US Army Corps of Engineers

2

TECHNICAL REPORT HL-90-4

YAZOO BACKWATER PUMPING STATION DISCHARGE OUTLET

by

James R. Leech

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

May 1990

Final Report

Prepared for US Army Engineer District, Vicksburg
Vicksburg, Mississippi 39181-0060

HYDRAULICS LABORATORY

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION
Unclassified

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release;
distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
Technical Report HL-90-4

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
USAEWES
Hydraulics Laboratory

6b. OFFICE SYMBOL *(If applicable)*
CEWES-HS-S

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS *(City, State, and ZIP Code)*
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

7b. ADDRESS *(City, State, and ZIP Code)*

8a. NAME OF FUNDING / SPONSORING ORGANIZATION
USAED, Vicksburg

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State, and ZIP Code)*
PO Box 60
Vicksburg, MS 39181-0060

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE *(Include Security Classification)*
Yazoo Backwater Pumping Station Discharge Outlet

12. PERSONAL AUTHOR(S)
Leech, James R.

13a. TYPE OF REPORT
Final report

13b. TIME COVERED
FROM ________ TO ______

14. DATE OF REPORT *(Year, Month, Day)*
May 1990

15. PAGE COUNT
55

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Aprons
Channel stabilization
End sills
Exit channels
Shutter gates
Yazoo backwater area

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

The 1:24-scale physical model investigation of the discharge outlet of the Yazoo Backwater pumping station, west-central Mississippi, was conducted to give a three-dimensional analysis of the proposed outlet structure and channel. The model evaluated flow patterns for different operating conditions and channel stability.

Model tests indicated that the original apron could be shortened with the addition of an end sill. Riprap protection remained stable, providing a stable channel for all conditions tested. The effects of a shutter gate on the velocities in the outlet channel were identified.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL

22b. TELEPHONE *(Include Area Code)*

22c. OFFICE SYMBOL

DD Form 1473, JUN 86 — *Previous editions are obsolete.*

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

PREFACE

The model investigation reported herein was authorized by the Headquarters, US Army Corps of Engineers (HQUSACE), on 15 February 1984 at the request of the US Army Engineer District, Vicksburg (LMK).

The study was conducted during the period February 1984 to March 1988 in the Hydraulics Laboratory (HL) of the US Army Engineer Waterways Experiment Station (WES) under the direction of Messrs. F. A. Herrmann, Jr., Chief, HL, and R. A. Sager, Assistant Chief, HL; and under the general supervision of Messrs. G. A. Pickering, Chief, Hydraulic Structures Division (HSD), HL, and N. R. Oswalt, Chief, Spillways and Channels Branch (SCB), HSD. The project engineer for the model study was Mr. J. R. Leech, SCB. This report was prepared by Mr. Leech and edited by Mrs. Marsha C. Gay, Information Technology Laboratory, WES.

During the course of the investigation, Mr. Thomas E. Munsey, HQUSACE; Messrs. William L. Holman and Malcolm L. Dove, US Army Engineer Division, Lower Mississippi Valley; and Messrs. John A. Meador, Larry E. Banks, Fred Lee, Jr., and Johnny G. Sanders, LMK, visited WES to discuss the program and results of model tests, observe the model operation, and correlate these results with design studies.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

Page

PREFACE.. 1

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT......... 3

PART I: INTRODUCTION.. 5

Prototype.. 5
Purpose and Scope of Model Study..................................... 6

PART II: MODEL.. 8

Description.. 8
Scale Relations.. 8

PART III: TESTS AND RESULTS....................................... 9

Pump Outlet.. 9
Flow Patterns in the Outlet Channel.................................. 9
Velocities in the Outlet Channel..................................... 11

PART IV: CONCLUSIONS AND RECOMMENDATIONS........................... 13

PHOTOS 1-15

PLATES 1-23

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

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

Multiply	By	To Obtain
acres	4,046.873	square metres
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
square miles	2.589998	square kilometres

