$

G_n is the minimum distance. ℓ is minimum when $\frac{d\ell}{dX_s} = 0$

$$\frac{d\ell}{dX_s} = \frac{1}{2}\left\{(X_{sn} - X_\ell)^2 + [f(X_{sn}) - Y_\ell]^2\right\}^{-1/2} \cdot \left\{2(X_{sn} - X_\ell) + 2[f(X_{sn}) - Y_\ell]\frac{df(X_{sn})}{dX_s}\right\} = 0$$

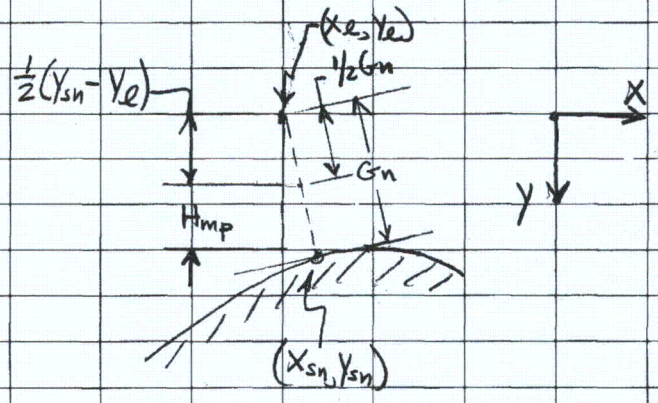
$$\Rightarrow 0 = \frac{(X_{sn} - X_\ell) + [f(X_{sn}) - Y_\ell]\frac{df(X_{sn})}{dX_s}}{\ell_{minimum}}$$

where $X_{sn} = X_s$ for minimum ℓ. $\ell_{minimum} \equiv G_n$

Solve: $X_{sn} - X_\ell + [f(X_{sn}) - Y_\ell]\frac{df(X_{sn})}{dX_s} = 0$ for X_{sn}

Then: $Y_{sn} = f(X_{sn})$ and $\boxed{G_n = \sqrt{(X_{sn} - X_\ell)^2 + (Y_{sn} - Y_\ell)^2}}$

Mid-Point Head, H_{mp}



$$H_{mp} = Z_{tr} - Z_c - Y_\ell - \frac{1}{2}(Y_{sn} - Y_\ell)$$

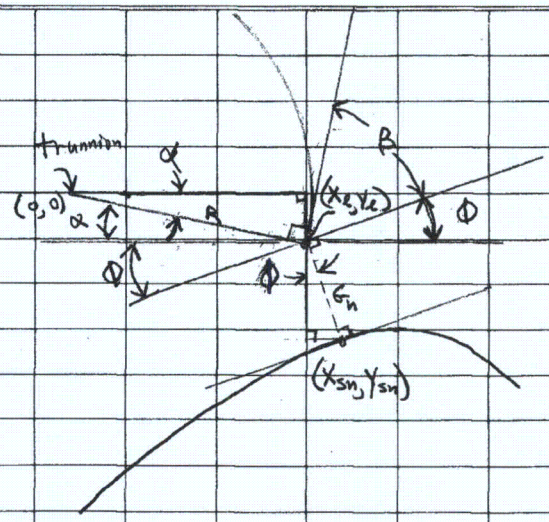
$$\Rightarrow \boxed{H_{mp} = V - \frac{1}{2}(Y_{sn} - Y_\ell)}$$

Spillway Gate Geometry

COMPUTED GAS DATE

CHECKED DATE

Angle, β



$$\beta + \frac{\pi}{2} + \alpha + \Phi = \pi$$

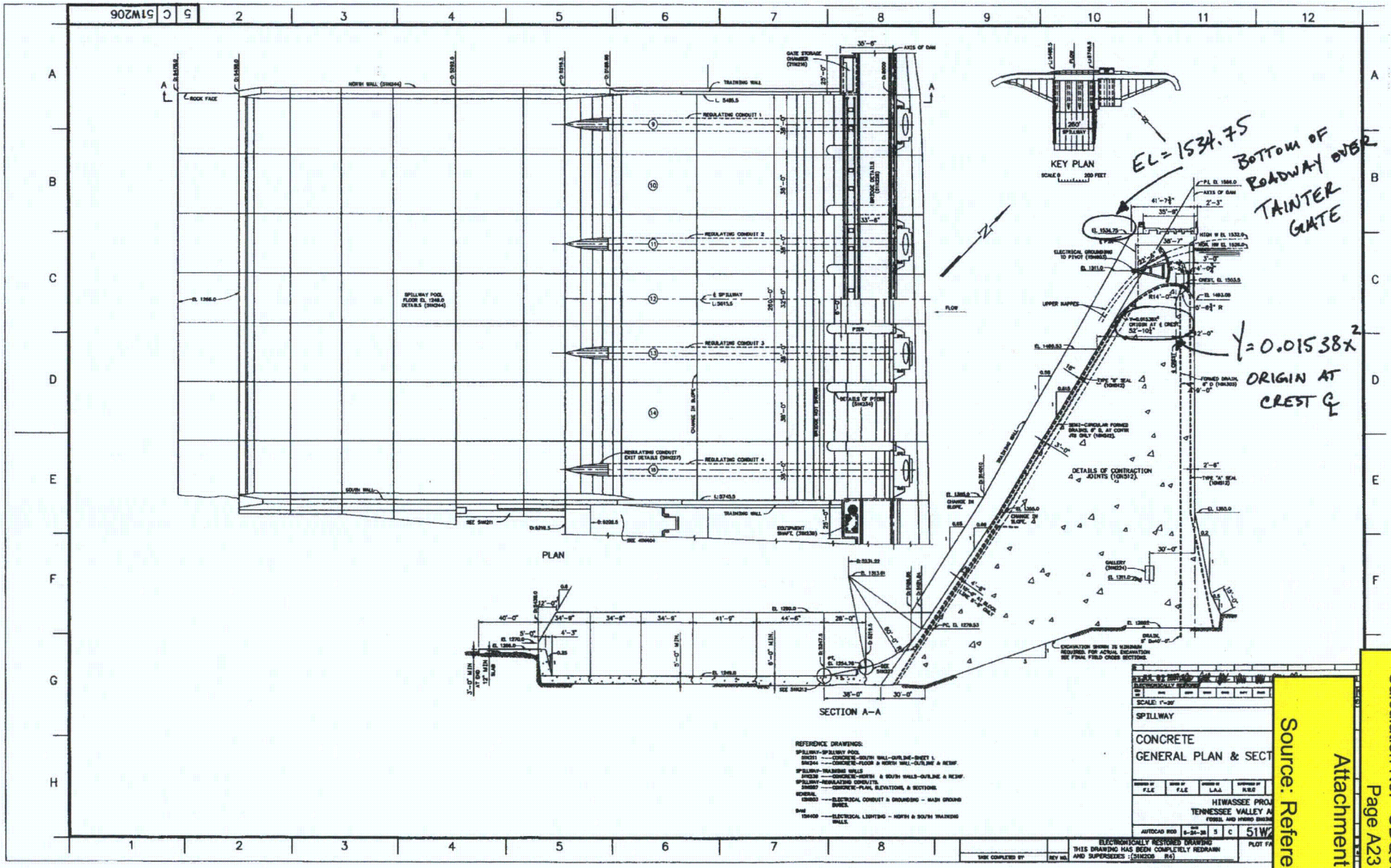
$$\beta + \Phi = \frac{\pi}{2} - \alpha$$

$$\beta = \frac{\pi}{2} - \alpha - \Phi$$

$$\alpha = \tan^{-1}\left(\frac{y_l}{x_l}\right)$$

$$\Phi = \tan^{-1}\left(\frac{x_{sn} - x_l}{y_{sn} - y_l}\right)$$

$$\boxed{\beta = \frac{\pi}{2} - \tan^{-1}\left(\frac{y_l}{x_l}\right) - \tan^{-1}\left(\frac{x_{sn} - x_l}{y_{sn} - y_l}\right)}$$



Calculation No: CDQ00002008001 2
Page A23

Attachment A8

Source: Reference A5

Hiwassee Model Data For Headwater Ratings.xls, Spillway Rating Data

Hiwassee Project
Tainter Gates Fully Opened
Data from 1:55 scale model
EQUIVALENT PROTOTYPE
L = 224 feet

Free Discharge Curve

Hc data	Q data	Q fit	Fit Eq.	
2.64	2907	2881	$Q=144.96*H_c^2+1019.45*H_c-820.51$	$H_c < 10.94$
2.97	3527	3486		
4.46	6578	6610		
4.46	6474	6610		
4.56	6849	6842		
6.22	11180	11129		
6.6	12280	12222		
8.08	16940	16880		
8.25	17480	17456		
8.64	18710	18809		
10.94	27460	27657	$Q=103.88*Hc2+1520.67*Hc-1411.74$	$H_c >= 10.94$
11.94	31500	31554		
13.09	36250	36293		
13.86	39690	39619		
15.4	46710	46642		
15.56	47470	47400		
15.9	49350	49028		
16.12	50340	50094		
16.66	52680	52754		
17.27	56040	55832		
17.54	57160	57218		
19.08	64900	65418		
19.08	65310	65418		
19.42	67350	67295		
20.4	73000	72839		
23.21	89580	89841		
23.43	91060	91242		
25.46	104800	104638		
27.39	118300	118168		
29.11	Extrapolated	130869		

Hiwassee Project
Tainter Gates Partially Opened
Data from 1:55 scale model
EQUIVALENT PROTOTYPE
L = 224 feet

Gated Discharge Data

Hc data	Q data			Q Gated Fit
2.64	2907	*		3059
2.8	3078			3141
2.8	3150			3141
2.86	3174			3172
3.08	3410			3283
3.46	3518			3472
3.85	3670			3660
4.24	3870			3843
4.62	4065		V=1.17	4017
6.82	4909			4932
10.18	6039			6078
12.6	6753			6753
15.4	7385			7421
17.05	7753			7777
17.71	7975			7914
21.18	8635			8613
24.7	9335			9353
$Q = 0.3525*H_c^3 - 21.151*H_c^2 + 623.1*H_c + 1554.5$				
4.35		+		6364
5.5	7029			6987
7.81	8271			8197
10.78	9250			9667
11.16	10020		V=2.32	9848
15.24	11830			11694
21.18	14080			14057
26.02	15670			15699
$Q = -5.446*H_c^2 + 596.24*H_c + 3872.1$				
6.67		+		12439
10.34	15450			15437
14.36	18400			18441
17.49	20610		V=4.22	20576
20.57	22500			22500
24.2	24540			24546
$Q = -9.164*H_c^2 + 973.703*H_c + 6348.86$				

Hc data	Q data			Q Gated Fit
10.29		+		25005
12.6	27410			27420
15.24	30150			30126
19.03	33920			33918
21.4	36160		V=7.16	36233
23.38	38210			38135
24.59	39280			39282
26.57	41120			41135
$Q = -3.821*H_c^2 + 1131.43*H_c + 13770.64$				
14.66		+		43190
17.6	46150			46097
19.25	47780			47867
22.11	51190		V=10.28	51174
24.86	54690			54640
27	57500			57531
$Q = 18.52*H_c^2 + 390.35*H_c + 33490.63$				
18.86		+		64197
20.96	65240			65135
21.34	65260			65386
24.48	68450		V=13.09	68419
27	72080			72090
$Q = 86.65*H_c^2 - 3004.07*H_c + 90034.17$				
23.21	89580	*		89580
25.3	89490			89457
25.58	89490		V=16.17	89518
27.56	90480			90475
$Q = 117.60*H_c^2 - 5737.3*H_c + 159682$				

* H_{Imin} From model data

\+ H_{Imin} estimated from extrapolation of model data

Hiwassee Project
Tainter Gates Partially Opened
Data from 1:55 scale model
EQUIVALENT PROTOTYPE
L = 224 feet

