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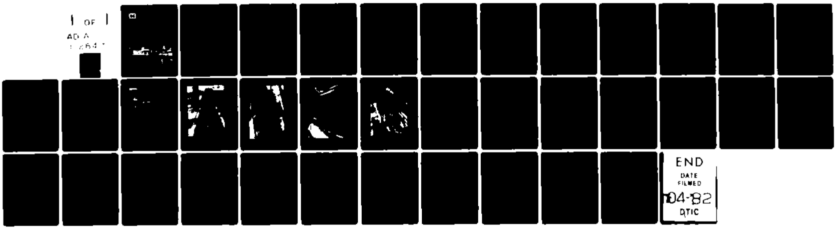

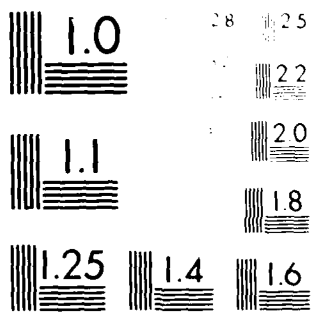
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TECHNICAL REPORT HL-82-4

POLLUTION CONTROL FACILITIES PROJECT SOUTHEASTERN OAKLAND COUNTY SEWAGE DISPOSAL SYSTEM OAKLAND COUNTY, MICHIGAN

Hydraulic Model Investigation

by

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February 1982

Final Report

Approved For Public Release; Distribution Unlimited

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Head losses through the Red Run Drain Pollution Control Structure were determined for a range of discharges and tailwaters. Two 1:20-scale models were used to determine the head losses through two vee-shaped weir and baffle structures. These results were combined with calculations made using Manning's equation to determine the total head losses. Modifications to the structure were tested to determine their effect on head losses.

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PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers, U. S. Army, on 29 May 1980, at the request of the U. S. Army Engineer District, Detroit.

The study was conducted in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., during the period May 1980 to April 1981 under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Mr. J. L. Grace, Jr., Chief of the Hydraulic Structures Division, and under the general supervision of Mr. N. R. Oswalt, Chief of the Spillways and Channels Branch. The project engineer for the model study was Mr. R. R. Copeland, assisted by Mr. E. L. Jefferson. Mr. B. F. Stanfield is acknowledged for his outstanding work in constructing the models.

During the course of the study, Messrs. Bruce Holbrook, John Karpij, Posey Mills, and Dennis Oaks of the Detroit District; and Gary Emore and Jim Mazanec of the North Central Division visited WES to discuss the program of model tests, observe the model in operation, and correlate test results with concurrent design work.

Commanders and Directors of WES during the conduct of this investigation and the preparation and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENTS

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
gallons (U. S. liquid)	0.00378541	cubic metres
miles (U. S. statute)	1.609347	kilometres
square miles (U. S. statute)	2.5899978	square kilometres

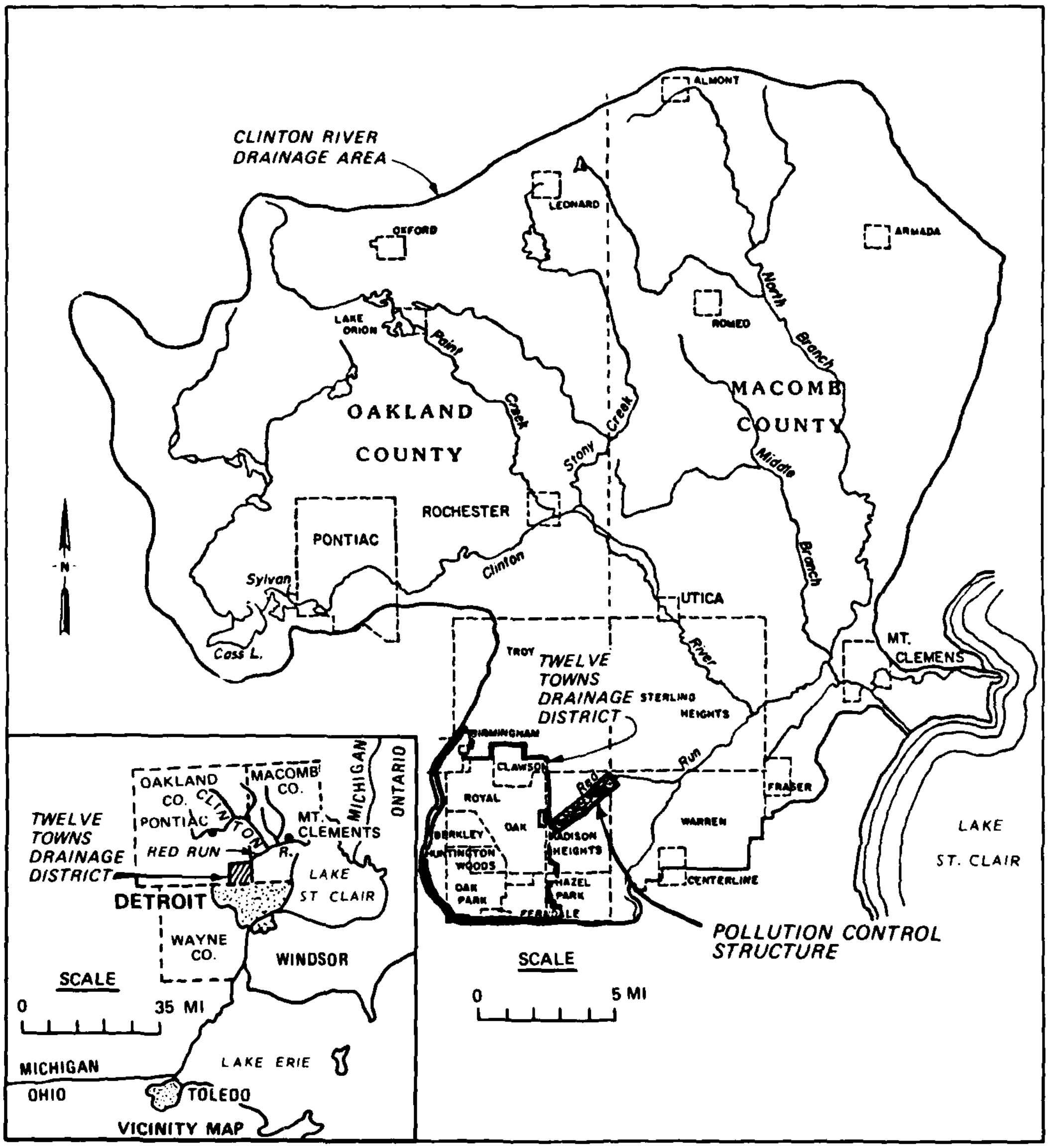

Figure 1. Project location

POLLUTION CONTROL FACILITIES PROJECT
SOUTHEASTERN OAKLAND COUNTY
SEWAGE DISPOSAL SYSTEM
OAKLAND COUNTY, MICHIGAN

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The pollution control structure modeled in this investigation is the terminus structure in the Twelve Towns Drainage District's combined sewer and storm drain system. The district includes about 38 square miles* of southeastern Oakland County in Michigan (Figure 1). The concrete structure consists of a vee-shaped weir with baffle wall located at each end of the structure and an approximately 12,000-ft-long connecting tunnel that functions as a retention basin with a capacity of 62.2 million gallons. The structure is connected to the Detroit Wastewater System, to which normal dry weather flows up to 260 cfs are diverted. Additional flows are retained in the retention basin where partial physical and chemical treatment occurs. The physical treatment consists of solids settlement and is controlled by the downstream baffle wall and weir. However, the pollution control structure is capable of storing runoff from only minor storms. Excess combined sewage and storm flows pass over the weir and into Red Run Drain which flows into the Clinton River and eventually into Lake St. Clair about 20 miles north of the city of Detroit. Plan, profile, and cross-sectional views of the structure are shown in Figures 2-4.

2. Flooding in the Twelve Towns Drainage District occurs due to surcharge storage and inadequate pipe capacity in the combined sewage

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* A table of factors for converting inch-pound units of measurement to metric (SI) units is presented on page 3.