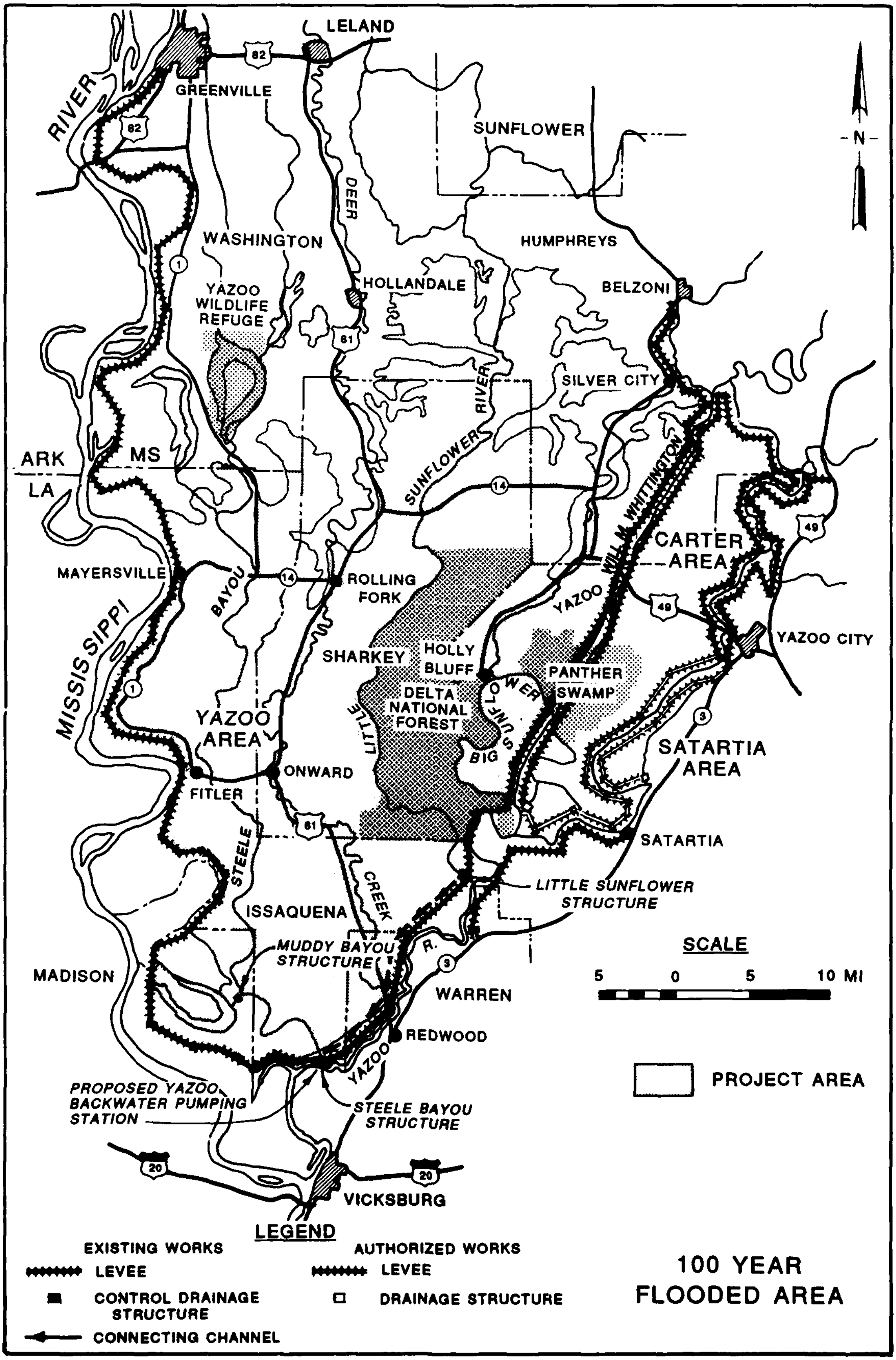


Figure 1. 100-year flooded area

YAZOO BACKWATER PUMPING STATION
DISCHARGE OUTLET

PART I: INTRODUCTION

Prototype

1. The Yazoo Backwater Area (Figure 1) is located in west-central Mississippi and lies between the east-bank Mississippi River levee on the west and the hills on the east. Construction of the Will M. Whittington Auxiliary Channel divided the area west of the Yazoo River into two areas. The larger, more westerly of the areas, which is known as the Yazoo Area, contains approximately 1,406 square miles* protected from backwater flooding and has a drainage area of 4,093 square miles of alluvial land.

2. The project area comprises approximately 539,000 acres in the lower portion of the Yazoo Area. This area is generally triangular in shape and extends northward from Vicksburg some 60 miles to the latitude of Hollandale and Belzoni, MS. Big Sunflower and Little Sunflower Rivers, Deer Creek, and Steele Bayou flow through the area. The Deer Creek ridge, a ridge of higher ground along which US Highway 61 runs, divides the area into two separate ponding areas. Interior drainage in the upper ponding area is evacuated by a drainage structure (design capacity 8,000 cfs) at the mouth of the Little Sunflower River, while interior drainage in the lower ponding area is evacuated by a drainage structure (design capacity 19,000 cfs) at the mouth of Steele Bayou.

3. When the Little Sunflower River and Steele Bayou drainage structures are closed because of high stages on the Mississippi River, flooding from ponding of interior drainage is the principal problem in the project area. Damage to agricultural crops, rural residential property, and public roads and bridges from frequent flooding is a major problem.

4. A proposal to provide additional relief during high river stages consists of a pumping plant with a design capacity of 13,140 cfs to pump the interior drainage over the levee. The pumping station will be located west of

---

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

the Steele Bayou drainage structure as shown in Figure 2. The proposed project would also include an inlet channel from Steele Bayou and an outlet channel to the Yazoo River.

Purpose and Scope of Model Study

5. The primary purpose of the 1:24-scale model study was to develop a stable discharge channel from the Yazoo pumping station to the Yazoo River for all possible discharges and to evaluate the hydraulic performance of the outlets with and without shutter gates installed.