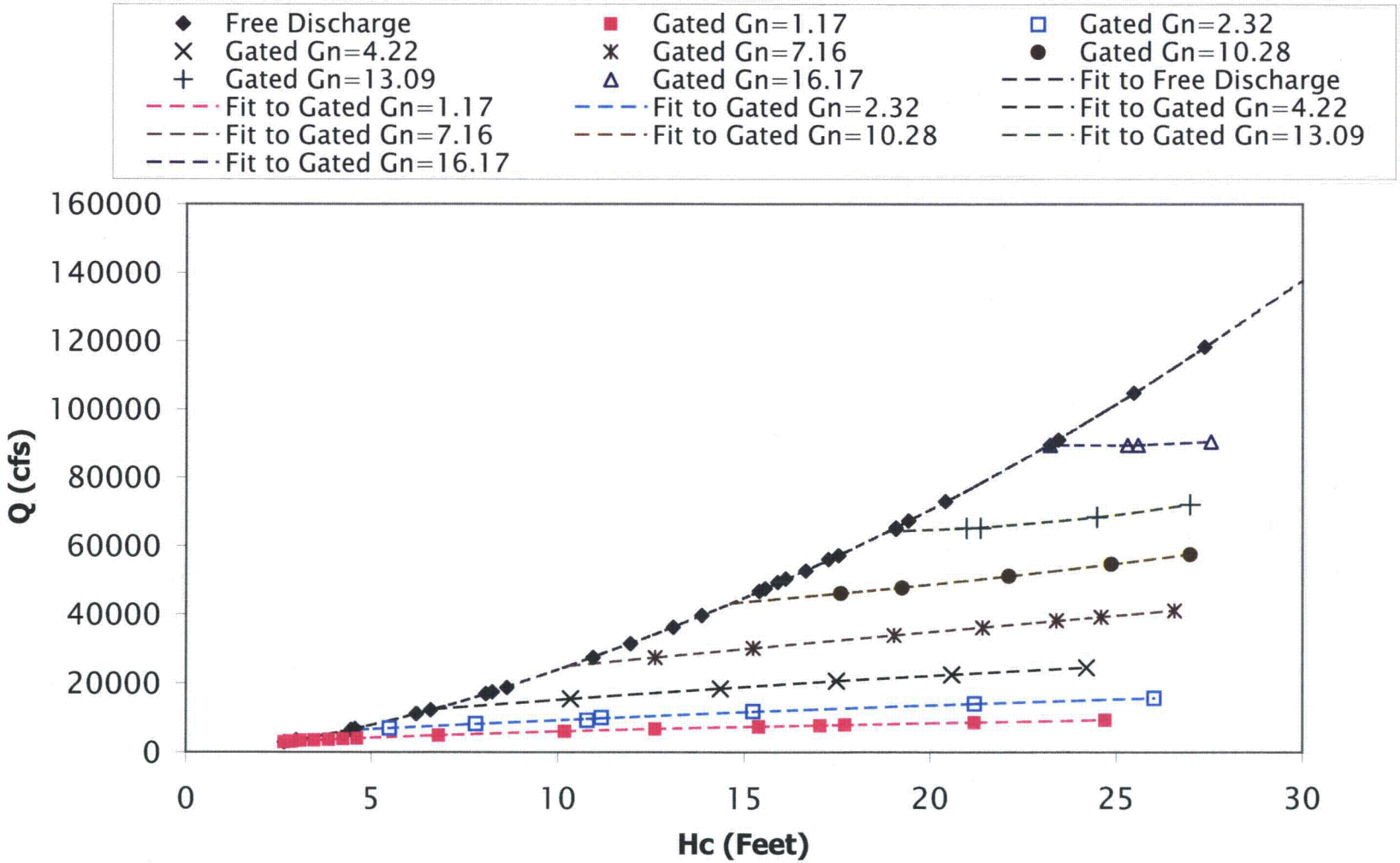
Gated Discharge Data

Hc data	Q data		Q Gated Fit
2.64	2907		3059
2.8	3078		3141
2.8	3150		3141
2.86	3174		3172
3.08	3410		3283
3.46	3518		3472
3.85	3670		3660
4.24	3870		3843
4.62	4065	V=1.17	4017
6.82	4909		4932
10.18	6039		6078
12.6	6753		6753
15.4	7385		7421
17.05	7753		7777
17.71	7975		7914
21.18	8635		8613
24.7	9335		9353
$Q = 0.3525*H_c^3 - 21.151*H_c^2 + 623.1*H_c + 1554.5$			
4.35			6364
5.5	7029		6987
7.81	8271		8197
10.78	9250	V=2.32	9667
11.16	10020		9848
15.24	11830		11694
21.18	14080		14057
26.02	15670		15699
$Q = -5.446*H_c^2 + 596.24*H_c + 3872.1$			
6.67			12439
10.34	15450		15437
14.36	18400		18441
17.49	20610	V=4.22	20576
20.57	22500		22500
24.2	24540		24546
$Q = -9.164*H_c^2 + 973.703*H_c + 6348.86$			

Hc data	Q data		Q Gated Fit
10.29			25005
12.6	27410		27420
15.24	30150		30126
19.03	33920	V=7.16	33918
21.4	36160		36233
23.38	38210		38135
24.59	39280		39282
26.57	41120		41135
$Q = -3.821*H_c^2 + 1131.43*H_c + 13770.64$			
14.66			43190
17.6	46150		46097
19.25	47780	V=10.28	47867
22.11	51190		51174
24.86	54690		54640
27	57500		57531
$Q = 18.52*H_c^2 + 390.35*H_c + 33490.63$			
18.86			64197
20.96	65240		65135
21.34	65260	V=13.09	65386
24.48	68450		68419
27	72080		72090
$Q = 86.65*H_c^2 - 3004.07*H_c + 90034.17$			
23.21	89580		89580
25.3	89490		89457
25.58	89490	V=16.17	89518
27.56	90480		90475
$Q = 117.60*H_c^2 - 5737.3*H_c + 159682$			

* H_{lmin} From model data
˜ H_{lmin} estimated from extrapolation of model data

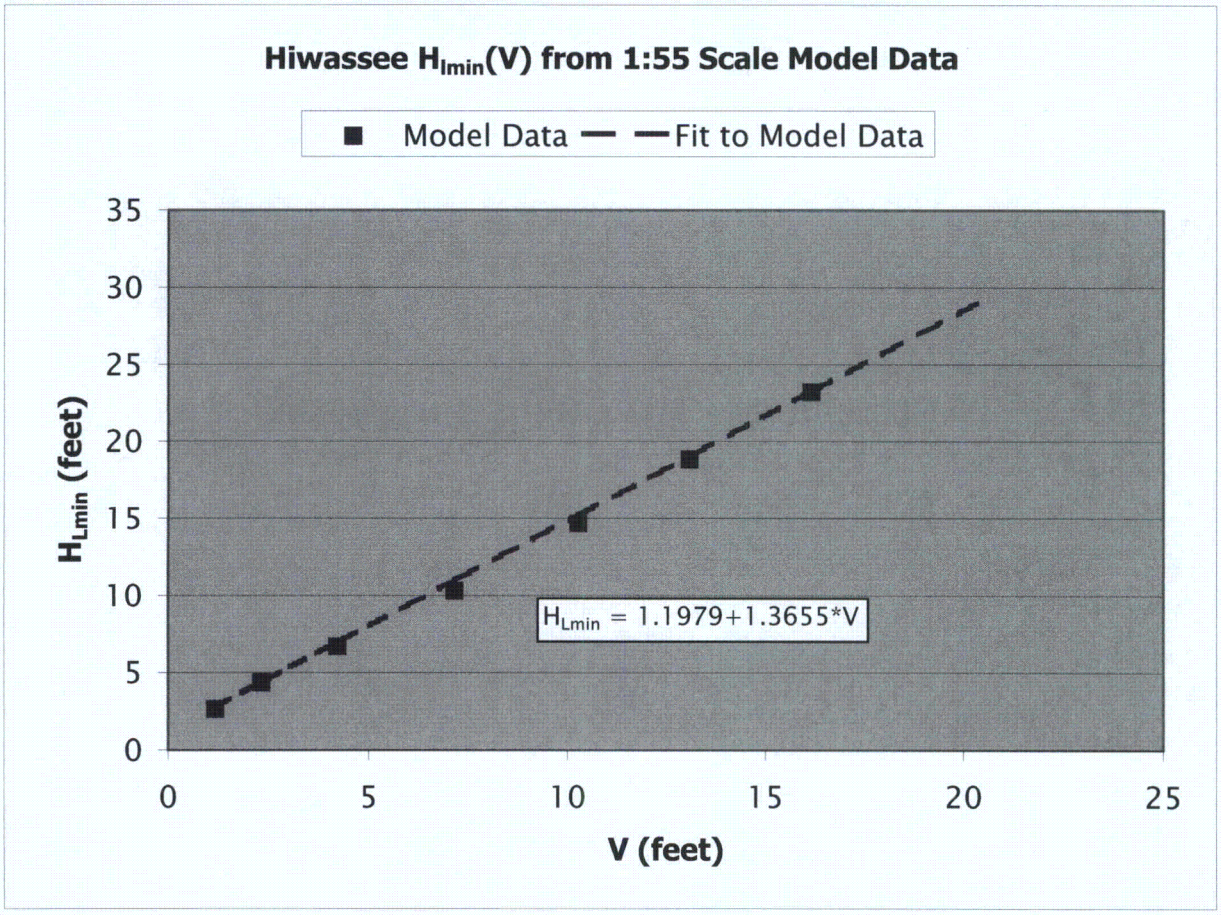
Hiwassee Spillway Rating Curve from 1:55 Scale Model Data



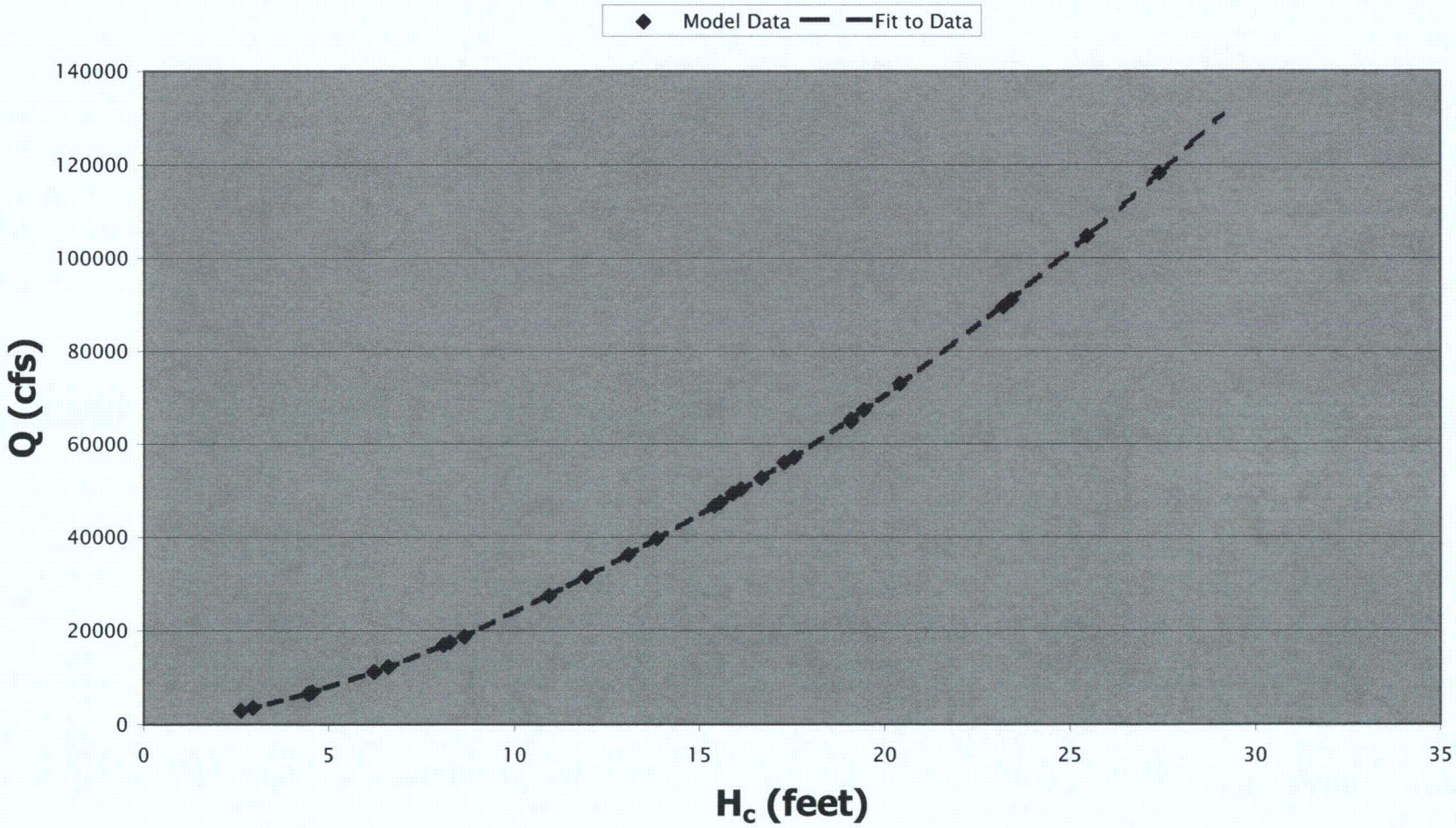
Hiwassee Project
Tainter Gates Partially Opened
Data from 1:55 scale model
EQUIVALENT PROTOTYPE

V data		H_{Lmin} data	H_{Lmin} fit	
1.17	*	2.64	2.80	
2.32	+	4.35	4.37	
4.22	+	6.67	6.96	
7.16	+	10.29	10.97	
10.28	+	14.66	15.24	
13.09	+	18.86	19.07	
16.17	*	23.21	23.28	
20.44			29.11	Extrapolated