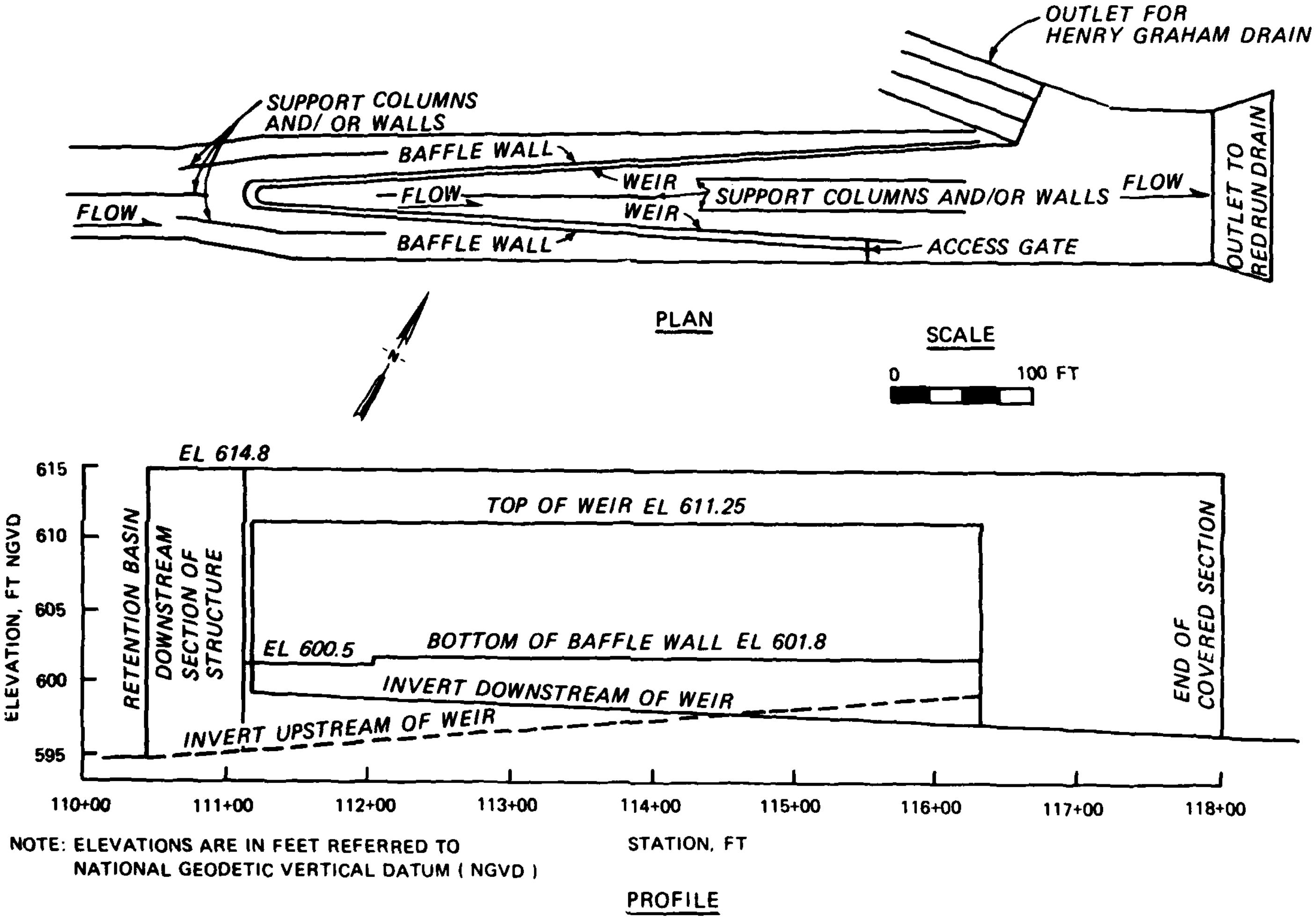


Figure 2. Plan and profile views, downstream section of structure

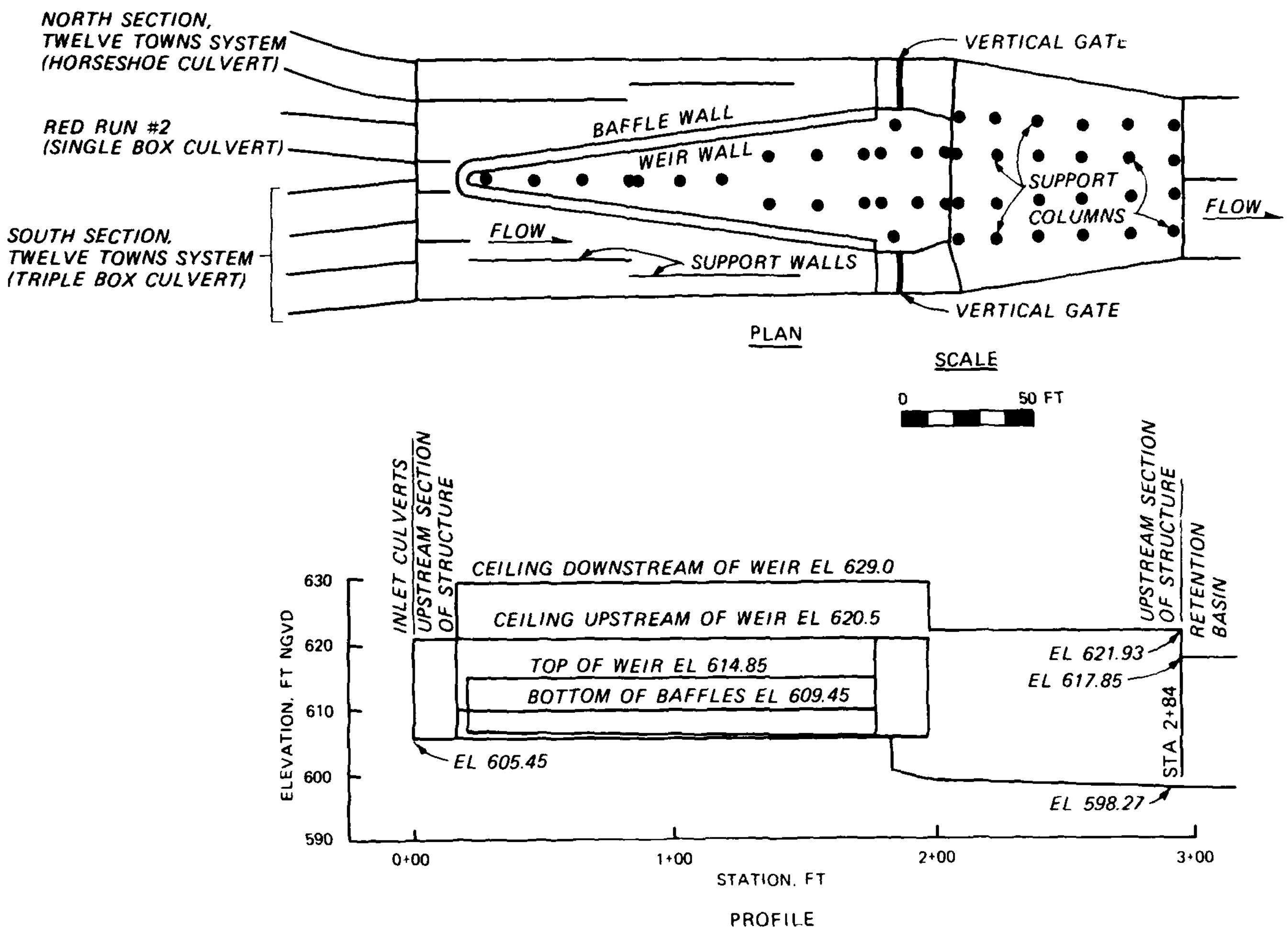
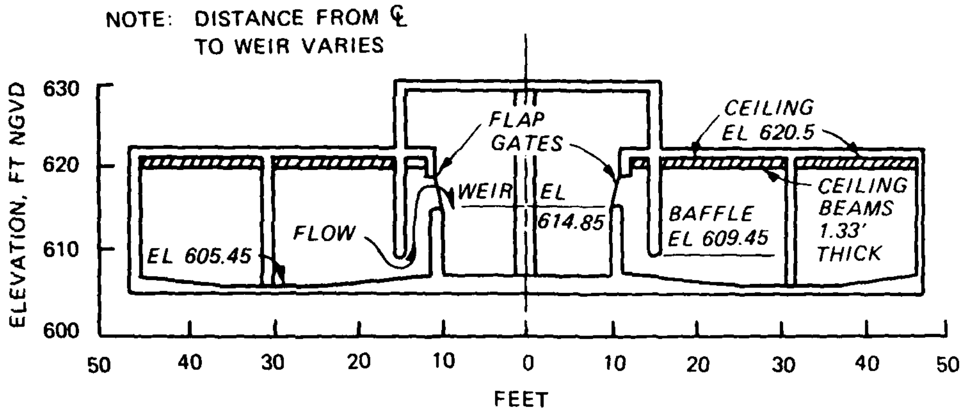
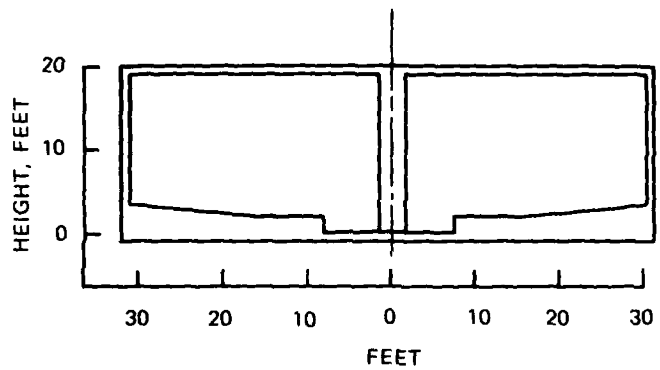


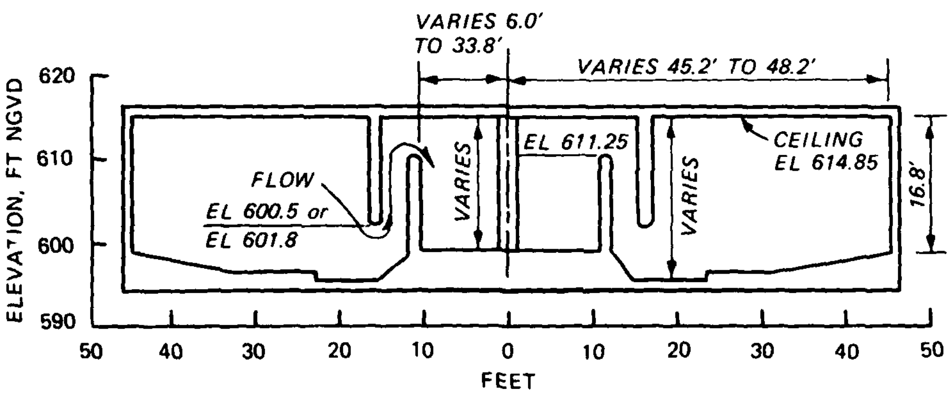
Figure 3. Plan and profile views, upstream section of structure



UPSTREAM SECTION OF STRUCTURE



RETENTION BASIN



DOWNSTREAM SECTION OF STRUCTURE

Figure 4. Typical cross sections

and storm drain system. The Detroit District is conducting Phase I General Design Memorandum studies to address the flooding problem as part of the Red Run Drain and Lower Clinton River, Michigan, Flood Control and Major Drainage Project authorized in 1970 and 1975. The pollution control structure acts as one of the downstream controls for the Twelve Towns system; thus, its ability to pass flood flows without creating excessive head losses and subsequent surcharging and basement flooding will affect any flood control proposals.

Purpose of Model Study

3. The upstream and downstream weirs and baffle walls have very complex configurations which make analytical hydraulic calculations difficult. A physical model study was therefore conducted to determine head losses through both the upstream and downstream sections of the structure for a range of tailwaters and discharges. Structural and operational modifications were also tested. This information will enable the Detroit District to determine flood damages within the project area attributable to high tailwater conditions within Red Run Drain and the pollution control structure.