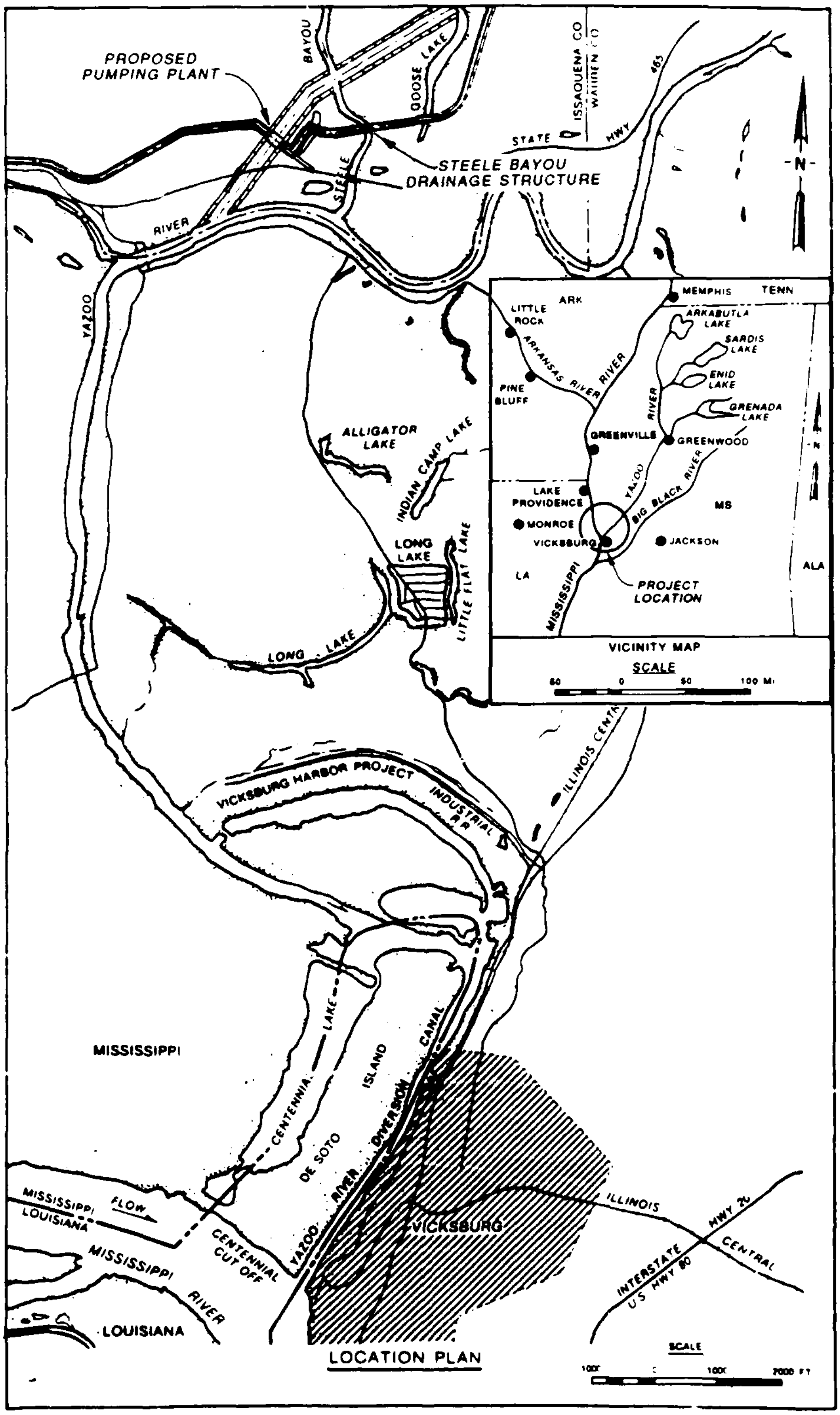


Figure 2. Location and vicinity map

PART II: MODEL

Description

6. The 1:24-scale model (Photo 1) reproduced nine outlets, 3,000 ft of outlet channel, a 50-ft concrete apron, riprap protection (Photo 2), and the Mississippi Highway 465 bridge and piers. The portion of the model representing the outlet channel and overbank area (Photo 1) was molded of cement mortar to sheet metal templates and given a brushed finish. The discharge outlets were constructed of Plexiglas. The bridge and piers were fabricated of sheet metal. Model limits of the discharge outlet are shown in Plate 1.

7. Water used in the operation of the model was supplied by a pump and delivered through a manifold. Discharges were measured by orifice plate meters. Steel rails set to grade provided reference planes for measuring devices. Tailwater elevations were set using point gages. Velocities were measured with pitot tubes. Current patterns were determined by observing the movement of dye injected into the water and confetti sprinkled on the water surface.