* H_{lmin} From model data
+ H_{lmin} estimated from extrapolation of model data



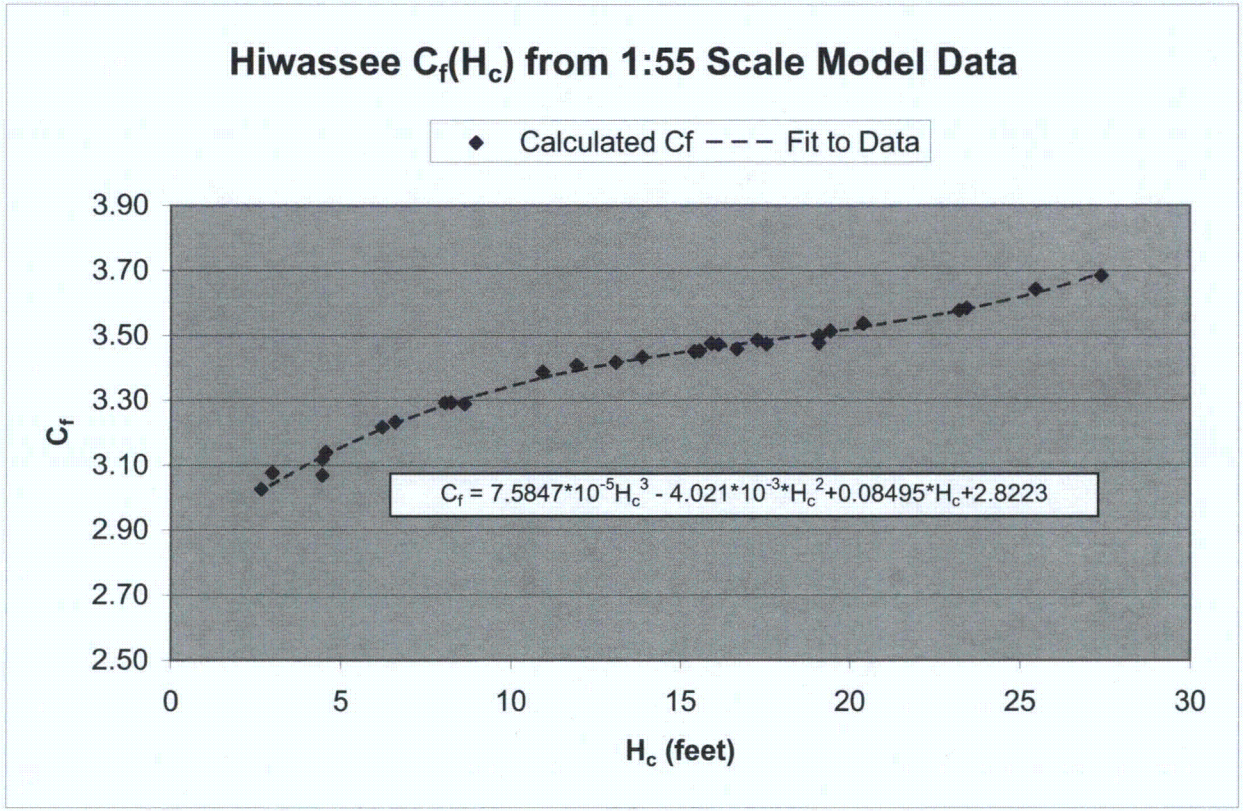
Hiwassee Free Discharge $Q(H_c)$ from 1:55 Scale Model Data



Hiwassee Project
Tainter Gates Fully Opened
Data from 1:55 scale model
EQUIVALENT PROTOTYPE
L = 224

Free Discharge

H_c data	Q data	C_f Calculated	C_f Fit
2.64	2907	3.03	3.02
2.97	3527	3.08	3.04
4.46	6578	3.12	3.13
4.46	6474	3.07	3.13
4.56	6849	3.14	3.13
6.22	11180	3.22	3.21
6.6	12280	3.23	3.23
8.08	16940	3.29	3.29
8.25	17480	3.29	3.29
8.64	18710	3.29	3.31
10.9	27460	3.39	3.37
11.9	31500	3.41	3.39
13.1	36250	3.42	3.42
13.9	39690	3.43	3.43
15.4	46710	3.45	3.45
15.6	47470	3.45	3.46
15.9	49350	3.47	3.46
16.1	50340	3.47	3.46
16.7	52680	3.46	3.47
17.3	56040	3.49	3.48
17.5	57160	3.47	3.48
19.1	64900	3.48	3.51
19.1	65310	3.50	3.51
19.4	67350	3.51	3.51
20.4	73000	3.54	3.53
23.2	89580	3.58	3.58
23.4	91060	3.58	3.58
25.5	104800	3.64	3.63
27.4	118300	3.68	3.69



Attachment 23 Hiwassee Model Data For Headwater Ratings, Gated Discharge Coefficient

Hiwassee Project
Tainter Gates Partially Opened
Data from 1:55 scale model
EQUIVALENT PROTOTYPE
L = 224

Gated Discharge Data

	Hc data	Q data	V	Hmp	Gn	Cg Calc
+	6.67	12439	4.22	1.999	4.473	0.7155
	10.34	15450	4.22	1.999	4.473	0.6653
	14.36	18400	4.22	1.999	4.473	0.6509
	17.49	20610	4.22	1.999	4.473	0.6513
	20.57	22500	4.22	1.999	4.473	0.6494
	24.20	24540	4.22	1.999	4.473	0.6478
	41.50					0.6460 #
+	10.29	25005	7.16	3.495	7.369	0.7243
	12.60	27410	7.16	3.495	7.369	0.6857
	15.24	30150	7.16	3.495	7.369	0.6641
	19.03	33920	7.16	3.495	7.369	0.6496
	21.40	36160	7.16	3.495	7.369	0.6451
	23.38	38210	7.16	3.495	7.369	0.6468
	24.59	39280	7.16	3.495	7.369	0.6456
	26.57	41120	7.16	3.495	7.369	0.6462
	41.50					0.6470 #
+	14.66	43190	10.28	5.060	10.491	0.7393
	17.60	46150	10.28	5.060	10.491	0.6911
	19.25	47780	10.28	5.060	10.491	0.6726
	22.11	51190	10.28	5.060	10.491	0.6574
	24.86	54690	10.28	5.060	10.491	0.6518
	27.00	57500	10.28	5.060	10.491	0.6510
	30.00					0.6490 #
	41.50					0.6490 #
+	18.86	64197	13.09	6.456	13.340	0.7602
	20.96	65240	13.09	6.456	13.340	0.7144
	21.34	65260	13.09	6.456	13.340	0.7054
	24.48	68450	13.09	6.456	13.340	0.6723
	27.00	72080	13.09	6.456	13.340	0.6632
	29.00					0.6610 #
	31.00					0.6590 #
	41.50					0.6590 #
*	23.21	89580	16.17	7.970	16.516	0.7729
	25.30	89490	16.17	7.970	16.516	0.7241
	25.58	89490	16.17	7.970	16.516	0.7183
	27.56	90480	16.17	7.970	16.516	0.6886
	29.25					0.6790 #
	31.00					0.6770 #
	33.00					0.6753 #
	41.50					0.6753 #
+	29.11	130869		10.029	21.065	0.7912
	32.00			10.029	21.065	0.7247 #
	33.50			10.029	21.065	0.7022 #
	34.00			10.029	21.065	0.6994 #
	34.50			10.029	21.065	0.6967 #
	41.50			10.029	21.065	0.6967 #

* H_{lmin} & Q From model data

\+ H_{lmin} & Q estimated from extrapolation of model data

\# C_g Estimated

Hiwassee Project
Tainter Gates Partially Opened
Data from 1:55 scale model
EQUIVALENT PROTOTYPE
L = 224

Gated Discharge Data

	Hc data	Q data	V	Hmp	Gn	Cg Calc
+	6.67	12439	4.22	1.999	4.473	0.7155
	10.34	15450	4.22	1.999	4.473	0.6653
	14.36	18400	4.22	1.999	4.473	0.6509
	17.49	20610	4.22	1.999	4.473	0.6513
	20.57	22500	4.22	1.999	4.473	0.6494
	24.20	24540	4.22	1.999	4.473	0.6478
	34.00					0.6460 #
+	10.29	25005	7.16	3.495	7.369	0.7243
	12.60	27410	7.16	3.495	7.369	0.6857
	15.24	30150	7.16	3.495	7.369	0.6641
	19.03	33920	7.16	3.495	7.369	0.6496
	21.40	36160	7.16	3.495	7.369	0.6451
	23.38	38210	7.16	3.495	7.369	0.6468
	24.59	39280	7.16	3.495	7.369	0.6456
	26.57	41120	7.16	3.495	7.369	0.6488
	34.00					0.6520 #
+	14.66	43190	10.28	5.060	10.491	0.7393
	17.60	46150	10.28	5.060	10.491	0.6911
	19.25	47780	10.28	5.060	10.491	0.6726
	22.11	51190	10.28	5.060	10.491	0.6574
	24.86	54690	10.28	5.060	10.491	0.6518
	27.00	57500	10.28	5.060	10.491	0.6510
	30.00					0.6500 #
	34.00					0.6490 #
+	18.86	64197	13.09	6.456	13.340	0.7602
	20.96	65240	13.09	6.456	13.340	0.7144
	21.34	65260	13.09	6.456	13.340	0.7054
	24.48	68450	13.09	6.456	13.340	0.6723
	27.00	72080	13.09	6.456	13.340	0.6632
	29.00					0.6570 #
	31.00					0.6540 #
	34.00					0.6590 #
*	23.21	89580	16.17	7.970	16.516	0.7729
	25.30	89490	16.17	7.970	16.516	0.7241
	25.58	89490	16.17	7.970	16.516	0.7183
	27.56	90480	16.17	7.970	16.516	0.6886
	29.25					0.6790 #
	31.00					0.6770 #
	33.00					0.6753 #
	34.00					0.6750 #
+	29.11	130869		10.029	21.065	0.7912
	32.00			10.029	21.065	0.7247 #
	33.50			10.029	21.065	0.7022 #
	34.00			10.029	21.065	0.6994 #
	34.50			10.029	21.065	0.6967 #