PART II: THE MODEL

Description

4. Two 1:20-scale models were used to reproduce the two sections of the structure and appropriate lengths of the approach and exit channels. The models were constructed of transparent plastic to permit visual observations of partial and full conduit flow conditions. The weight of the flap gates (see Figure 4) on the upstream section of the structure was simulated in the model; the prototype's rubber hinges were simulated by cloth tape in the model. The hydraulic pressure gradient through the models was measured with piezometers attached to the outside walls and bottom. Discharges into the models were measured with venturi meters. Tailwater elevations were determined with point gages. Energy losses in the retention basin were calculated using Manning's equation and combined with results from the model tests to determine the total head losses through the pollution control structure. The models are shown in Figures 5-9. Portions of the plastic ceiling were removed for the photographs to facilitate viewing.

Interpretation of Model Results

5. The flow in the pollution control structure is influenced primarily by gravitational, pressure, and inertial forces. Dynamic similarity is achieved in the model by applying the accepted equations of hydraulic similitude, based on the Froudian criteria. The general relations expressed in terms of the model scale or length ratio L_r are:

Characteristic	Ratio	Scale Relation
Length	L_r	1:20
Area	$A_r = L_r^2$	1:400

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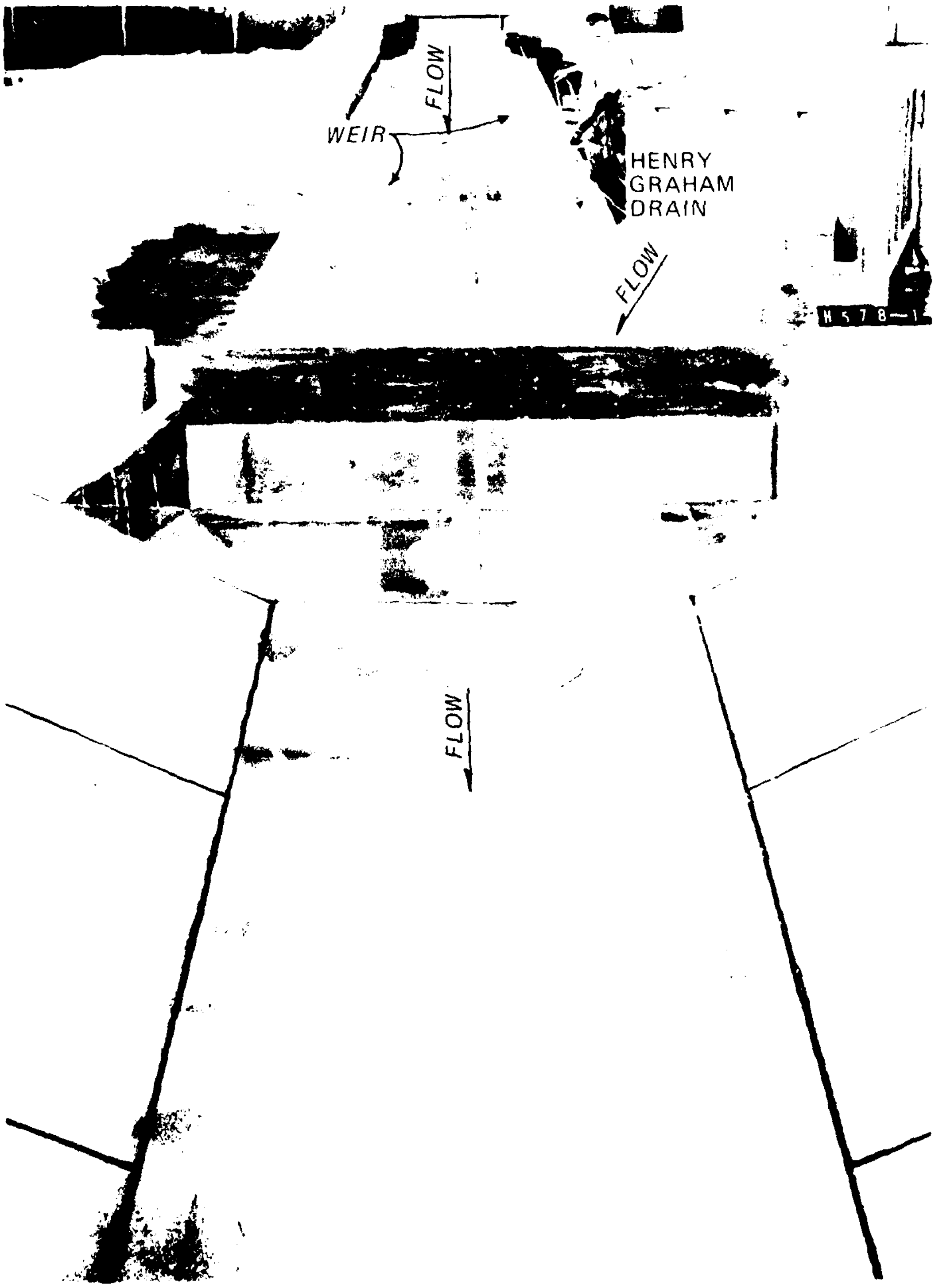

Figure 5. Downstream section of structure looking upstream from outlet channel

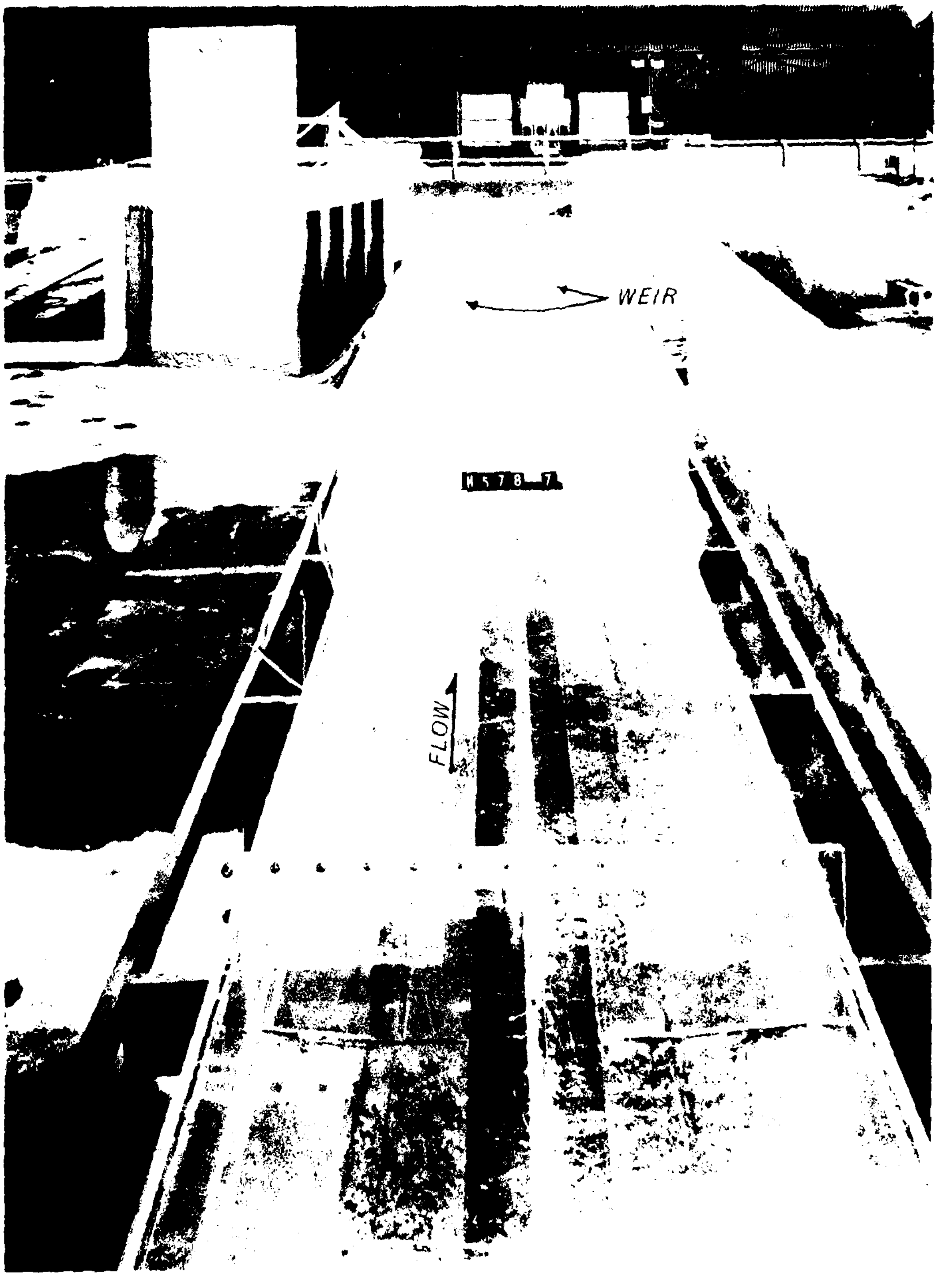

Figure 6. Downstream section of structure looking downstream from retention basin