Scale Relations

8. The accepted equations of hydraulic similitude, based upon Froudian criteria, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and prototype. The general relations expressed in terms of the model scale or length ratio L_r are presented in the following tabulation:

Dimension	Ratio	Scale Relations Model:Prototype
Length	L_r	1:24
Area	$A_r = L_r^2$	1:576
Velocity	$V_r = L_r^{1/2}$	1:4.899
Discharge	$Q_r = L_r^{5/2}$	1:2,821.8
Time	$T_r = L_r^{1/2}$	1:4.899

9. Model measurements of each dimension or variable can be transferred quantitatively to prototype equivalents using these scale relations.

PART III: TESTS AND RESULTS

Pump Outlet

10. Details of the pump outlet are presented in Plates 2 and 3. Plate 2 is the structural plan view of the pumping station. Section A-A (Plate 3) shows a cross-sectional view of the structure. Notice the shape of the discharge outlet. The model outlet started at the section of conduit downstream of the pump and continued to the concrete apron. Operating conditions consisted of a maximum discharge of 1,460 cfs and tailwater elevations ranged from 79* to 100. Plate 4 is a view of the port opening of the outlet for maximum discharge. The average velocity through the port was 7.5 fps. Shutter gates (Plate 5) were installed in the outlet port to create additional head on the pump during minimum river conditions to force the pump to operate at a higher efficiency. At higher river stages the shutter gates were raised out of the flow. Each shutter gate consisted of six ports with a cross-sectional area of 15 sq ft per port. At maximum discharge the average velocity through the port was 16.2 fps. The model outlet concrete apron (Plate 3) extended 50 ft downstream of the discharge outlet and was keyed in with a 24-in.-thick riprap blanket. Photo 2 shows the riprap protection for the outlet channel. The 24-in. blanket thickness extended 200 ft downstream and was followed by an 18-in.-thick riprap blanket extending another 1,000 ft downstream.

Flow Patterns in the Outlet Channel

11. Initial tests consisted of documenting the flow patterns for a combination of operating conditions. Turbulent flow on the concrete apron and a uniform flow distribution in the exit channel occurred with pumps 1-9 operating at maximum discharge with the shutter gates in place (throttled discharge) and the minimum tailwater elevation of 79 (Photo 3). Photo 4 shows the same flow condition with shutter gates lifted above the outlet port (unthrottled discharge). The unthrottled discharge was not as turbulent over the apron and

---

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

had a uniform flow distribution in the exit channel. With pumps 1-9 operating at maximum throttled discharge and tailwater el 100, the turbulence over the apron was dampened (Photo 5) and the surface flow pattern showed an eddy on the east side of the exit channel. This eddy was only on the surface and did not affect the channel protection. Photo 6 depicts the same flow condition with an unthrottled discharge. There was little change to the flow pattern.

12. Operating pumps 3-7 at maximum throttled discharge and minimum tailwater produced the flow patterns shown in Photo 7. This condition caused concentrated flow in the center of the outlet channel and two small eddies along each bank line. The eddies were not strong enough to cause damage to the riprap protection on the side slopes. The unthrottled discharge (Photo 8) did not affect the flow pattern for this condition. For the same combination of pumps, a throttled discharge, and tailwater el 100, flow concentrated to the west bank line (Photo 9) due to eddies created in front of outlets 1 and 2 and 8 and 9. However, the riprap remained stable. The unthrottled condition did not affect flow patterns.

13. With pumps 1-3 and 7-9 operating at maximum throttled discharge and minimum tailwater (Photo 10), a reverse flow condition formed on the apron in front of outlets 4-6. Flow remained uniform in the exit channel, and the reverse flow did not affect channel stability. The unthrottled condition was not as turbulent on the apron, and flow remained uniform in the exit channel (Photo 11). Throttled discharge for these pumps with tailwater el 100, as shown in Photo 12, created an eddy in the middle of the exit channel. Reverse flow conditions existed downstream of bays 4, 5, and 6, but the channel protection remained stable. No change was observed for the unthrottled condition.

14. Operating pumps 1-5 at maximum throttled discharge and minimum tailwater (Photo 13) created an eddy over the entire flow depth in front of outlets 6-9. This eddy extended about 350 ft downstream into the exit channel along the east bank line. Flow concentrated along the west bank line for about 350 ft downstream, and from that point on was uniform across the channel. The unthrottled discharge for these conditions (Photo 14) shows the same flow pattern. Riprap protection remained stable for the conditions in Photos 13 and 14. Photo 15 shows pumps 1-5 operating at maximum unthrottled discharge and tailwater el 100. The eddy moved downstream and was larger; however, the riprap protection remained stable.

Velocities in the Outlet Channel

15. Model velocity measurements were made in the outlet channel initially with the original outlet apron design shown in Plate 3. All model velocities were obtained with the pump outlets operating at maximum discharge. The velocities were measured 4 ft above the channel bottom, starting at the end of the apron and extending 400 ft downstream. Plates 6 and 7 present the model velocities with pumps 1-9 operating with tailwater el 79, with and without the shutter gate, respectively. The highest measured velocity over the end of the apron was 3.5 fps with the throttled flow condition, and the average velocity was 2.3 fps in the outlet channel. The shutter gate created higher velocities just over the apron, but these higher velocities were dampened in the outlet channel where the velocities were basically the same with or without the shutter gate. Plate 8 displays the velocities for pumps 1-9 operating with tailwater el 100. The highest velocity over the apron was 3.3 fps and the average velocity in the outlet channel was 1.2 fps. For the higher tailwater elevation, the outlets were so deeply submerged that the velocities were quickly dampened.