* H_{lmin} & Q From model data

\+ H_{lmin} & Q estimated from extrapolation of model data

\# C_g Estimated

Superceded in Rev 1
Included for Information Only

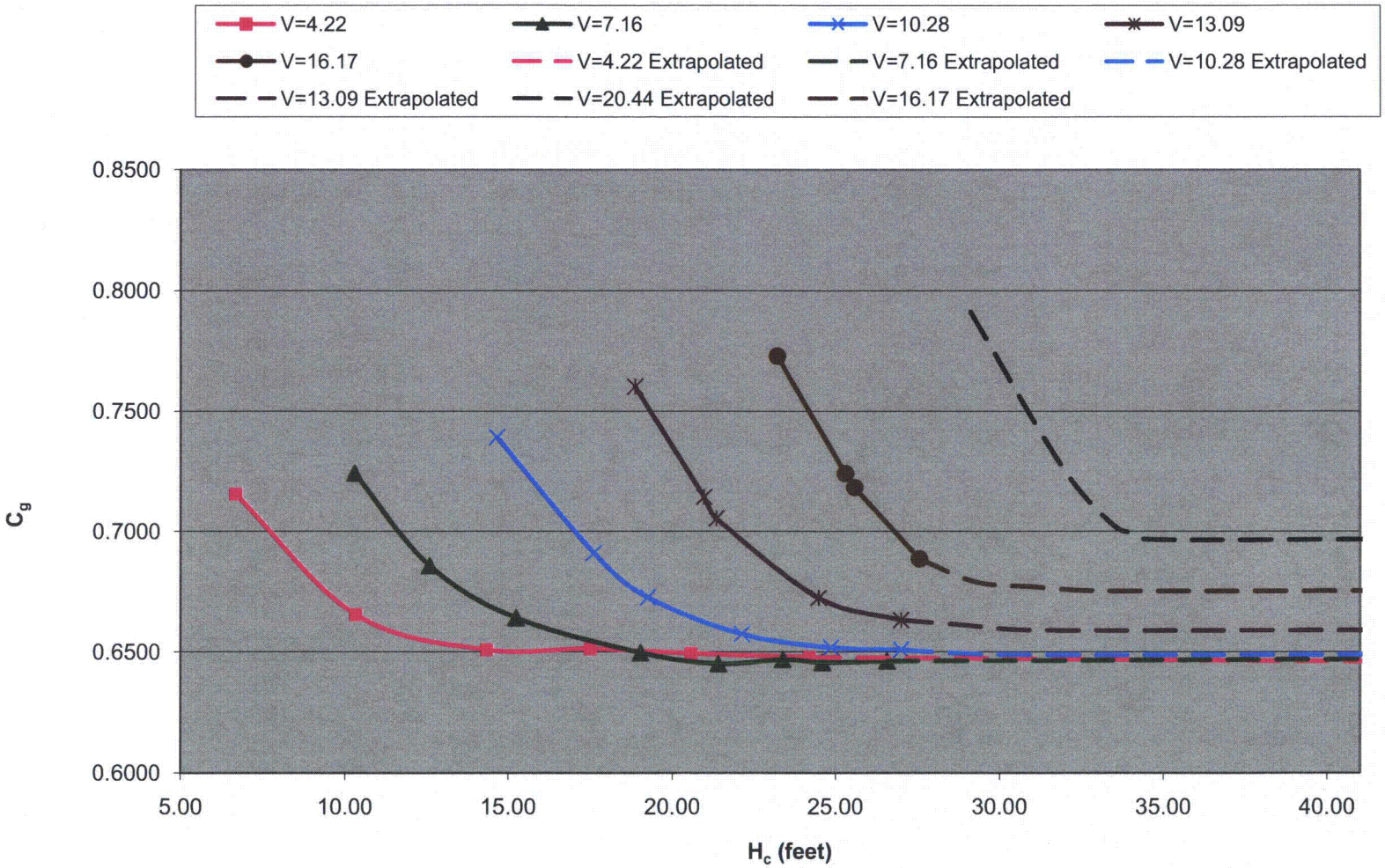
Attachment A13-2

Attachment 23 Hiwassee Model Data For Headwater Ratings, Cg Versus Hc

Calculation No: CDQ000020080012

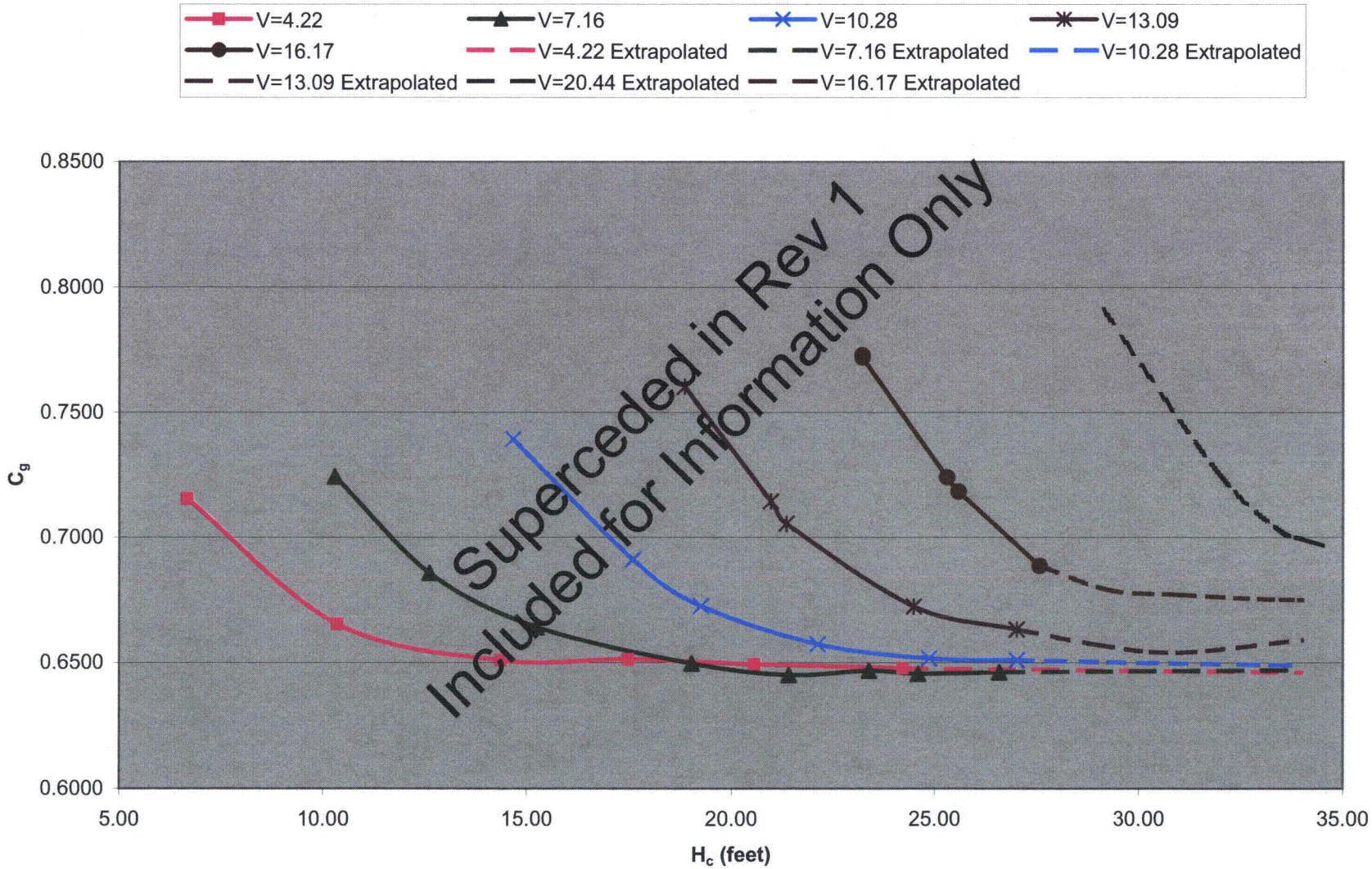
Page A31

Hiwassee $C_g(H_c)$ Estimated from 1:55 Scale Model Data



Attachment 23 Hiwassee Model Data For Headwater Ratings.xls, Cg Versus Hc

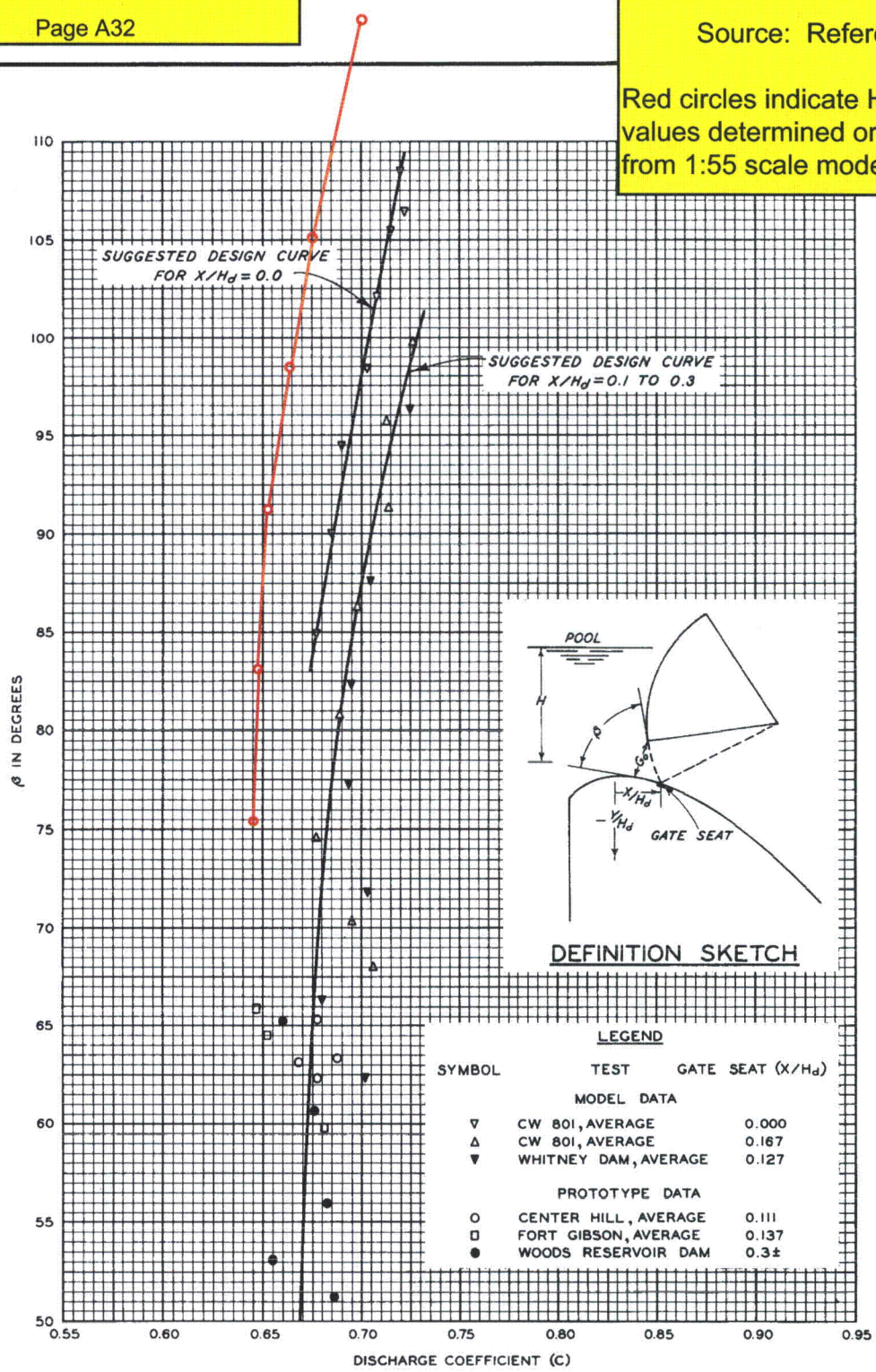
Hiwassee $C_g(H_c)$ Estimated from 1:55 Scale Model Data



Attachment A14

Source: Reference A2

Red circles indicate Hiwassee values determined or estimated from 1:55 scale model data



FORMULA

$$Q = CG_oB\sqrt{2gH}$$

WHERE:

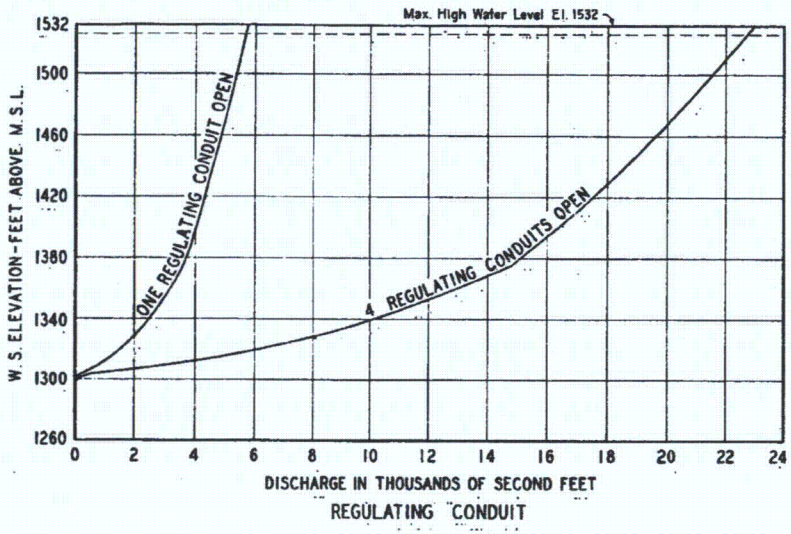
G_o = NET GATE OPENING
B = GATE WIDTH
H = HEAD TO CENTER OF GATE OPENING

TAINTER GATES ON SPILLWAY CRESTS

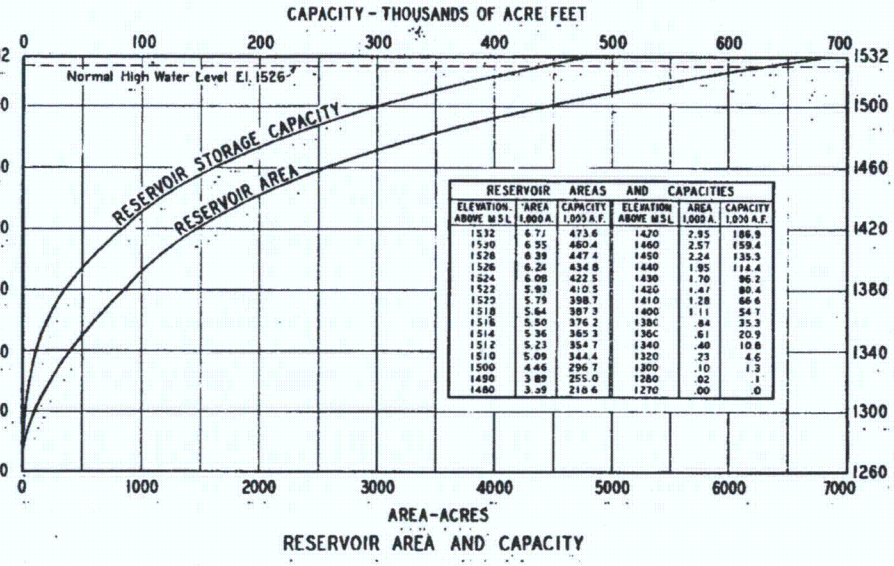
DISCHARGE COEFFICIENTS

HYDRAULIC DESIGN CHART 311-1

WES 3-56

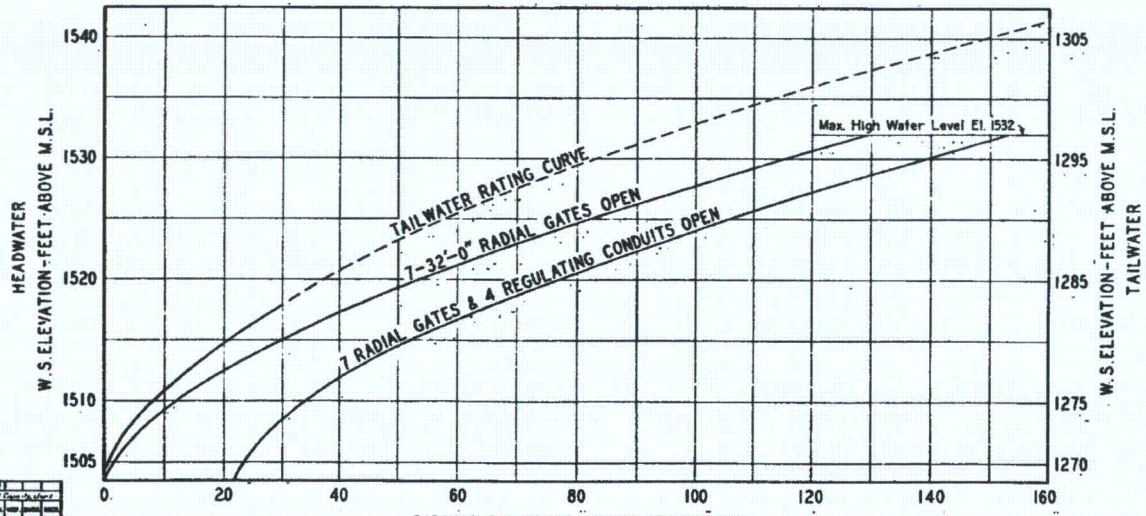


REGULATING CONDUIT



RESERVOIR AREA AND CAPACITY

RESERVOIR AREAS AND CAPACITIES					
ELEVATION ABOVE M.S.L.	AREA 1,000 A.	CAPACITY 1,000 A.F.	ELEVATION ABOVE M.S.L.	AREA 1,000 A.	CAPACITY 1,000 A.F.
1532	6.71	473.6	1470	2.95	186.9
1530	6.55	460.4	1460	2.57	159.4
1528	6.39	447.4	1450	2.24	135.5
1526	6.24	434.8	1440	1.95	114.4
1524	6.08	422.5	1430	1.70	96.2
1522	5.93	410.5	1420	1.47	80.4
1520	5.79	398.7	1410	1.28	66.6
1518	5.64	387.3	1400	1.11	54.7
1516	5.50	376.2	1380	.84	35.3
1514	5.36	365.3	1360	.61	20.9
1512	5.23	354.7	1340	.40	10.8
1510	5.09	344.4	1320	.23	4.6
1500	4.46	296.7	1300	.10	1.3
1490	3.89	255.0	1280	.02	.1
1480	3.39	218.6	1270	.00	.0



SPILLWAY AND TAILWATER

EQUATIONS AND ASSUMED LOSSES:

SPILLWAY

$Q = \frac{CLH^{1.5}}{D^{0.12}} = 569.36H^{1.5}$ (R.N. Brudenell, Univ. of Iowa)

Where

C = 3.80 This value determined and the computed discharge checked by model tests in the T.V.A. Hydraulic Laboratory.

L = Length of Crest = 224'

D = Design Head on Crest = 28.5'

H = Actual Head on Crest

$H_d = 28.5'$

REGULATING CONDUIT

Entrance Loss $= 0.05\frac{V^2}{2g}$

Friction Loss $= \frac{2.87n^2 L V^2}{D^{4/3}}$ (Manning's Formula)

Nozzle Loss $= \left(\frac{1}{C_v^2} - 1\right)\frac{V_1^2}{2g}$

Where

V = Velocity in Pipe

V_1 = Velocity at Small End of Nozzle (Dia. = 7'-10")

n = 0.010

L = Length of Straight Pipe = 180.5'

D = Diameter of Pipe = 8'-6"

C_v = 0.98 (King's Handbook of Hydraulics, Pg. 58)

NOTE:
Solid portion of tailwater rating curve is based on actual gage readings; dashed portion is estimated by area-mean depth method.

REFERENCE DRAWINGS:
301 M1 ... Reservoir Areas and Volumes.
C-85365 ... Tailwater Rating Curve.

DAM
HYDRAULICS

AREA, CAPACITY & DISCHARGE CURVES

HIWASSEE PROJECT
TENNESSEE VALLEY AUTHORITY
ENGINEERING DESIGN DEPARTMENT

SUBMITTED	RECOMMENDED	APPROVED
Lucie Pierce	Ross M. Riegel	[illegible]

KNOXVILLE 12-19-37 S. C. A. 10K214-R1

Attachment A15
Source: Reference A6

Calculation No: CDQ00002008012
Page A33

A 489 (EN DES-11-76)

SHEET B 1 OF B7

DAM RATING CURVE - HIWASSEE

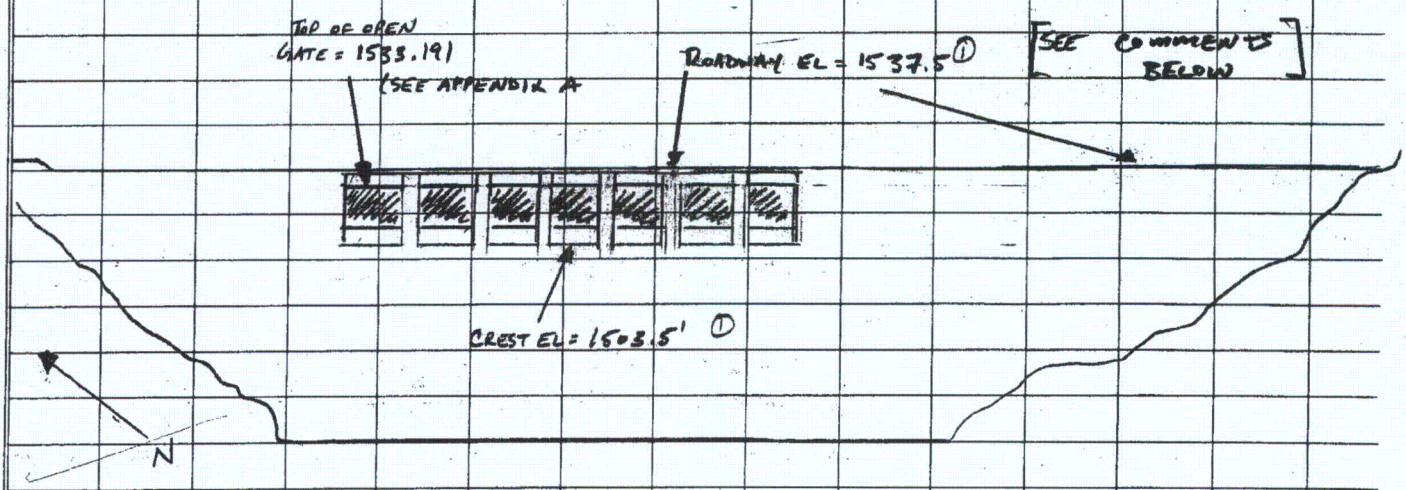
HIWASSEE - DAM PROFILE.

COMPUTED CTS DATE 11/12/2008

CHECKED JBM DATE 12/18/2008

DRAWINGS

1	10M201	R5	(REF 5, ATT 6)	5	21N206	R5	(REF 3, ATT 4)
2	14W372	R8	(REF 12, ATT 11)	6	21N213	R5	(REF 14 ATT 15)
3	51W206	R5	(REF A5, ATT A8)	7			
4	21N217	R4	(REF 4, ATT 5)				



DAM PROFILE

~~THE ROADWAY ELEVATION VARIES ACROSS THE ENDS OF THE DAM (BLOCKS 1-4 AND 25-27) HOWEVER, THE MAXIMUM ROADWAY ELEVATIONS IN THESE BLOCKS ARE SUFFICIENT TO PREVENT OVERTOPPING AT THE PMF ELEVATION OF 1537.5' (SEE 1, 5, 6). REGARDLESS OF ROADWAY ELEVATION, THE CONCRETE CURBING ON EITHER SIDE OF THE ROADWAY WOULD PREVENT OVERFLOW~~

~~THE ROADWAY ACROSS THE MIDDLE PORTION OF THE DAM (BLOCKS 5-24) IS AT AN ELEVATION OF 1537.5' (WITH SLIGHT SLOPING TO THE CENTERLINE OF THE ROAD 5, 1). THE CONCRETE CURBING ON EITHER SIDE OF THE ROADWAY (EL - 1540.42') WOULD PREVENT OVERFLOW AT THE PMF HW~~

This comment no longer applies to Rev 1, when maximum headwater elevation is equal to 1545'
Revision 1
Author: CTS Date: 2/6/09
Checked: SEM Date:2/9/09

DAM RATING CURVE - HIWASSEE

HIWASSEE - FLOW OVER WIDE-OPEN TAINTER GATES

COMPUTED CTS DATE 11/12/2008

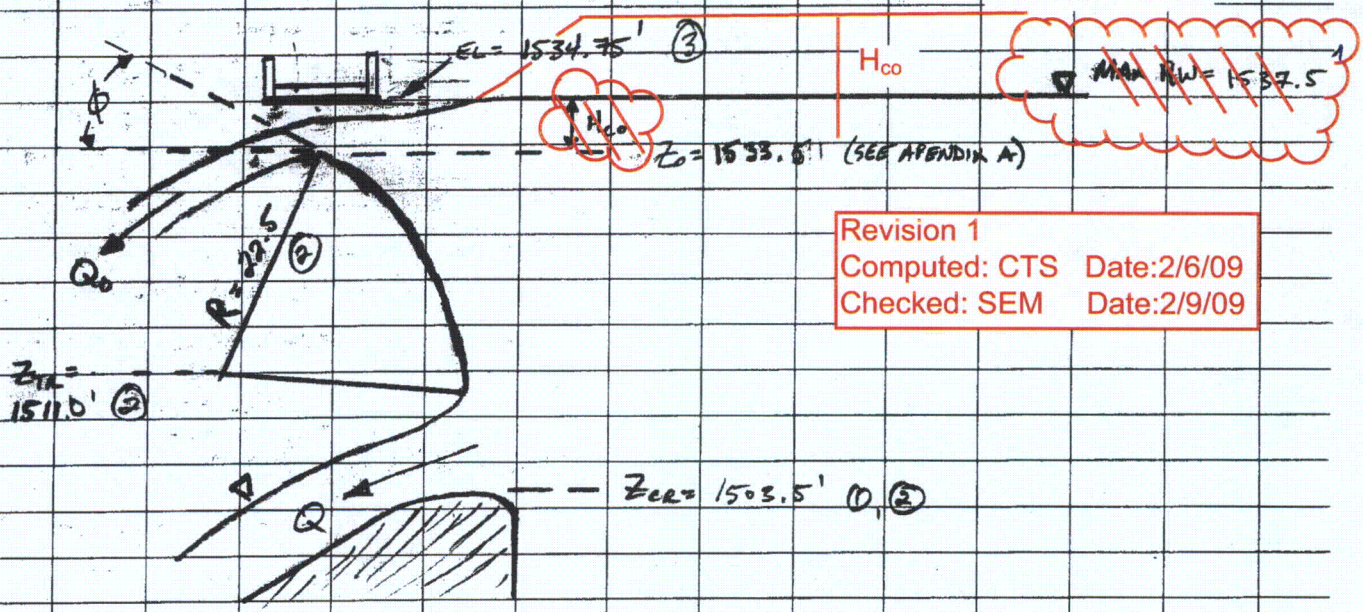
CHECKED JBM DATE 12/18/2008

WITH REFERENCE TO THE SKETCH BELOW, DISCHARGE OVER THE TOPS OF THE OPEN TAINTER GATES IS COMPUTED AS

$$Q_o = C_o L_o H_{co}^{3/2}$$

WHERE L_o = TOTAL LENGTH OF OVERFLOWING GATES = SPILLWAY LENGTH = 224'

Max HW=1545'



Revision 1
Computed: CTS Date:2/6/09
Checked: SEM Date:2/9/09

A REASONABLE APPROACH TO SPECIFYING C_o IS TO USE DISCHARGE COEFFICIENTS FOR DRUM GATES WHICH PRESENT THE SAME CIRCULAR SURFACE TO OVERFLOW. DISCHARGE COEFFICIENTS FOR DRUM GATES ARE AVAILABLE IN REF 11, ATT 10

$$C_q = C_q(\theta, H/r)$$

WHERE $C_q = C_o$ AS IN ABOVE EQUATION

$\theta = \phi$ AS ABOVE (SEE ATT A6 IN APPENDIX A)

$H = H_{co}$ AS ABOVE

$r = R$ = GATE RADIUS = 22.5' (SEE ATT 11)

ANGLE $\phi = \tan^{-1}\left(\frac{x_o}{y_o}\right)$ WITH $x_o = R\cos(\theta - \alpha)$, $y_o = Z_o - Z_{TR}$ } SEE ATT A6 IN APPENDIX A

FOR MAX V

$x_o = 22.5' \cos(64.393° - (-35.107°)) = -3.714$

$y_o = 1533.5 - 1511 = 22.5$

DAM RATING CURVE - HIWASSEE

HIWASSEE - FLOW OVER WIDE OPEN TAINTER GATES

COMPUTED CTS DATE 11/12/2008

CHECKED JBM DATE 12/18/2008

Revision 1
Computed: CTS Date:2/6/09
Checked: SEM Date: 2/9/09

$$\phi = \tan^{-1}\left(\frac{-3.714}{22.15}\right) = -9.371^\circ$$

HEADWATER RATING CURVE COMPUTED TO HW EL = 1545'

$$0 \le H_{co} \le 1545' \quad -1533.5'$$

$$0 \le H_{co} \le 11.5'$$

AND

$$0 \le H/r \le \frac{11.5'}{22.5'} = 0.511$$

FROM REF 11, ATT 10, FIGURE 6

$$\frac{H}{r} \sim 0.05 \longrightarrow 3.02 < C_q < 3.55 \quad \frac{H}{r} \sim 0.511$$

$$\boxed{C_o = 3.1}$$

FOR HEADWATER RATINGS, IT IS BETTER TO USE VALUES NEAR THE LOW END FOR ALL HEADS. THIS IS BECAUSE UNCERTAINTIES AND THE MAGNITUDE OF THE OVERFLOW DISCHARGE DO NOT JUSTIFY FURTHER REFINEMENT. THE LOW END IS USED BECAUSE THE OVERFLOW Q IS PROBABLY LESS THAN DRUM GATE Q. THE REASONING IS

- AT SOME POINT, THE OVERFLOW MAY TRANSITION TO ORIFICE DISCHARGE RATHER THAN FREE DISCHARGE, HOWEVER, NO MODEL DATA EXISTS TO PREDICT THE TRANSITION POINT (HW EL.). ORIFICE FLOW WILL RESULT IN SMALLER Q AS RESISTANCE TO FLOW INCREASES DURING ORIFICE DISCHARGE.