Figure 7. Downstream section of structure baffle and weir walls

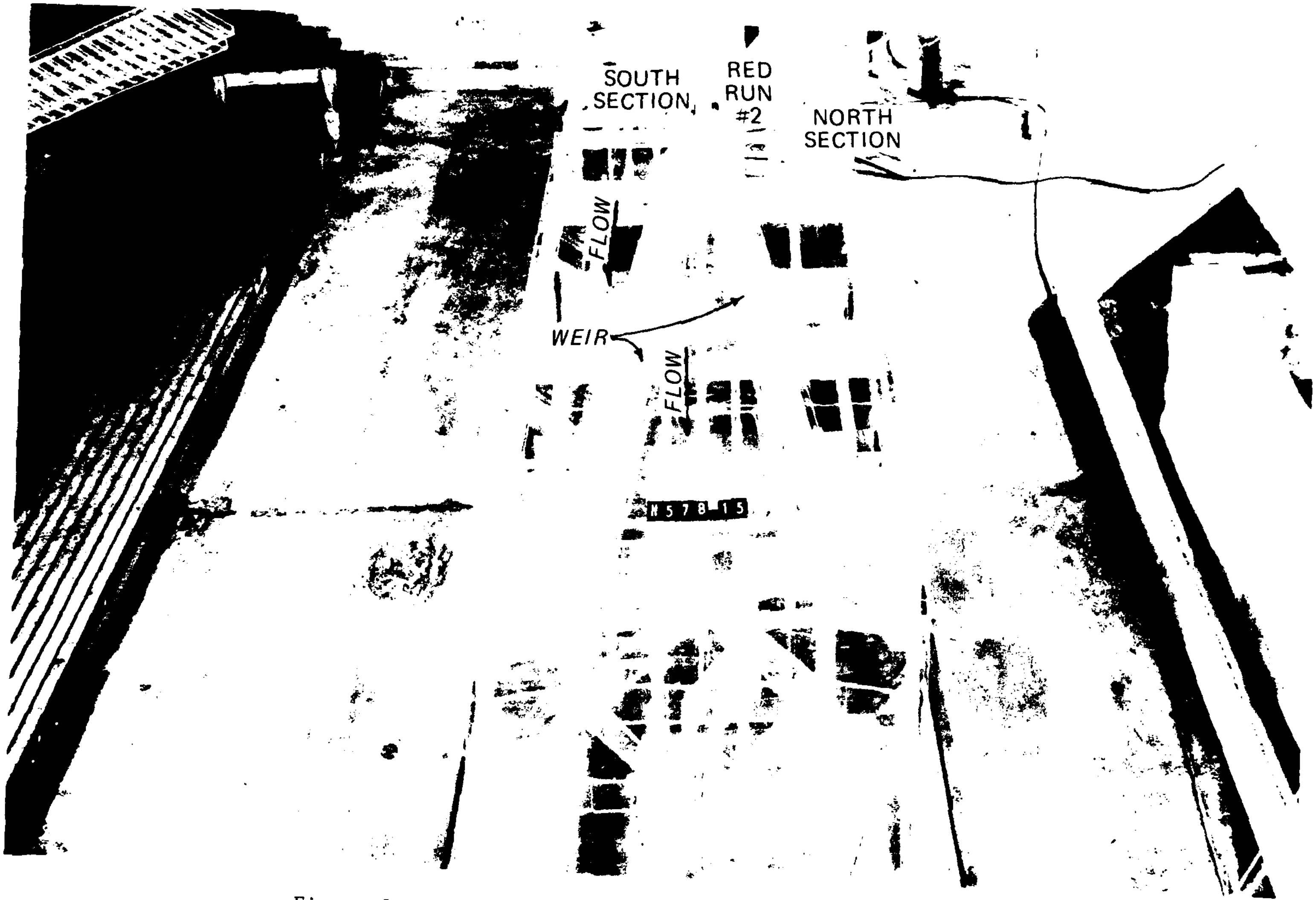

Figure 8. Upstream section of structure looking upstream

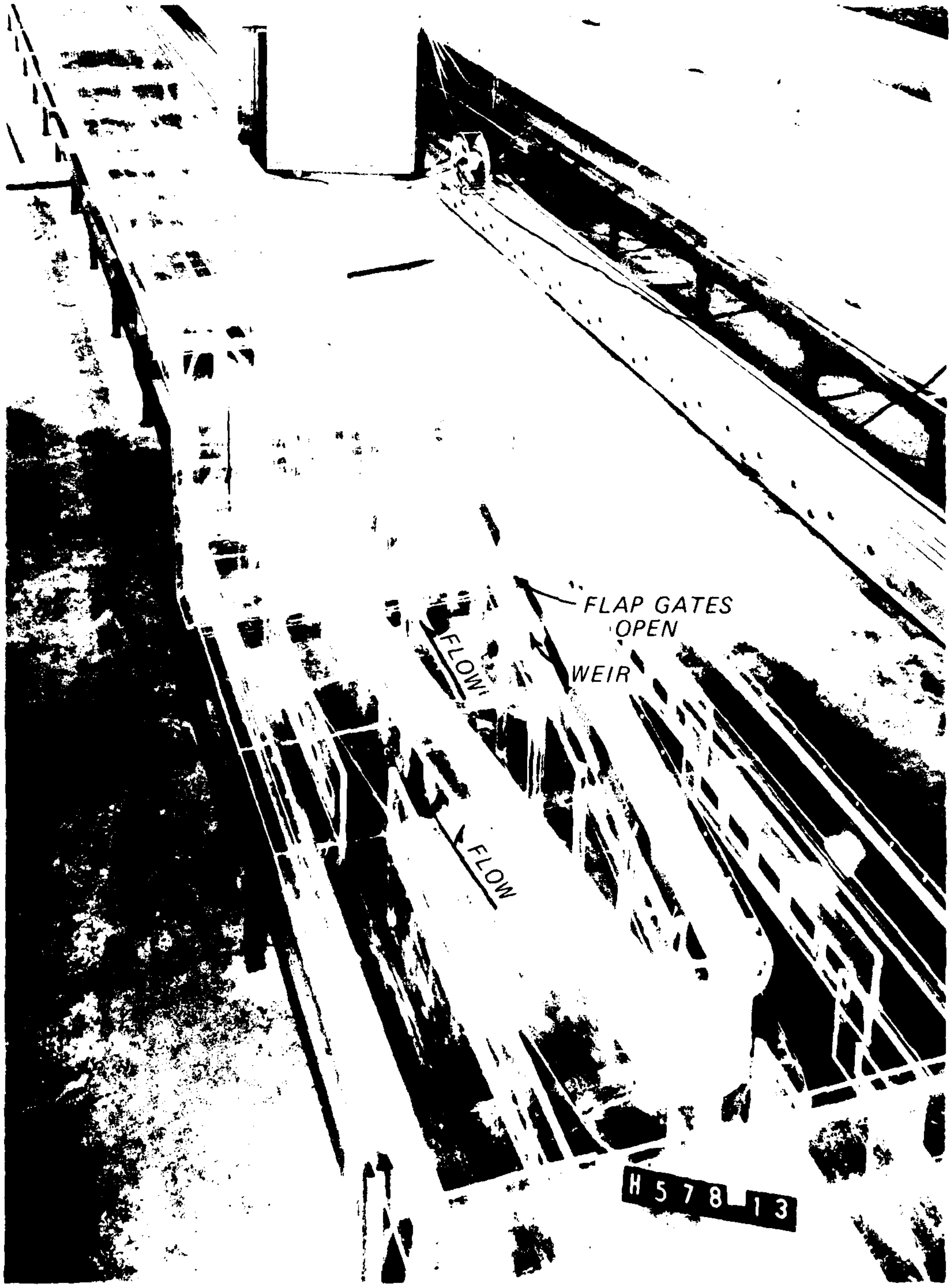

Figure 9. Upstream section of structure and portion of retention basin looking downstream

Characteristic	Ratio	Scale Relation
Velocity	$V_r = L_r^{1/2}$	1:4.472
Discharge	$Q_r = L_r^{5/2}$	1:1789
Time	$T_r = L_r^{1/2}$	1:4.472
Manning's n	$n_r = L_r^{1/6}$	1:1.648
Weight	$W_r = L_r^3$	1:8000

Measurement of each of the dimensions or variables can be transferred quantitatively from model to prototype equivalents by means of the above scale relations. For example, the plastic used to construct the model has a Manning's n value of 0.009 which would correspond to a value of 0.015 in the prototype. Forces due to viscosity, surface tension, and elasticity can also influence the hydraulic characteristics in the prototype and model. In this model study, Reynolds numbers were sufficiently large (10^5) to render the effects of these forces negligible.

6. The 1:20-scale model is of sufficient size to determine head losses within an acceptable accuracy range. Model results from a single test had an accuracy of ± 0.5 ft. A sufficient number of tests were made so that the final average values had an accuracy of ± 0.1 ft.

PART III: TESTS AND RESULTS

Head Losses

7. Head losses* through the upstream and downstream sections of the structure were determined for discharges ranging from 4,000 to 14,000 cfs and tailwaters in Red Run Drain ranging from el 605.3 to 623.** The results of these tests are shown in Figures 10 and 11, in which change in hydraulic grade line is plotted against tailwater for various discharges. At low tailwaters, the hydraulic grade line upstream of each section of the structure is controlled by the weir crests and is independent of the tailwater. This condition is represented by the steep sloping portions of the curves in Figures 10 and 11. The weir control condition is more apparent in Figure 12, in which hydraulic grade line elevation is plotted against tailwater. In this figure, the horizontal portions of the curves represent weir control. As the tailwater increases, the weir becomes submerged until the pollution control structure acts as a closed conduit and head losses through it become constant for a given discharge. This condition is represented in Figures 10 and 11 by the horizontal portions of the curves.

8. When the conduit was flowing full, trapped air pockets developed along the ceiling of the structure. These were considered typical of the prototype; however, tests were conducted to determine if the air pockets had any significant effect on head losses. The air was removed by providing air vents in the models. There was no significant difference in head losses with or without the air vents.

9. The discontinuity that appears in Figure 10 at a tailwater of el 613.3 is caused by the operation schedule of the Henry Graham Drain. When the tailwater in Red Run Drain is less than el 613.3, the Henry Graham Drain discharges freely into the downstream section of the

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* In this report, head loss is defined as the difference in the hydrostatic heads at two points.