16. Operating pumps 1-3 and 7-9 with tailwater el 79, with and without throttled flow, produced the velocities presented in Plates 9 and 10, respectively. The highest velocity over the end of the apron was 4.5 fps with a throttled flow condition, and the average velocity in the outlet channel was around 2.0 fps.

17. Plates 11-13 show the velocities obtained for pumps 3-7 operating. The velocities in Plates 11 and 12 were measured with and without throttled conditions, respectively, and tailwater el 79. The highest velocity over the end of the apron was 3.5 fps with the throttled condition and the average velocity in the outlet was 2.2 fps. Plate 13 presents unthrottled conditions with tailwater el 100, which produced a high velocity of 4.0 fps over the end of the apron and an average velocity of 1.2 fps in the outlet channel.

18. The apron of the outlet was modified by reducing the length to 35 ft (Plate 14) and adding an end sill. Velocity measurements were obtained at the same locations as before and with the maximum discharge. Operating pumps 1-9 produced the velocities presented in Plates 15-17. Velocities in Plates 15 and 16 were measured with tailwater el 79 and with throttled and unthrottled flow conditions, respectively. The highest measured velocity was

4.9 fps and the average velocity in the outlet channel was 2.5 fps. The channel protection remained stable for these conditions. Plate 17 presents unthrottled velocities for tailwater el 100. These velocities are slightly higher along the first row due to the jet off the end sill. However, the velocity was quickly dampened in the outlet channel.

19. Operating pumps 1-3 and 7-9 (Plates 18 and 19) with tailwater el 79, with and without throttled flow, produced a high velocity of 4.6 fps with a throttled condition. The riprap remained stable for these conditions.

20. Velocity measurements obtained for pumps 3-7 operating are presented in Plates 20-22. Plates 20 and 21 show velocities for tailwater el 79 with and without throttled flow. The highest velocity measured for these conditions was 3.0 fps. Unthrottled velocities in Plate 22 were measured with tailwater el 100.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

21. The riprap protection for the exit channel was designed by the US Army Engineer District, Vicksburg, based on information provided in ETL 1110-2-120* for placement in the dry at locations subject to turbulent flow caused by energy dissipators, bridge piers, and abutments. This design provided a stable channel for all conditions tested. The maximum velocity measured in the model was 4.9 fps and is well below 11.8 fps obtained from the stone stability chart in Plate 23 (Hydraulic Design Chart 712-1**). The D_{50} used to enter the chart was one-half the blanket thickness based on ETL 1110-2-120. The shutter gates had very little effect on the flow patterns and increased the velocities for only approximately 75 ft downstream from the structure.

22. The concrete apron provided adequate scour protection; however, during conditions where different combinations of pumps were operating, there was a possibility for debris to wash onto the apron. Therefore, it is recommended that the apron length be reduced and that an end sill be installed to prevent reverse flow from washing debris onto the apron and possibly causing damage. The shorter apron with an end sill performed as well as the original apron.

---

* Headquarters, US Army Corps of Engineers. 1971 (14 May). "Additional Guidance for Riprap Channel Protection," ETL 1110-2-120, US Government Printing Office, Washington, DC.

** US Army Corps of Engineers, "Hydraulic Design Criteria," prepared for Headquarters, US Army Corps of Engineers, by US Army Engineer Waterways Experiment Station, Vicksburg, MS, issued serially since 1952.