- OVERFLOW DISCHARGE IS < 12% OF TOTAL DAM DISCHARGE (SEE RESULTS) SO SMALL VARIATIONS IN C_o HAVE NEGLIGIBLE EFFECTS ON TOTAL DAM DISCHARGE (10% CHANGE IN $C_o \Rightarrow \frac{.1}{3.1}(12\%) \approx 0.4\%$)

- FLOW UNDER GATE CAUSES SIGNIFICANT DRAWDOWN IN WATER LEVEL UPSTREAM FROM THE GATE WHICH SHOULD RESULT IN LESS OVERFLOW THAN PREDICTED FOR AN EQUIVALENT DRUM GATE

Appendix B: Overflow Parameters

Reference Drawings

1. TVA drawing no. 21N217 R4 (Ref. 4, Att. 5)
2. TVA drawing no. 21N206 R5 (Ref. 3, Att. 4)
3. TVA drawing no. 51N228 R3 (Ref. 18, Att. B1)
4. TVA drawing no. 31N221 R0 (Ref. 19, Att. B2)
5. TVA drawing no. 10M200 R5 (Ref. 20, Att. B3)
7. TVA drawing no. 21N213 R5 (Ref. 14, Att. 15)
8. TVA drawing no. 21N218 R7 (Ref. 21, Att. B4)
9. TVA drawing no. 10M201 R5 (Ref. 5, Att. 6)

Refer to Hydraulic Design Chart 711 (Attachment B5) for values of free flow discharge coefficient, C_f. The maximum headwater elevation used in this rating is 1545'.

Flow Over the Tops of the Blocks 2-7, 17-26, and portions of blocks 8 and 16

The width of the overflow section is taken as the width of the roadway. According to Attachment 5, the width of the roadway varies as it follows curves over blocks 2 through 5 and 25 through 27. At block 2, the width of the roadway is 34.25' (Att. 5). The roadway is 29 feet wide between blocks 5-7 and 20-24 (Attachment 4) and over the penstock intake in blocks 17-19 and portions of blocks 8 and 16 (Attachment B2). The roadway widens again as it traverses over blocks 25-26 with the width gradually increasing from 29' to 33' (Attachment 5). The increases in the width on the north and south abutments are neglected. Therefore, B is reasonably estimated as 29'.

The overflow elevation across this section also slightly varies. According to Attachments 4 and 5, the parapet on the upstream side of the dam will determine the elevation at which overflow occurs. For Blocks 5-7 and 20-24, the top of the upstream parapet is at 1540.42'. The parapet rises slightly as either end of the dam is neared to an elevation of 1540.74' at blocks 2 and 26. For the sake of this calculation, the slight rise in the parapet at the ends of the dam will be ignored. The overflow elevation for this section of dam is therefore 1540.42'.

$$0 \le \frac{H_c}{B} \equiv \frac{H_1}{B} \le \frac{1545' - 1540.42'}{29'}$$

$$0 \le \frac{H_c}{B} \le 0.158$$

$$C_f = 2.65$$

Because the C_f value determined for this section of the dam is the minimum value (2.65), the increases in width of the roadway on the approach curves has no effect on the calculated free discharge coefficient.

The overflow length can be determined from Attachment B3.

L = 429.75'(length of axis of dam between blocks 0 and 8) - 44.75'(upstream length of block 0) – 35' (upstream length of block 1) – 25' (Length of Emergency Gate Storage Chamber, scaled) + 407.292' (length of axis of dam between blocks 20 and 27) + 50' (length of block 19) + 50' (length of block 18) + 50' (length of block 17) + 40' (length of block 16) – 25' (length of Equipment Shaft Hatch, scaled) – 62.292' (length of block 27) = 835'

Flow Over the Spillway Bridge/Piers

Flow over the piers will be controlled by flow over the roadway and roadway parapets. The width of the roadway over the spillway is shown in Attachment B1 (B=35.75'). According to Attachment B3, the Conduit Emergency Gate Storage Chamber (in block 8) and the Equipment Shaft Hatch (in block 16) are slightly wider than the roadway over the spillway, however, these sections will be lumped into this analysis (justified below).

The overflow elevation is shown in Attachment B1 (1540.42')

$$0 \le \frac{H_c}{B} \equiv \frac{H_1}{B} \le \frac{1545' - 1540.42'}{35.75'}$$

$$0 \le \frac{H_c}{B} \le 0.128$$

$$C_f = 2.65$$

Because the C_f value determined for this section of the dam is the minimum value (2.65), the increase of width in blocks 8 and 16 due to the storage chamber and equipment shaft has no effect on the calculated free discharge coefficient.

The overflow length can be determined from Attachment B3.

L= 260' (length of Spillway) – 7*32' (length of spillway bays, Attachment 6) + 25' (Conduit Emergency Gate Storage Chamber) + 25' (Equipment Shaft Hatch) = 86'

Because the spillway bridge, block 2-7, 17-26, and potions of blocks 8 and 16 share a common value for C_f and overflow elevations, these sections can be combined. The properties for the non-overflow dam are therefore:

$C_f = 2.65$
$Z_c = 1540.42'$
L = 835' + 86' = 921'

Flow Over the Blocks 0, 1, and 27, (Abutment Sections)

The width of blocks 0 and 1 is 37' (Attachment 5), while the width of block 27 is 38' (Attachment 15). The discharge coefficient will be calculated with B=37' and will be shown to be insensitive to variations in width.

The overflow elevation as shown in Attachments 5 and 15 is 1542.57'

$$0 \le \frac{H_c}{B} \equiv \frac{H_1}{B} \le \frac{1545' - 1542.57'}{37'}$$

$$0 \le \frac{H_c}{B} \le 0.066$$

$$C_f = 2.65$$

Because the C_f value determined for this section of the dam is the minimum value (2.65), the increase of width in block 27 has no effect on the calculated free discharge coefficient.

The length of this section is determined from Attachment B3.

L = 44.75' (length of block 0) + 35' (length of block 1) + 30' (scaled length of block 27 from intersection with block 26 to intersection with 1545' elevation contour) = 109.75

Flow around North End of Hiwassee Dam

At high headwater elevation, flow may also pass between the parking area and the roadway on the north end of Hiwassee Dam. The discharge will be bottlenecked through the path bounded by block 0 and the parking area, therefore the characteristic length for discharge is the distance between the upstream wall of block 0 and the 1545' contour around the parking area (See Attachment B4). The overflow channel will be taken as rectangular (the sloping on the parking area is neglected), and overflow will occur when the headwater elevation is equal to the elevation of the sidewalk bounding the roadway (1538.57', Attachment 5). For overflowing discharge, B=98' as determined in Attachment B4 (approximate length from the 1545' contour to the drop beyond the furthest sidewalk).

$$0 \le \frac{H_c}{B} \equiv \frac{H_1}{B} \le \frac{1545' - 1538.57'}{98'}$$

$$0 \le \frac{H_c}{B} \le 0.066$$

$$C_f = 2.65$$

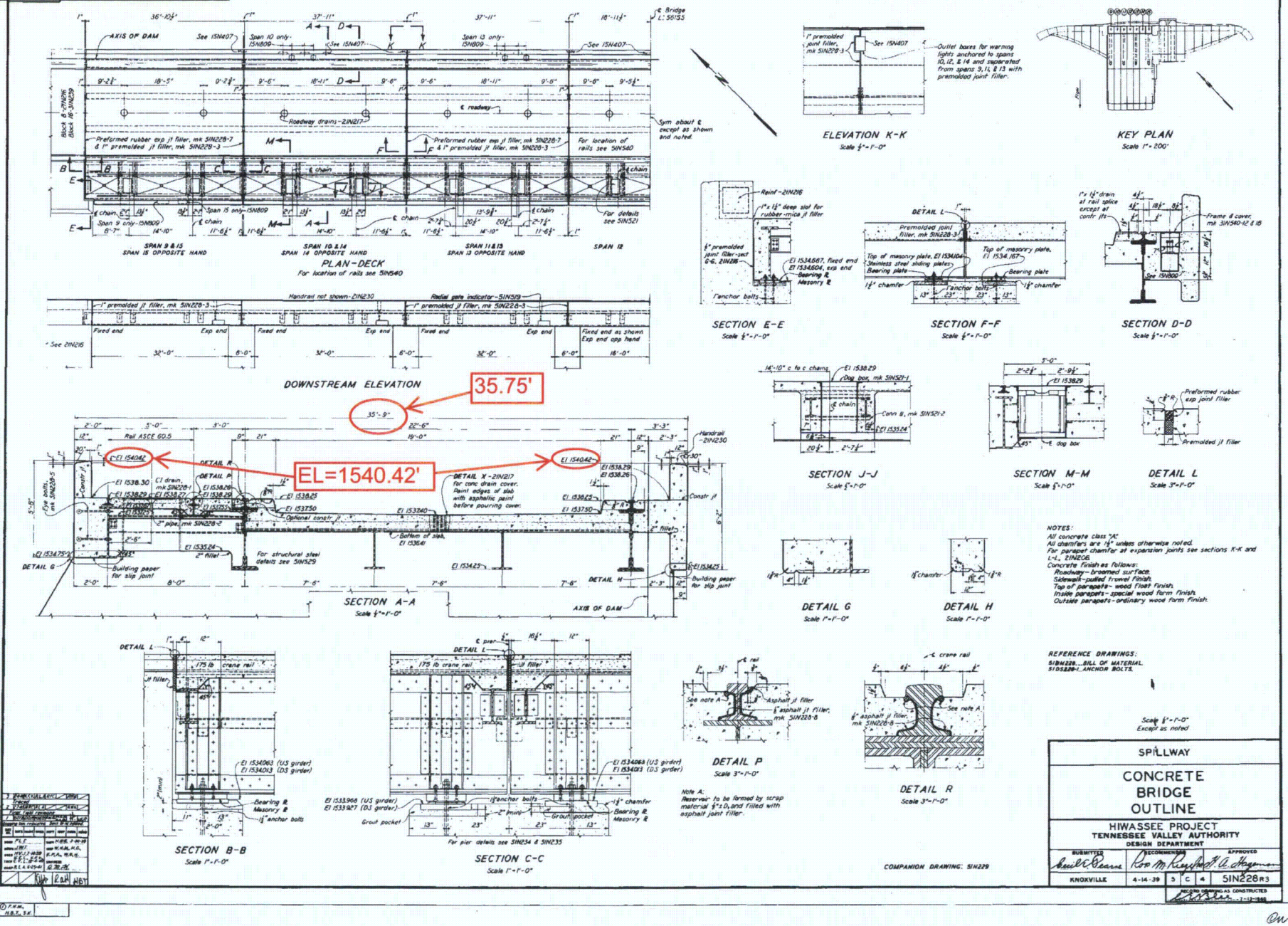
And L = 34' (Attachment B4, width of bottleneck channel)