** All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

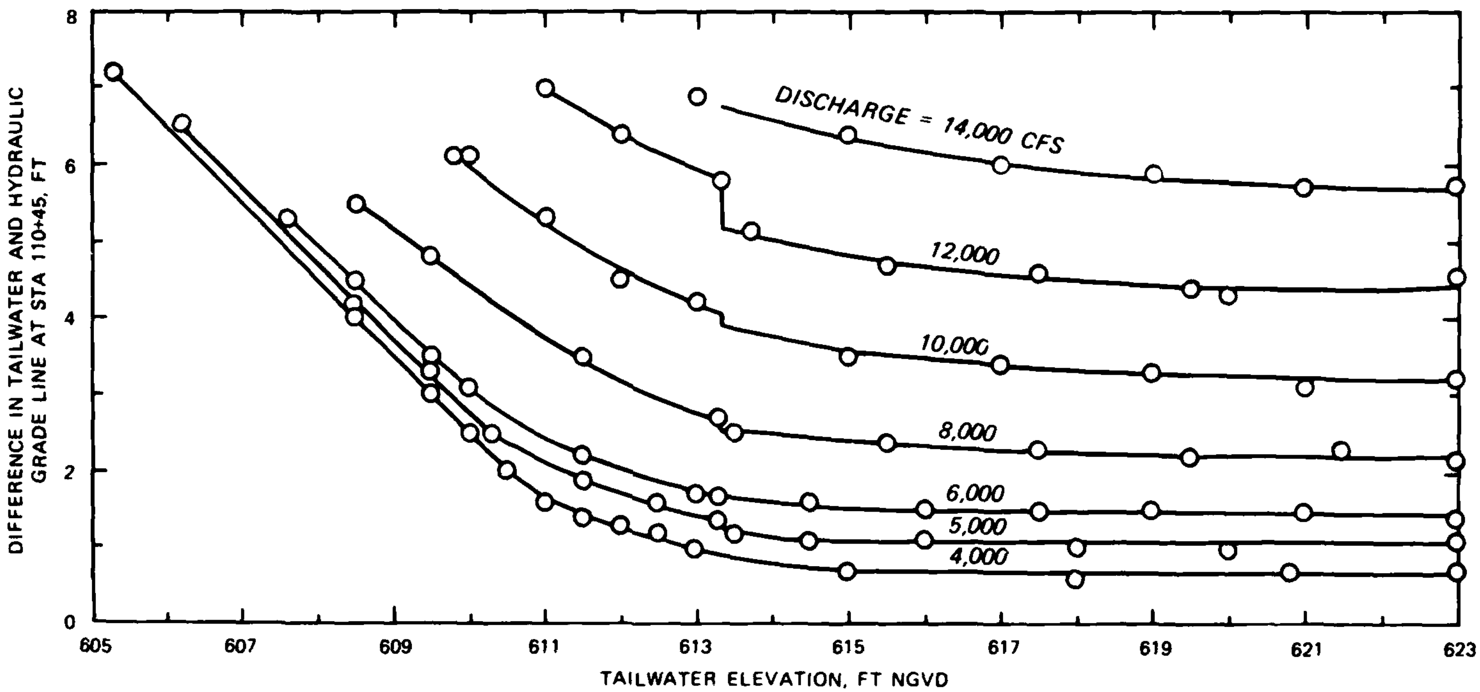

Figure 10. Head losses in downstream section of structure

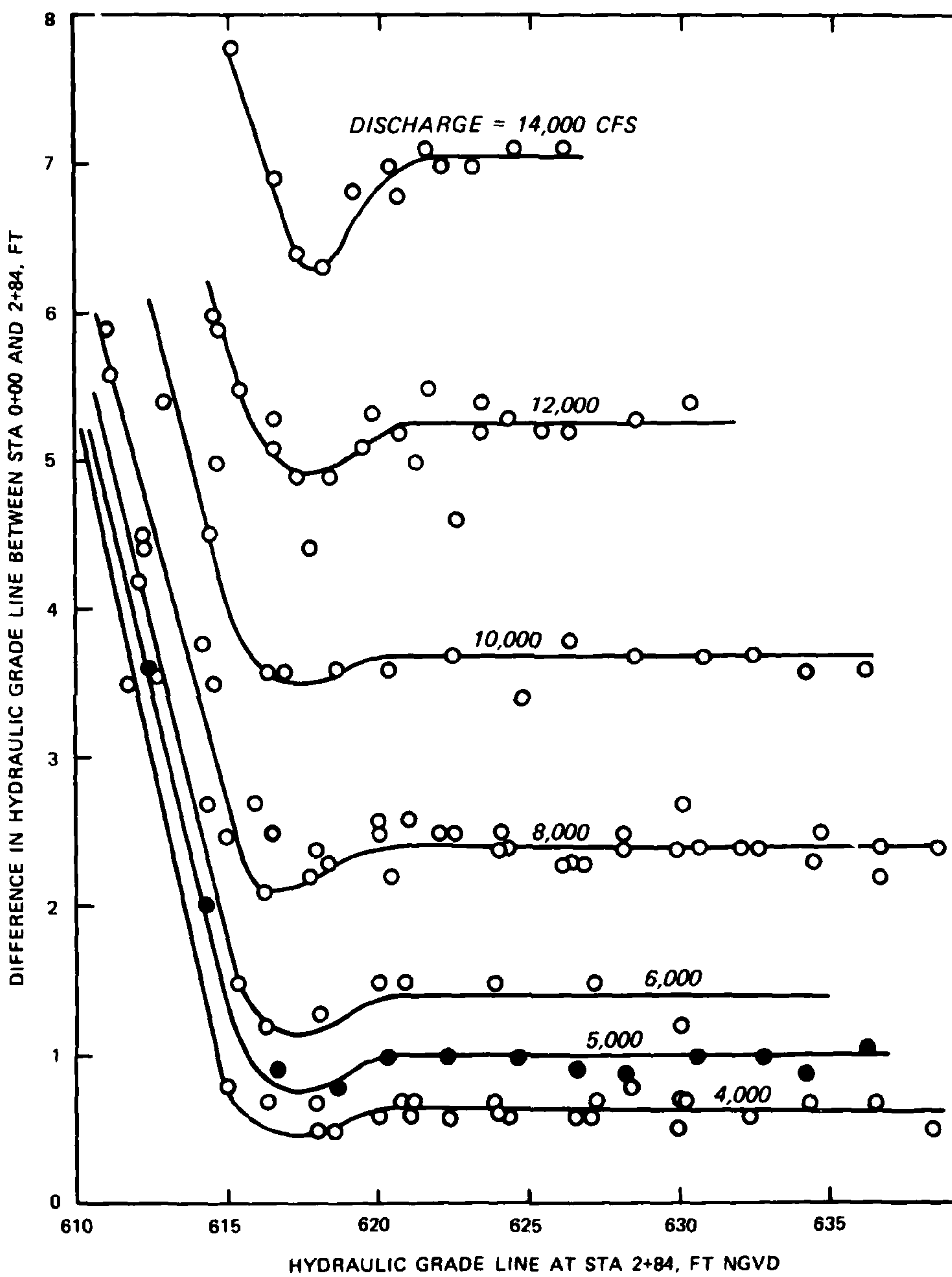

Figure 11. Head losses in upstream section of structure

structure, a flow equal to 22 percent of the flow in the pollution control structure upstream from the confluence. However, at higher tailwaters, the outflow is limited to 480 cfs. This factor accounts for the drop in head differential at higher tailwaters.

10. The entrance to the pollution control structure (station 0+00) is characterized by nonuniform flow patterns and pressure distribution due to the different geometries and discharges of the inlet conduits. Flow into the upstream section of the structure was distributed as follows: 50 percent from the south section of the Twelve Towns System, 20 percent from the north section, and 30 percent from Red Run #2. In analyzing model data, piezometer readings taken at station 0+35 were considered representative of the hydraulic grade line at station 0+00. The unequal entrance conditions also caused pressures on the left (north) side of the structure to be slightly higher than those on the right side. This differential varied from 0.1 ft at 4,000 cfs to 1.0 ft at 14,000 cfs. The pressure readings on both sides of the structure were averaged to obtain final values.

11. The maximum hydraulic grade line obtainable in the model at discharges of 12,000 and 14,000 cfs was about el 635. However, the change in hydraulic grade lines through the upstream section of the structure is constant for a given discharge at high tailwaters (Figure 11) so that additional values could be obtained by extrapolating the horizontal lines. These extrapolated values were added to losses calculated for the retention basin and measured for the downstream section of the structure to obtain total losses for hydraulic grade lines above el 635 as shown in Figure 12.

12. Head losses in the 12,000-ft-long retention basin were computed using Manning's equation. Two sets of calculations were made: one with a roughness coefficient of 0.012 and one with a coefficient of 0.016. This range is reasonable for friction factors for concrete structures. When the hydraulic grade line was below the ceiling elevation at station 110+45 (upstream end of downstream section of structure), backwater calculations were made to determine the station where full flow conditions began. The results of these calculations were combined with