Photo 1. Original channel design

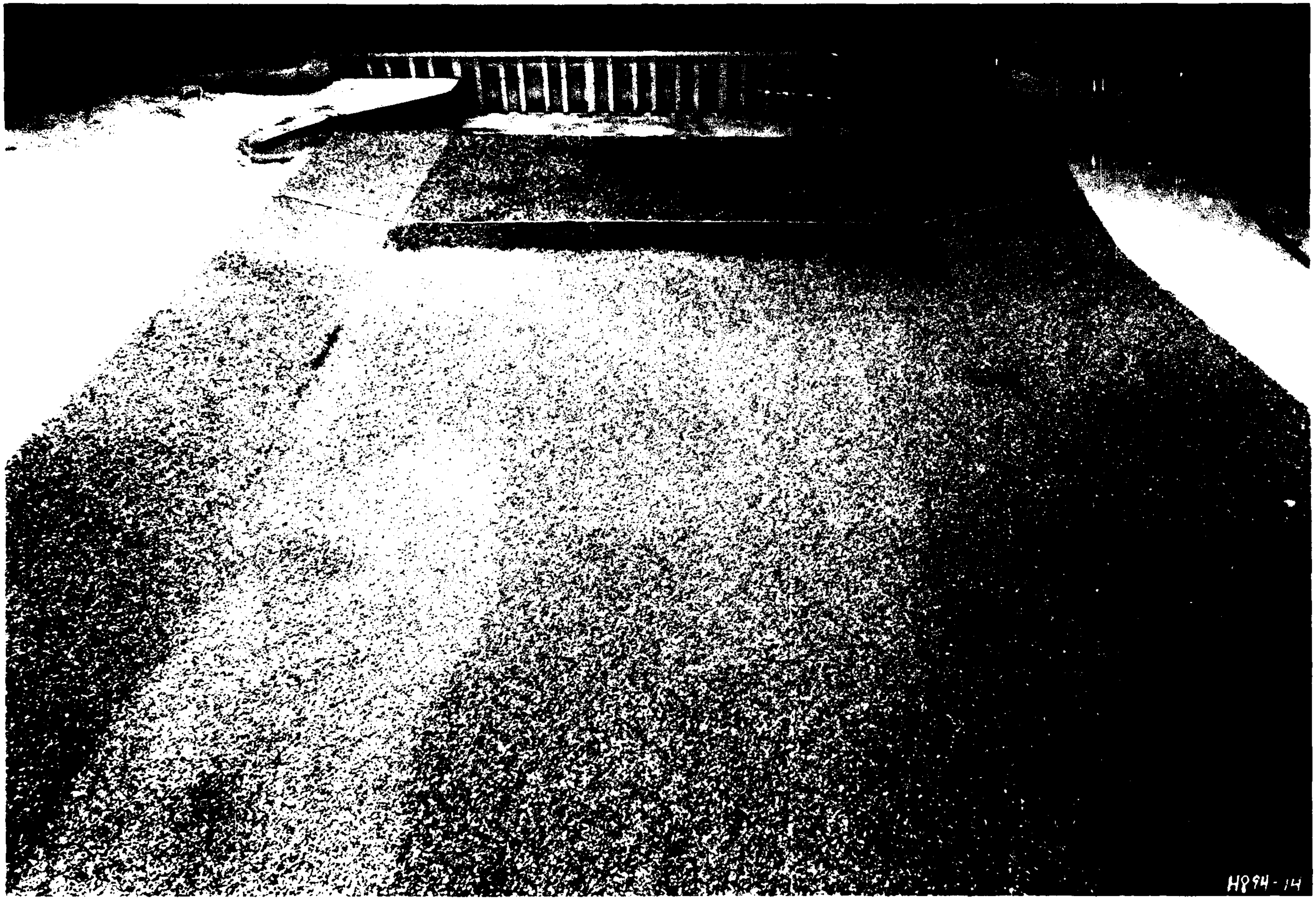


Photo 2. Riprap protection

Photo 3. Pumps 1-9 operating at maximum throttled discharge and minimum tailwater el 79

Photo 4. Pumps 1-9 operating at maximum unthrottled discharge and minimum tailwater el 79