Attachment B1

Source: Reference 18

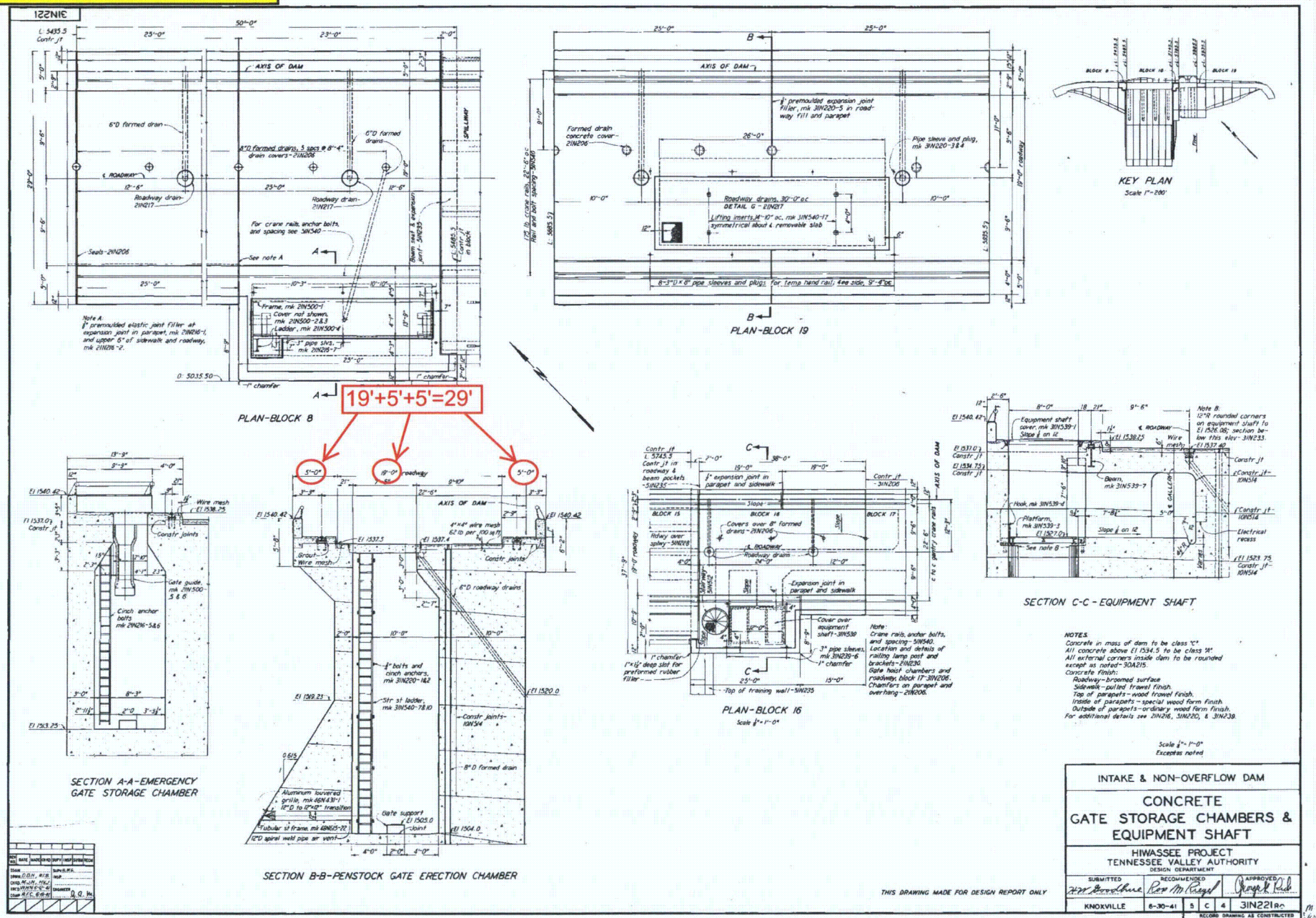
Calculation No: CDQ000020080012

Page B8

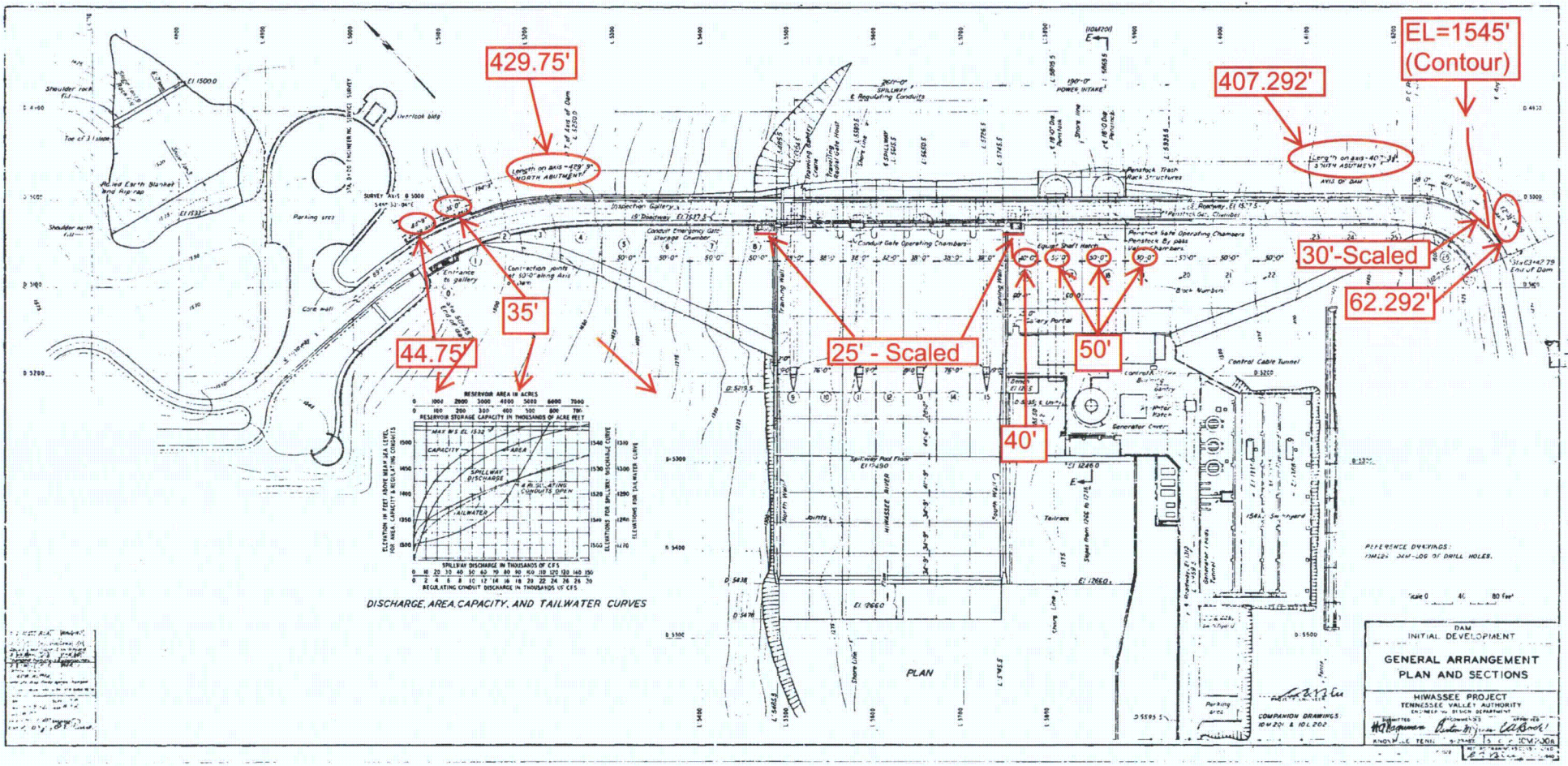


Attachment B2
Source: Reference 20

Calculation No: CDQ000020080012
Page B9



Attachment B3
Source: Reference 19



Attachment B-4

Source: Reference 21

Calculation No: CDQ000020080012

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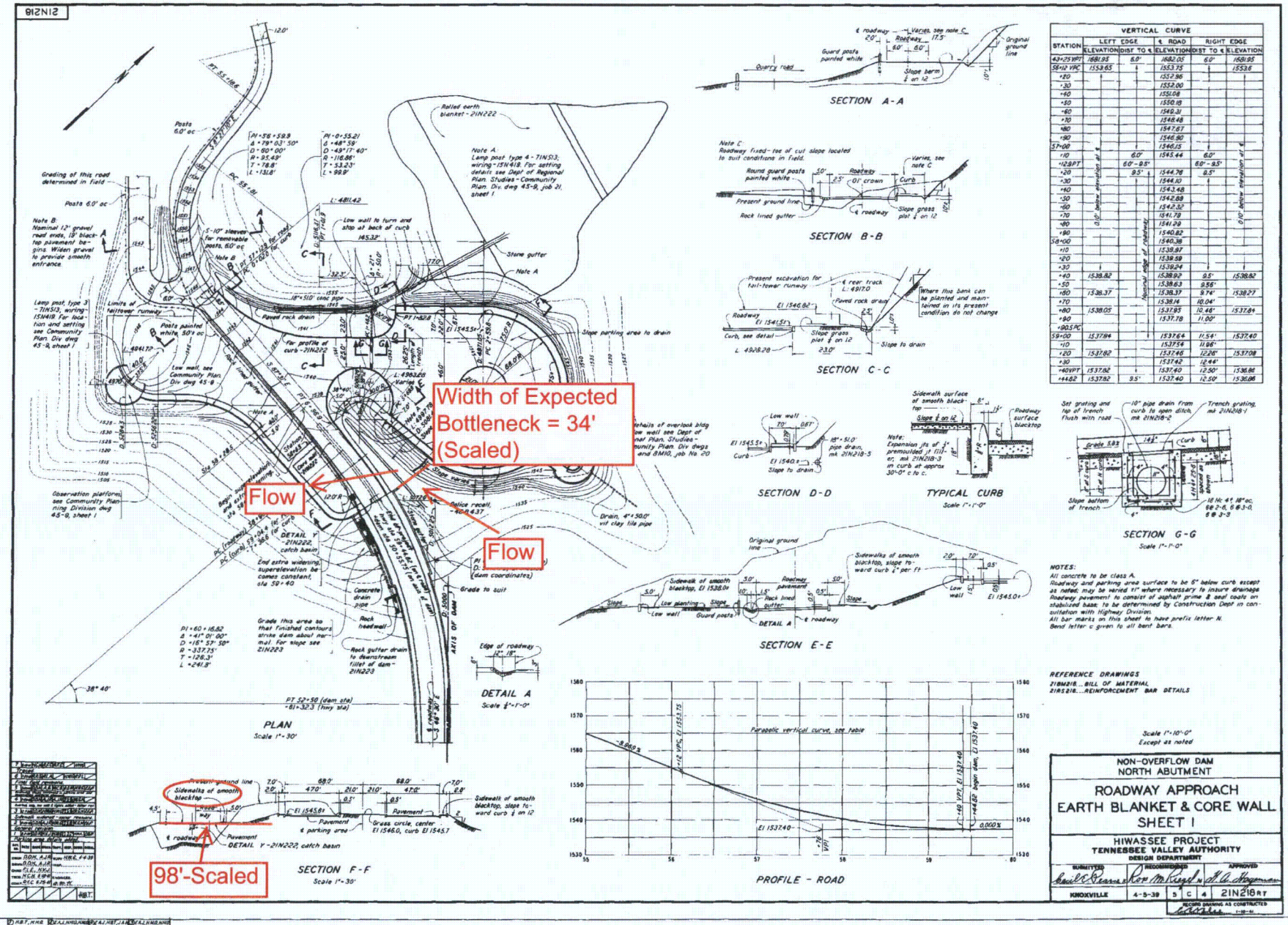
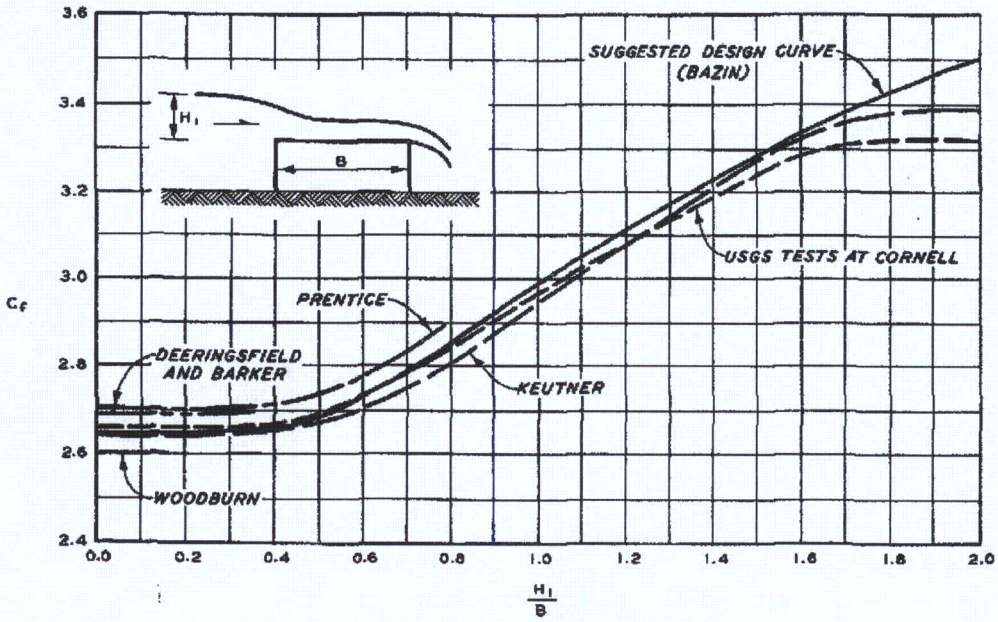
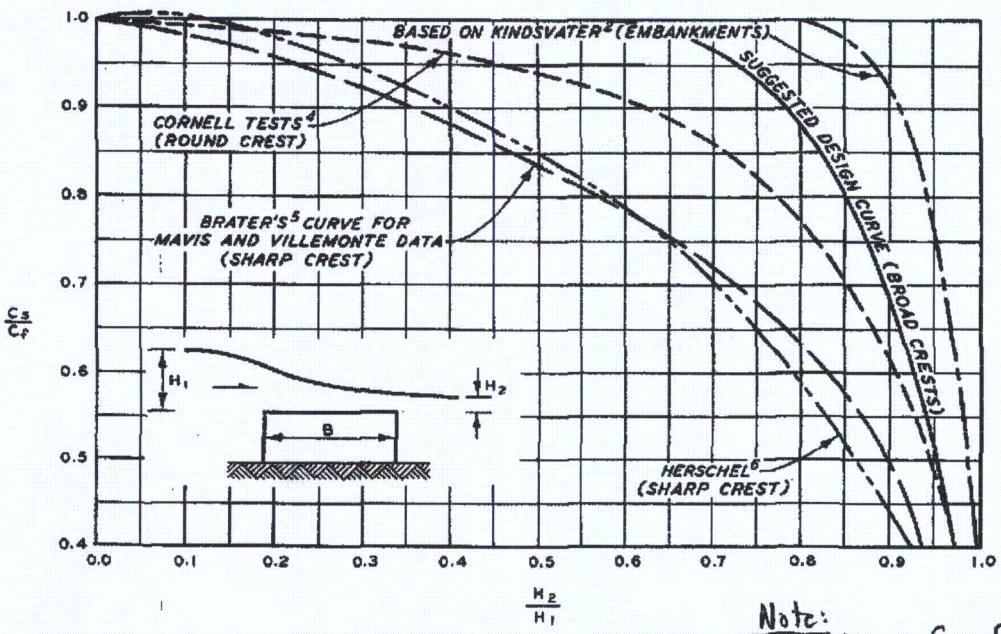