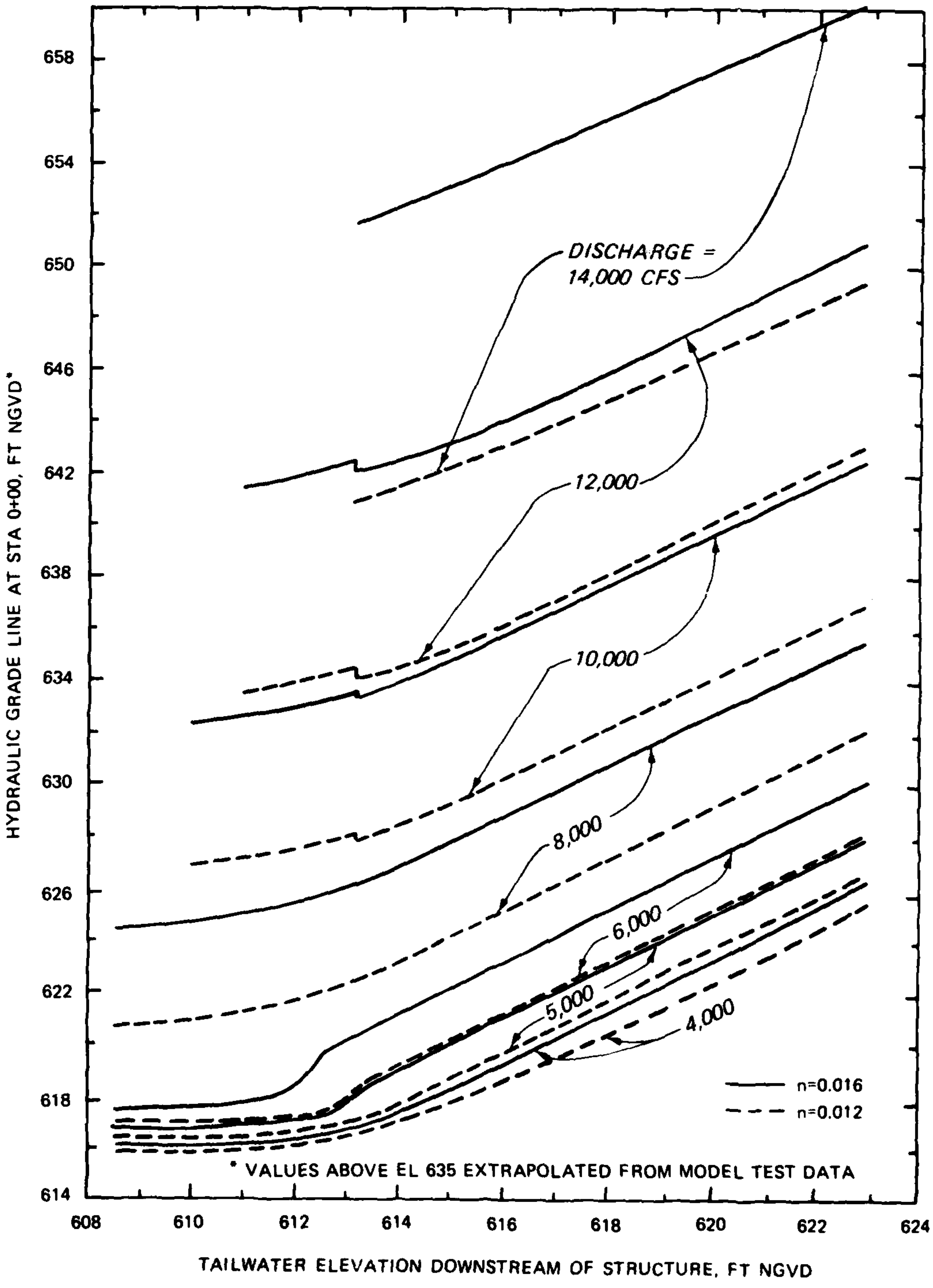

Figure 12. Total head losses

the results of the model tests to obtain a total head loss curve as shown in Figure 12. It can be seen from this figure that friction head losses are very significant and therefore that estimating the appropriate roughness coefficient is critical. The importance of the friction factor is further demonstrated in Table 1 where head losses for various discharges with tailwaters in Red Run Drain above el 616 are tabulated.

Table 1

Head Losses in Pollution Control Structure for Tailwaters in Red Run Drain Greater than El 616

	Head Loss, ft					
	Downstream Section of Structure	Retention Basin		Upstream Section of Structure	Total	
Discharge cfs		Manning's n = 0.012	Manning's n = 0.016		Manning's n = 0.012	Manning's n = 0.016
4,000	0.7	1.1	2.0	0.6	2.4	3.3
5,000	1.0	1.8	3.0	1.0	3.8	5.1
6,000	1.5	2.6	4.5	1.4	5.5	7.4
8,000	2.2	4.5	8.0	2.4	9.1	12.6
10,000	3.2	7.1	12.6	3.7	14.0	19.5
12,000	4.4	10.2	18.1	5.3	19.9	27.8
14,000	5.7	13.9	24.6	7.0	26.6	37.3

13. An equation for the change in hydraulic grade line between the tailwater in Red Run Drain and station 0+00 (the upstream end of the structure) was developed for full flow conditions. The relationship between the change in hydraulic grade line through each section of the structure and velocity in the retention basin was determined graphically from the test results and combined with head losses determined using Manning's equation for the retention basin. This equation relates the change in hydraulic grade line to the average velocity in the retention basin and Manning's roughness coefficient:

$$\Delta HCL = (510n^2 + 0.0378)v^2 + 0.0769v^{1.65}$$

where

ΔHCL = change in hydraulic grade line, ft

n = Manning's roughness coefficient

v = velocity, fps

Total head losses computed with this equation are compared to the results obtained from the model tests and calculations in Figure 13. As partially full flow develops in the structure, the equation becomes increasingly ineffective in predicting head losses. The equation is adequate when the tailwater in Red Run Drain exceeds el 614.

Stage-Discharge Curves

14. Stage-discharge curves were developed for station 1+65 (prototype staff gage location) on the right (south) side of the upstream weir for both open and closed vertical gate conditions. The curves were developed for a range of hydraulic grade lines at the downstream end of the upstream section of the structure (station 2+84). The inflow was distributed 50 percent, 30 percent, and 20 percent through the triple box, single box, and horseshoe culverts, respectively, for all discharges tested except 1000 cfs. It was necessary to bring 100 percent of the inflow through the single box culvert with the 1000-cfs discharge (the smallest tested) due to the difficulty encountered in measuring such relatively small discharges in the model facilities. Differences in hydraulic grade lines on the right and left sides of the structure were about 0.1 ft. This differential was comparable to that experienced with the higher discharges when inflow was distributed among all three inlet culverts. The model test results are presented in Figures 14-17. Figures 14 and 15 show the difference in hydraulic grade line between station 2+84 and station 1+65 for a range of discharges and tailwaters, and Figures 16 and 17 show the actual stage-discharge relationships.