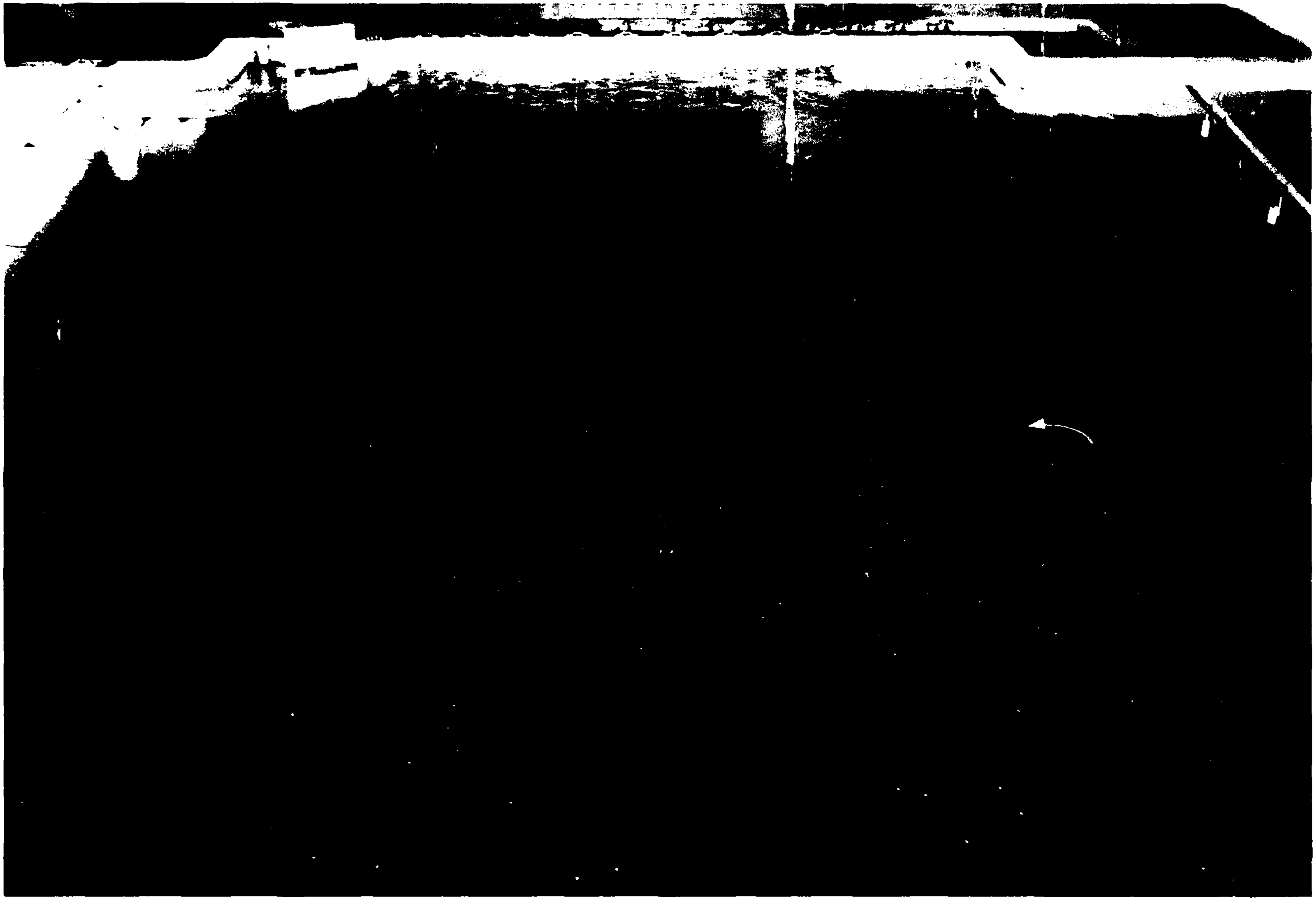


Photo 5. Pumps 1-9 operating at maximum throttled discharge and tailwater el 100

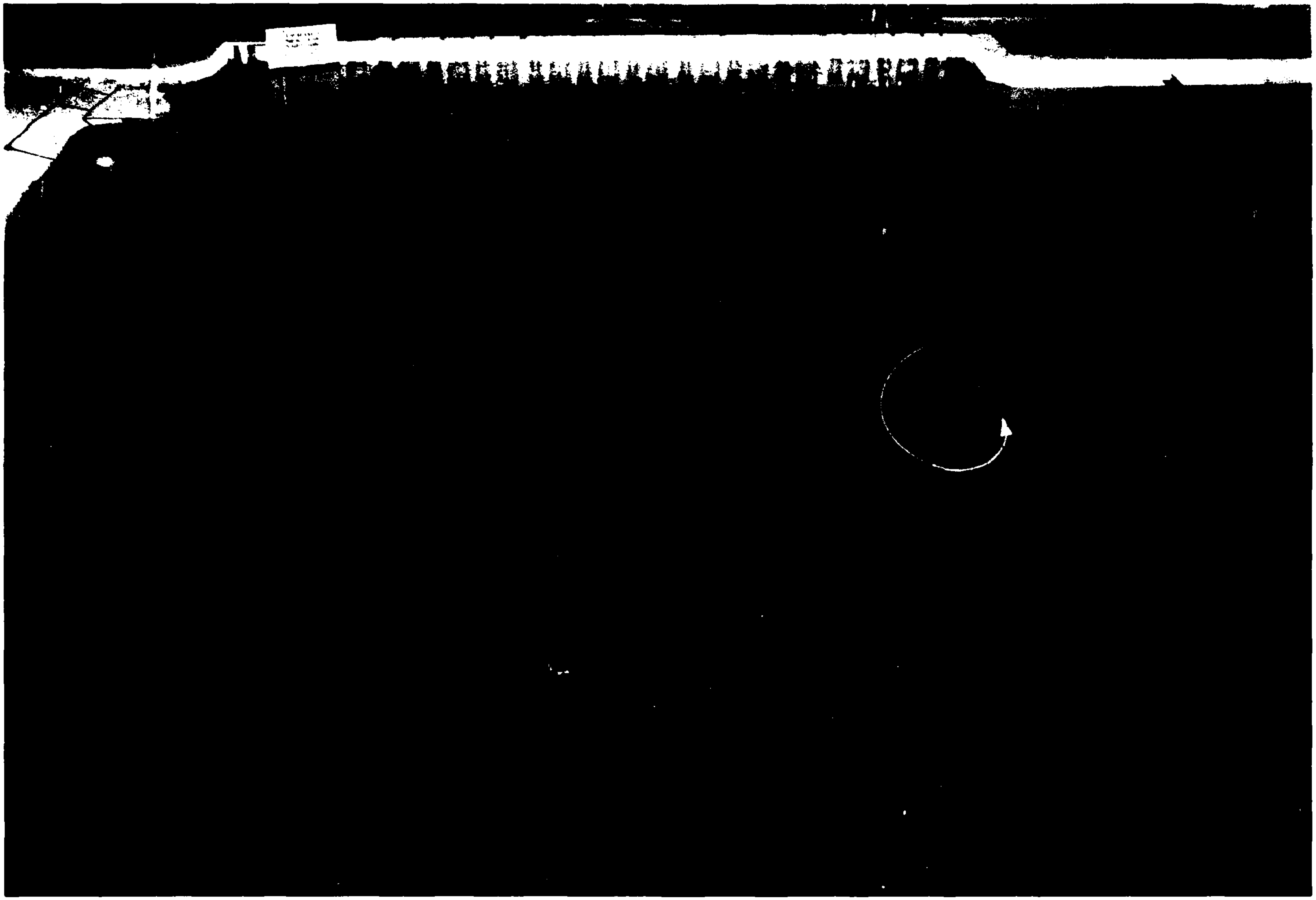


Photo 6. Pumps 1-9 operating at maximum unthrottled discharge and tailwater el 100