Attachment B5

Source: Reference 8



a. FREE FLOW



b. SUBMERGED FLOW

Note:
$H_1 \equiv H_c$
$H_2 \equiv d$
$\frac{C_s}{C_f} \equiv S_f$

NOTE: C_f = FREE-FLOW COEFFICIENT
C_s = SUBMERGED-FLOW COEFFICIENT
NEGLIGIBLE VELOCITY OF APPROACH
RAISED NUMBERS ON SUBMERGED FLOW CHART ARE REFERENCE NUMBERS FROM TEXT.

LOW-MONOLITH DIVERSION
DISCHARGE COEFFICIENTS

HYDRAULIC DESIGN CHART 711

PREPARED BY U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION, VICKSBURG, MISSISSIPPI

WES 1-66

Appendix C: Quantifying Effects of Tailwater Rating Curve on Sluice Flow.

From Equations (3) and (4), and the minimum headwater under investigation in this calculation (See Sections 4 and 7 for values of HW, Z_{Ref} and TW, Case 1)

$$\frac{Q_s}{Q_{sl}} - 1 = \left(\frac{4K\sqrt{HW - Z_{Ref}}}{4K\sqrt{HW - TW + 3.485}} - 1 \right) * 100\% = \left(\sqrt{\frac{1500 - 1265.29}{1500 - 1303.4 + 3.485}} - 1 \right) * 100\% = 8\%$$

Therefore, sluice flow calculated when neglecting tailwater effects is 8% larger than sluice flow which accounts for tailwater effects at this particular headwater elevation.

From the calculations results (See Section 7)

$$\frac{Q_{s1}}{Q} = \frac{19402}{28.64 * 1000} * 100\% = 67.7\%$$

Therefore sluice flow accounts for 67.7% of the total discharge past the dam at the minimum headwater elevation of this calculation. Neglecting tailwater effects on the sluice flow would therefore result in a 5.4 % change in the total discharge past the dam (0.677*0.08 = 0.054). The impact of neglecting tailwater effects on sluice flow at all headwater elevations is contained in Table C1. As evident from Table C1, the tailwater curve has minimal impact on sluice flow for Hiwassee Dam for Case 1. Case 2 will have similar results.

Table C1: Impact of Tailwater Rating Curve on Headwater Rating Curve Due to Sluice Discharge

HW	TW	((No TW) / TW)-1	Qs1/Q	Impact on Rating Curve
ft	ft	%	%	%
1500	1303.4	8%	67.7%	5.6%
1503.5	1303.5	8%	67.7%	5.5%
1504	1303.5	8%	67.2%	5.5%
1505	1303.8	8%	65.0%	5.3%
1506	1304.2	8%	62.0%	5.1%
1507	1304.8	8%	58.6%	4.9%
1508	1302.8	8%	74.8%	5.9%
1510	1304.3	8%	62.4%	5.1%
1512	1306.0	9%	52.0%	4.4%
1514	1307.9	9%	43.7%	3.9%
1516	1309.8	9%	37.1%	3.5%
1518	1311.8	10%	31.8%	3.1%
1520	1313.8	10%	27.6%	2.8%
1522	1315.8	11%	24.2%	2.6%
1524	1317.7	11%	21.3%	2.4%
1526	1319.7	11%	18.9%	2.2%
1528	1321.7	12%	16.9%	2.0%
1529	1322.7	12%	15.9%	1.9%
1530	1323.7	12%	15.1%	1.9%
1532.61	1326.2	13%	13.2%	1.7%
1533.5	1326.2	13%	13.2%	1.7%
1534	1326.2	13%	13.3%	1.7%
1535	1326.2	13%	13.3%	1.7%
1536	1326.3	13%	13.2%	1.7%
1537	1326.6	13%	13.1%	1.7%
1538.57	1327.5	13%	12.6%	1.6%
1539	1327.8	13%	12.4%	1.6%
1540.42	1328.7	13%	11.8%	1.5%
1541	1329.3	13%	11.6%	1.5%
1542.57	1331.4	14%	10.6%	1.4%
1543	1332.1	14%	10.3%	1.4%
1544	1333.9	14%	9.7%	1.4%
1545	1336.1	15%	9.0%	1.3%

Appendix D: Hydrostatic Loads on the Spillway Tainter Gates

The Hydrostatic loads on the spillway tainter gates for Hiwassee Dam can be found in the following calculations.

D1 References

D1. "Watts Bar Dam – Flood and Earthquake Analysis on Radial Spillway Gates, pages 76-100" Tennessee Valley Authority, HEPE3WBHSQN-WBNBLNBFN.

D2 Calculations

Reference D1 evaluates the structural capacity of the radial spillway gates at Watts Bar Dam. This reference was used as a basis for evaluating the margin between the forces on the closed gates (FR_{closed}) when the headwater elevation is at the top of the gate (1526.53 feet) and when the gates are completely open (FR_{open}) and the headwater elevation is at 1542.00 feet. The margin is defined at the ratio of FR_{open} to FR_{closed}. The calculation of these forces and the results of this comparison are shown in Figure D1.

Hiwassee Hydrostatic Forces on Gates

Comparison of forces when gates are closed and HW is at 1526.53 feet (top of gate) vs. when gates are fully open and HW at an elevation of 1542.00 feet.

Attribute	Symbol	Value	Unit
top elev	Zo	1526.53	ft
trun elev	Ztr	1511.00	ft
sill elev	Zsill	1503.03	ft
radius	R	22.50	ft
length	L	32.00	ft
angle up	α2	43.65	deg
angle lwr	α	20.75	deg
angle tot	θ	64.39	deg
area of lower slice	Aslice1	284.48	ft^2
proj area	AProjected	752.00	ft^2
Desgn LdH	FRx	551366.40	lbs
Result elv	Z1	1510.86	ft
Result ang deg		0.35	deg
Result ang rad		0.01	rad
Result Dsgn	Horiz	551356.23	lbs
Area slice upper	Aslice2	192.83	ft^2
Area triangle	Atriangle	126.42	ft^2
project vert	x1	6.22	ft
vert weight water	FRy	60251.12	lbs
Resultant load - Gates Closed	FR_{closed}	**554648.63**	lbs
vert open fm calc	calc App A	20.44	ft
max hw	calc	1542.00	ft
lwr lip elev	Z2	1523.47	ft
bot angle	α3	33.66	deg
top elev	Zo	1533.28	ft
project area for h lc	AProjected	313.86	ft^2
Flood LdH	FRx	266864.39	lbs
Height over gate	y1	8.72	ft
Height ratio to orig		1.66	(ratio)
project vert	x2	21.88	ft
Flood LdV1		381042.20	lbs
Flood lLdV2		101999.56	lbs
Total Flood LdV	FRy	483041.76	lbs
Resultant load - Gates Fully Open	FR_{open}	**551856.82**	lbs
Margin	FR_{open}/FR_{closed}	**0.99**	(ratio)

Figure D1: Hiwassee Spillway Gate Margin Evaluation

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Project: Hydrostatic Force on Gate
Description: Diagram
Project No. ____ Sheet No. ____ of ____
Designer: ____ Date: ____
Checker: ____ Date: ____

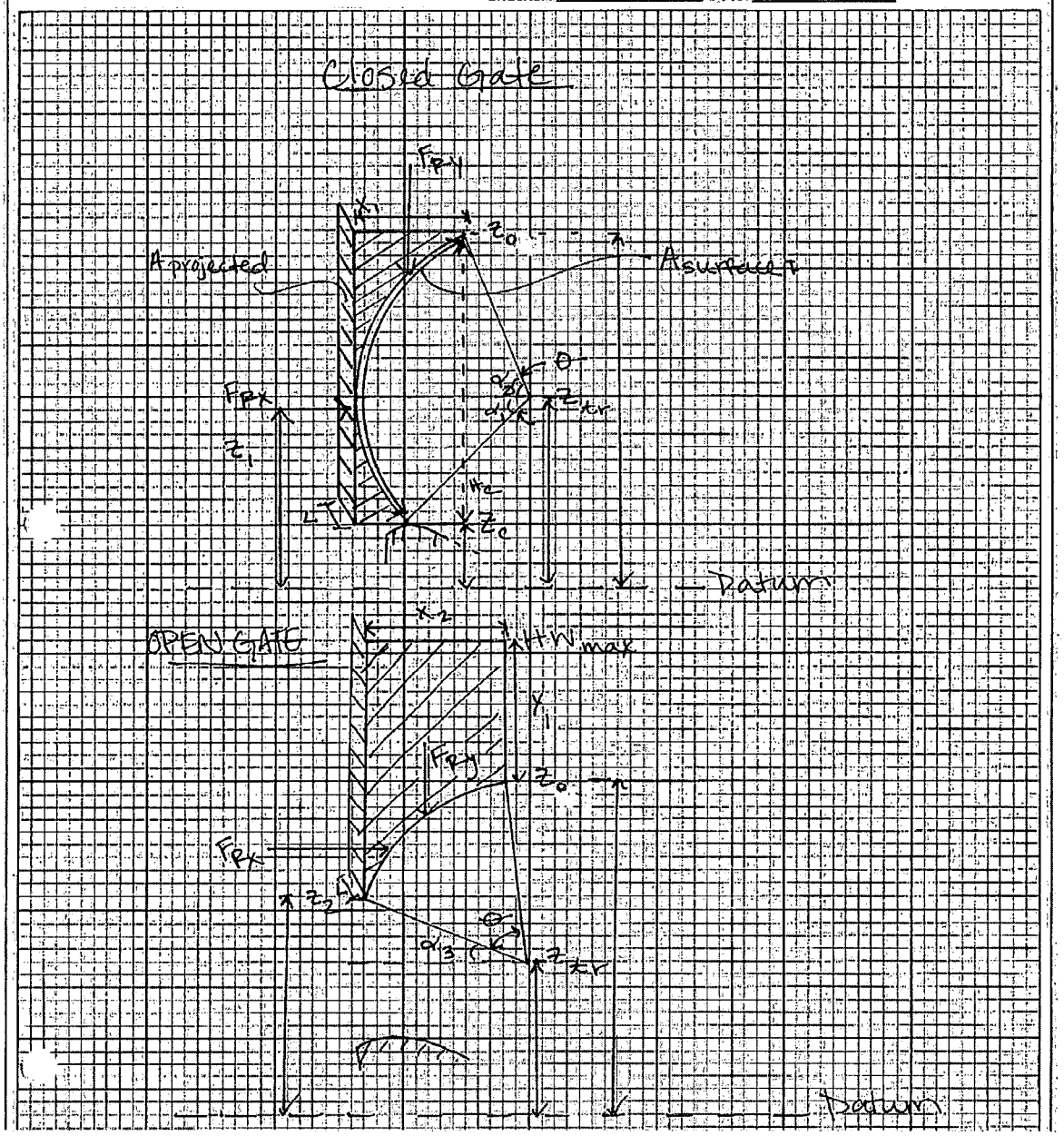

Figure D2: Diagram of Hydrostatic Forces