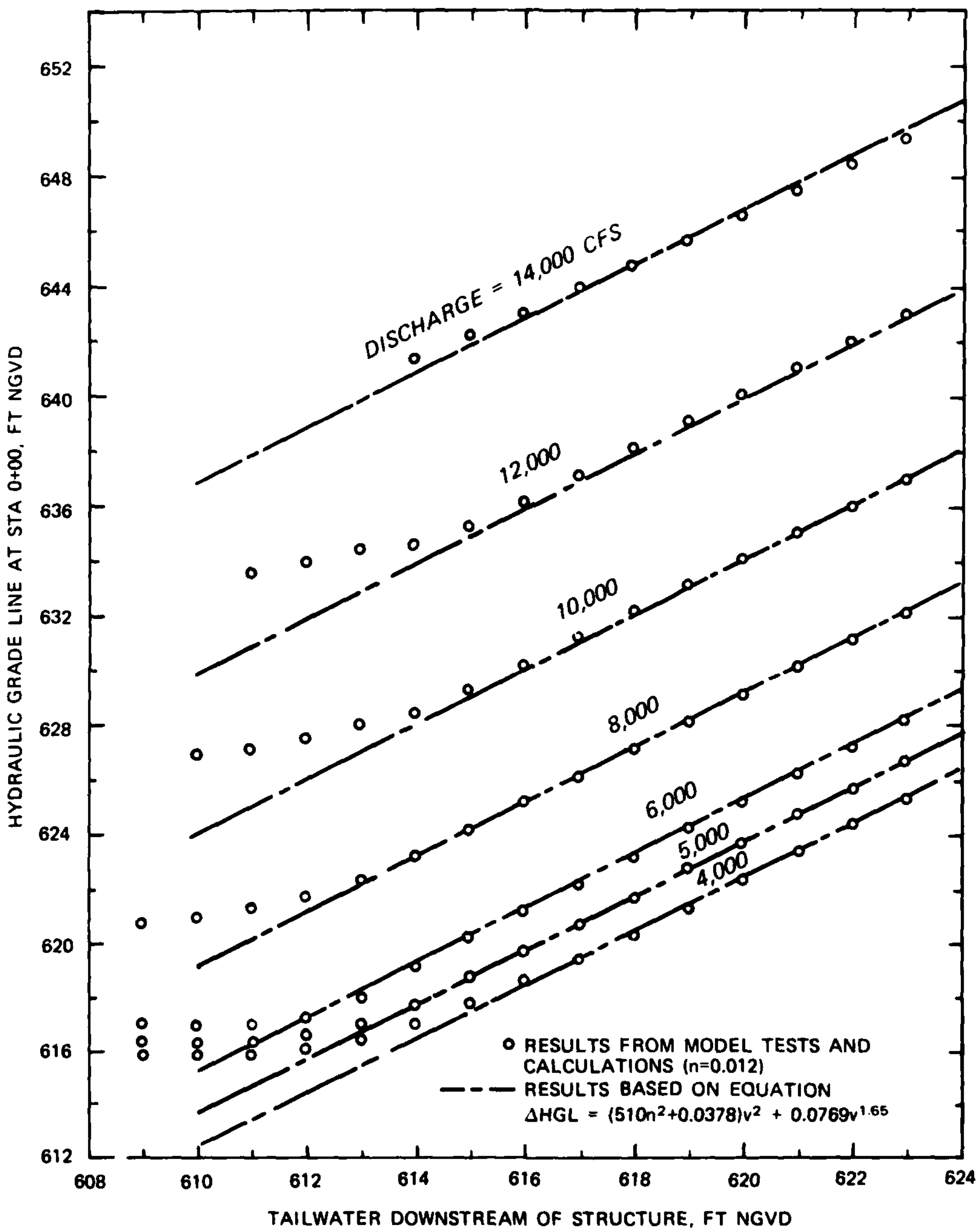

Figure 13. Comparison of total head losses

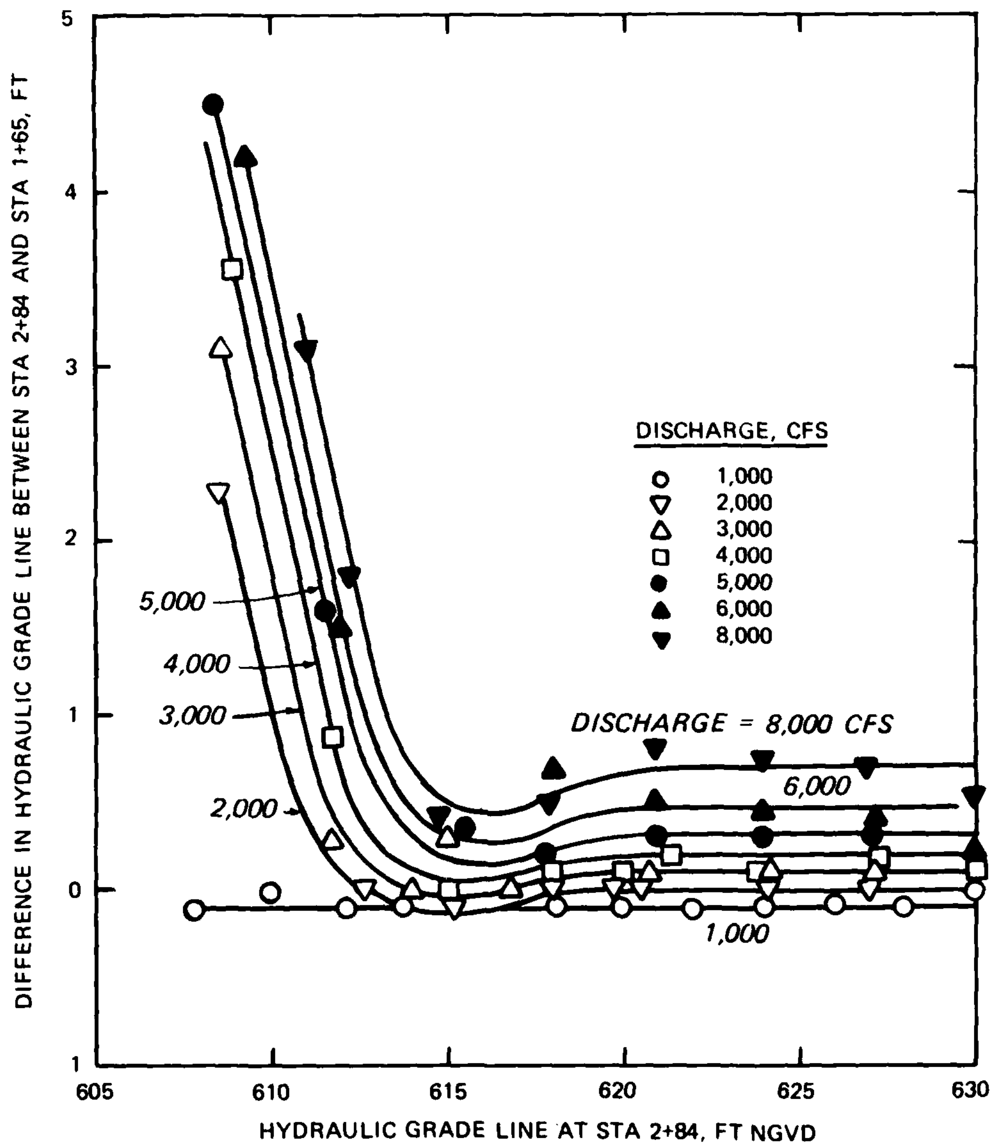

Figure 14. Hydraulic grade line differentials, vertical gates open

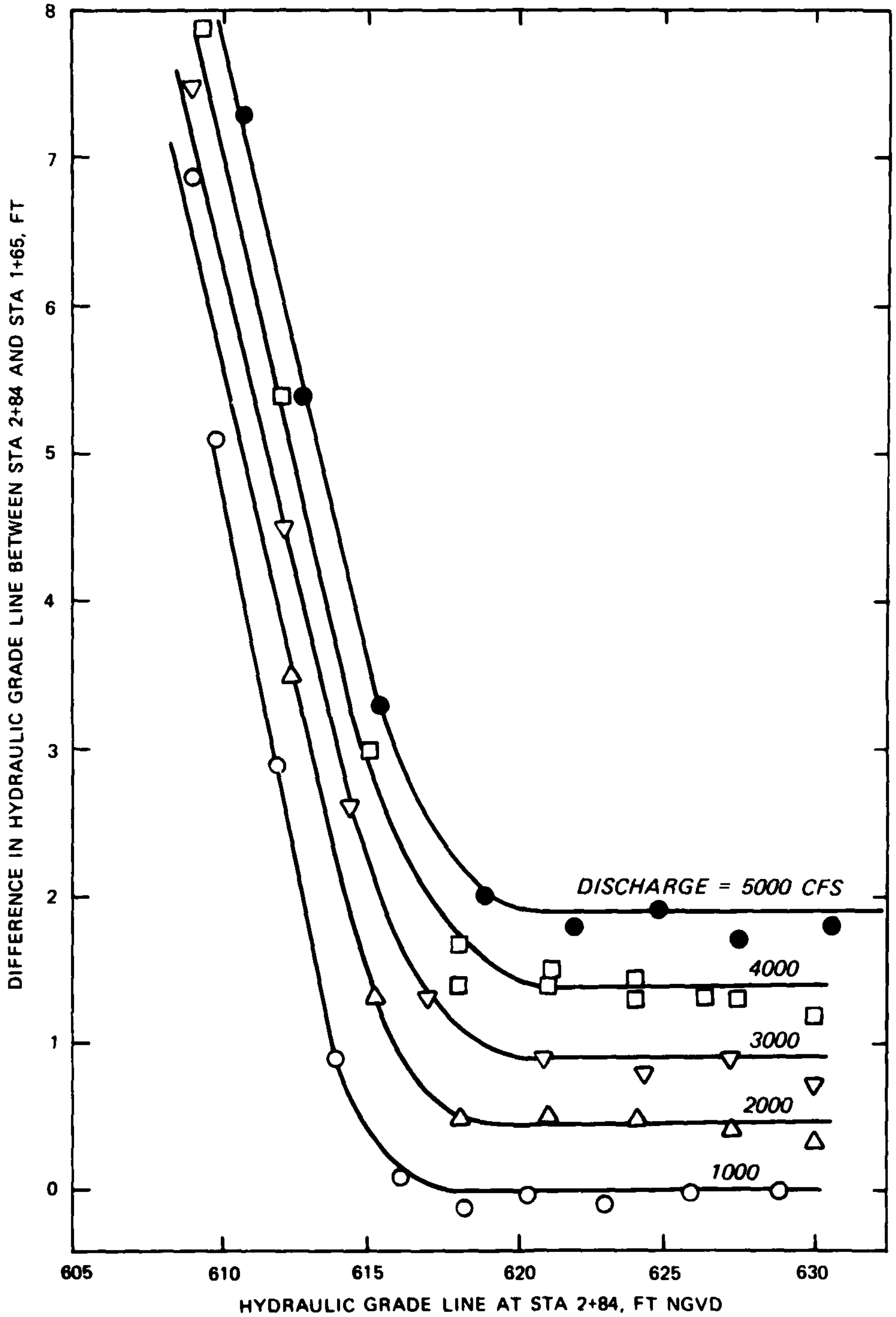

Figure 15. Hydraulic grade line differentials, vertical gates closed

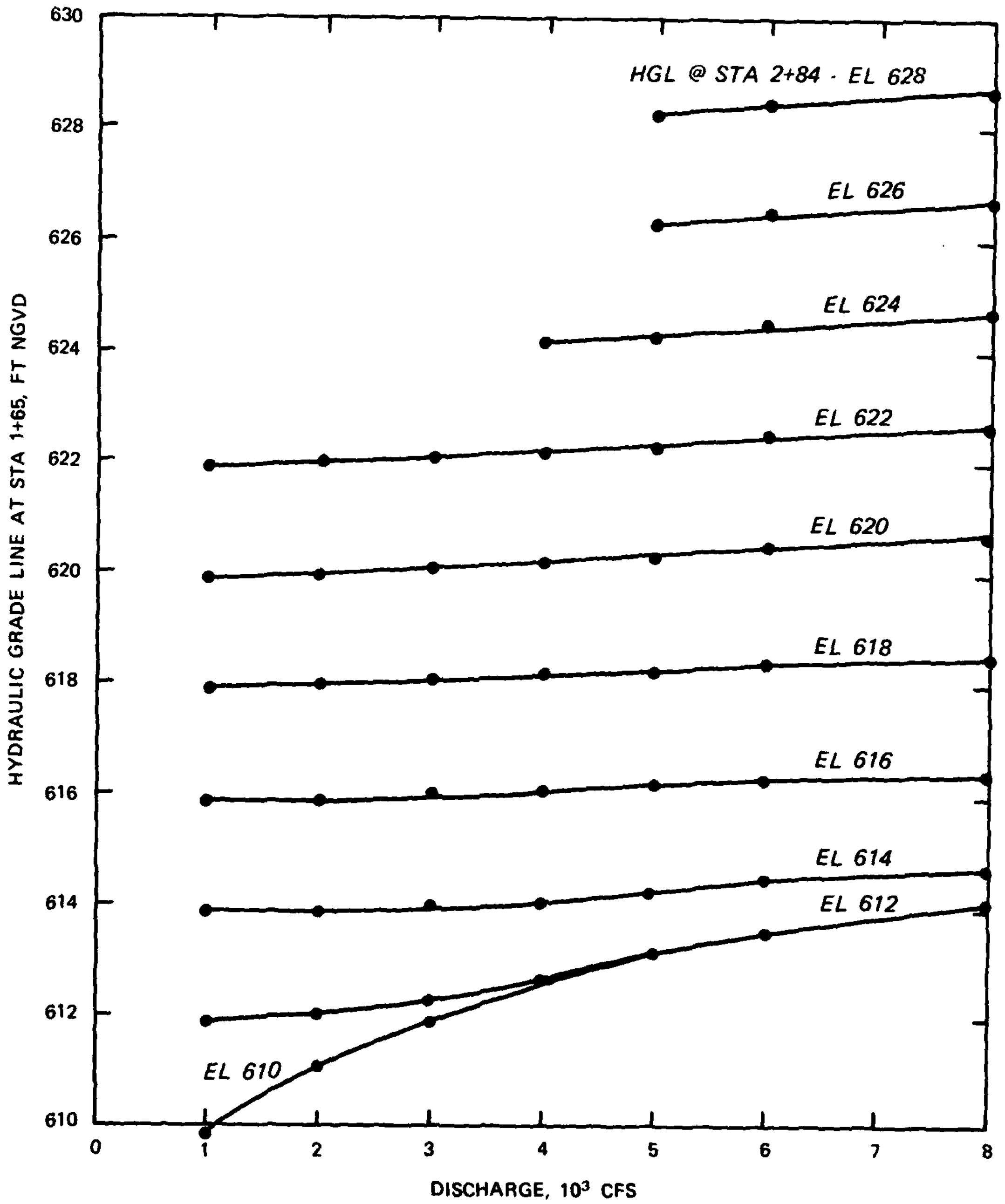

Figure 16. Stage-discharge curves, vertical gates open

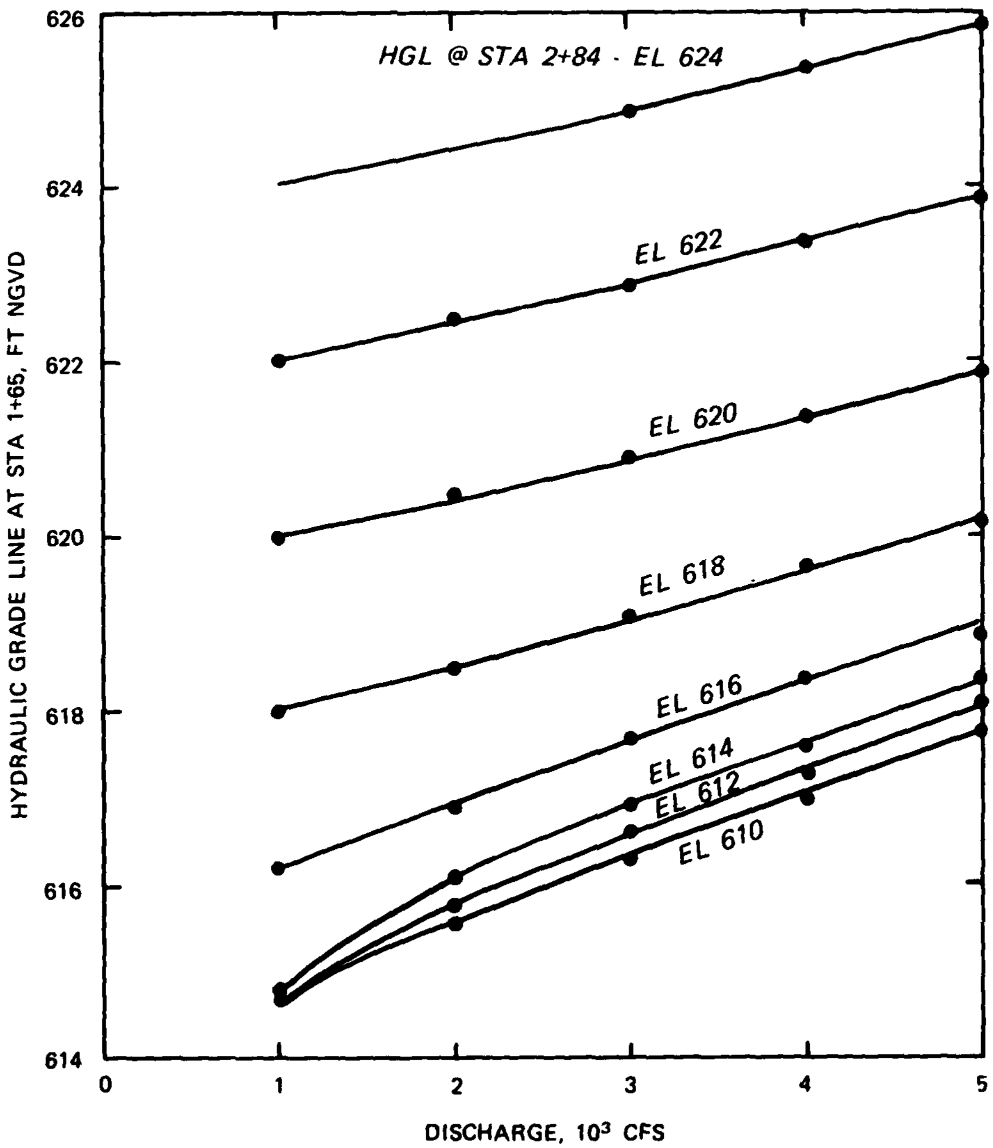

Figure 17. Stage-discharge curves, vertical gates closed

Operational Modification

15. A vertical gate is located on the right (south) side of the downstream section of the structure. This gate is intended for access to the retention basin for maintenance purposes and is closed when water is flowing through the structure. The effect of opening this gate when the discharge was 8000 cfs was tested in the model. The head loss through the structure was 0.5 ft lower for the entire range of designated tailwaters with the access gate open.

Physical Modifications

16. A transition wedge was placed in the ceiling of the upstream section of the structure at station 2+85 to streamline flow past a 4.08-ft vertical drop in the ceiling. The ceiling transition had a 1:4 taper and extended 16.32 ft upstream. When the hydraulic grade line at station 2+84 was greater than el 620, the reduction in head loss due to the transition was constant for a given discharge. Results for each of the discharges tested are shown in Table 2.

Table 2

Reduction in Head Loss When Tailwater Is Greater Than El 620

Discharge cfs	Reduction in Head Loss, ft: Transition Wedge	Smooth Ceiling	Combination
4,000	0.05	0.10	0.15
6,000	0.10	0.15	0.25
8,000	0.15	0.25	0.40
10,000	0.20	0.35	0.55
12,000	0.25	0.50	0.75

17. The ceiling upstream from the weir in the upstream section of the structure was streamlined by placing a thin sheet of plastic over

the ceiling beams. This modification resulted in a constant head loss reduction for a given discharge with varying hydraulic grade lines at station 2+84 greater than el 620. Results of these tests are listed in Table 2.

18. The effect of these modifications was minor when compared to the total head loss through the entire structure. Changes in hydraulic grade lines through the upstream section of the structure due to the modifications are shown in Figure 18. Additional modifications were discussed by representatives of the Detroit District, North Central Division, and WES, including (a) removing the hanging baffle walls located upstream of the vertical gates on the upstream section of the structure, (b) providing guide vanes to direct flow through the baffles and over the weirs, and (c) raising the floor elevation downstream of the weirs to reduce eddies. However, it was concluded that any benefit due to these modifications would be insignificant, and thus they were not tested.

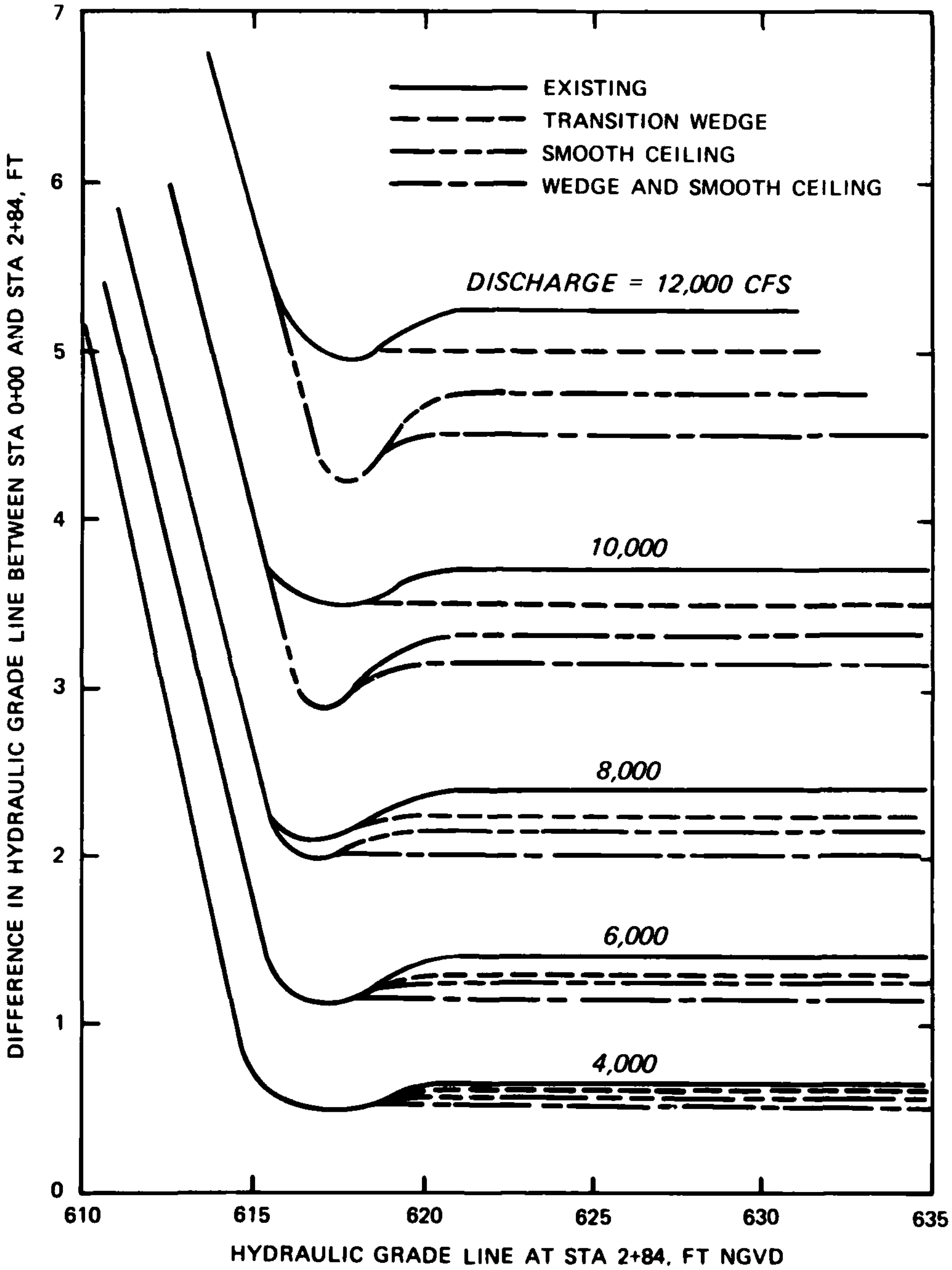

Figure 18. Effect of modifications on hydraulic grade line differentials

PART IV: SUMMARY

19. Head losses through the pollution control structure were determined for a range of discharges and tailwater . Model tests were used to determine the head losses through the geometrically complicated weir and baffle structures, and calculations, using Manning's equation, were used to determine losses in the retention basin. The analysis showed that the roughness of the retention basin is highly significant in determining head losses. Curves were developed that can be used to determine head losses for a given discharge and tailwater. An equation to calculate head loss through the structure was also developed; however, this equation is limited to cases where the tailwater in Red Run Drain is greater than el 614.

20. Modifications to the pollution control structure were tested. These included streamlining an abrupt ceiling transition and eliminating roughness caused by ceiling beams. These modifications had little effect on the total head loss through the structure.

21. A modification to the operating procedure was also tested for a single discharge. It was determined that opening the downstream access gate would have an insignificant effect on total head losses.

22. Sufficient information was obtained from the model study so that the effect of the pollution control structure on flooding in the upstream drainage basin could be evaluated.

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