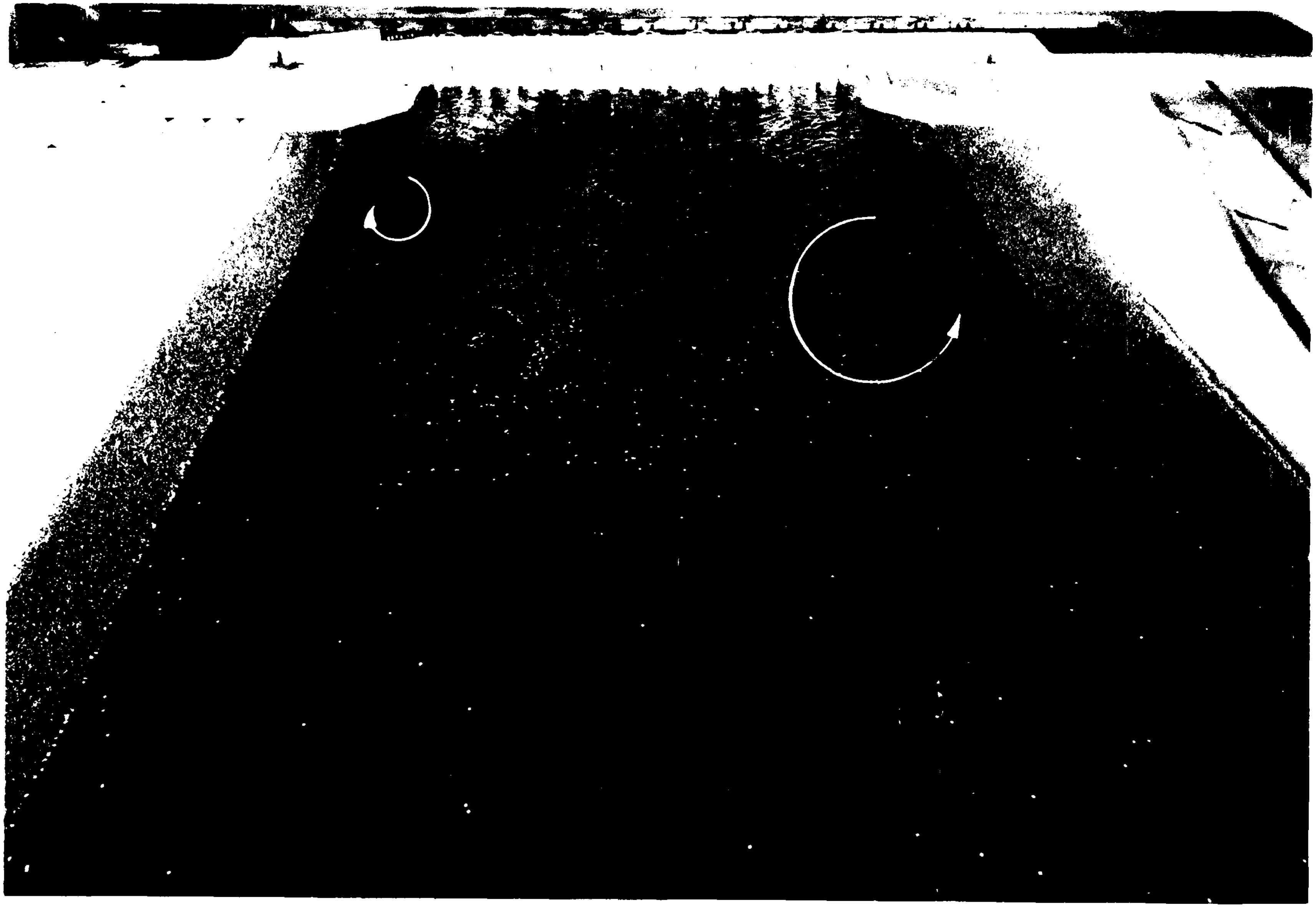


Photo 7. Pumps 3-7 operating at maximum throttled discharge and tailwater el 79

Photo 8. Pumps 3-7 operating at maximum unthrottled discharge and tailwater el 79

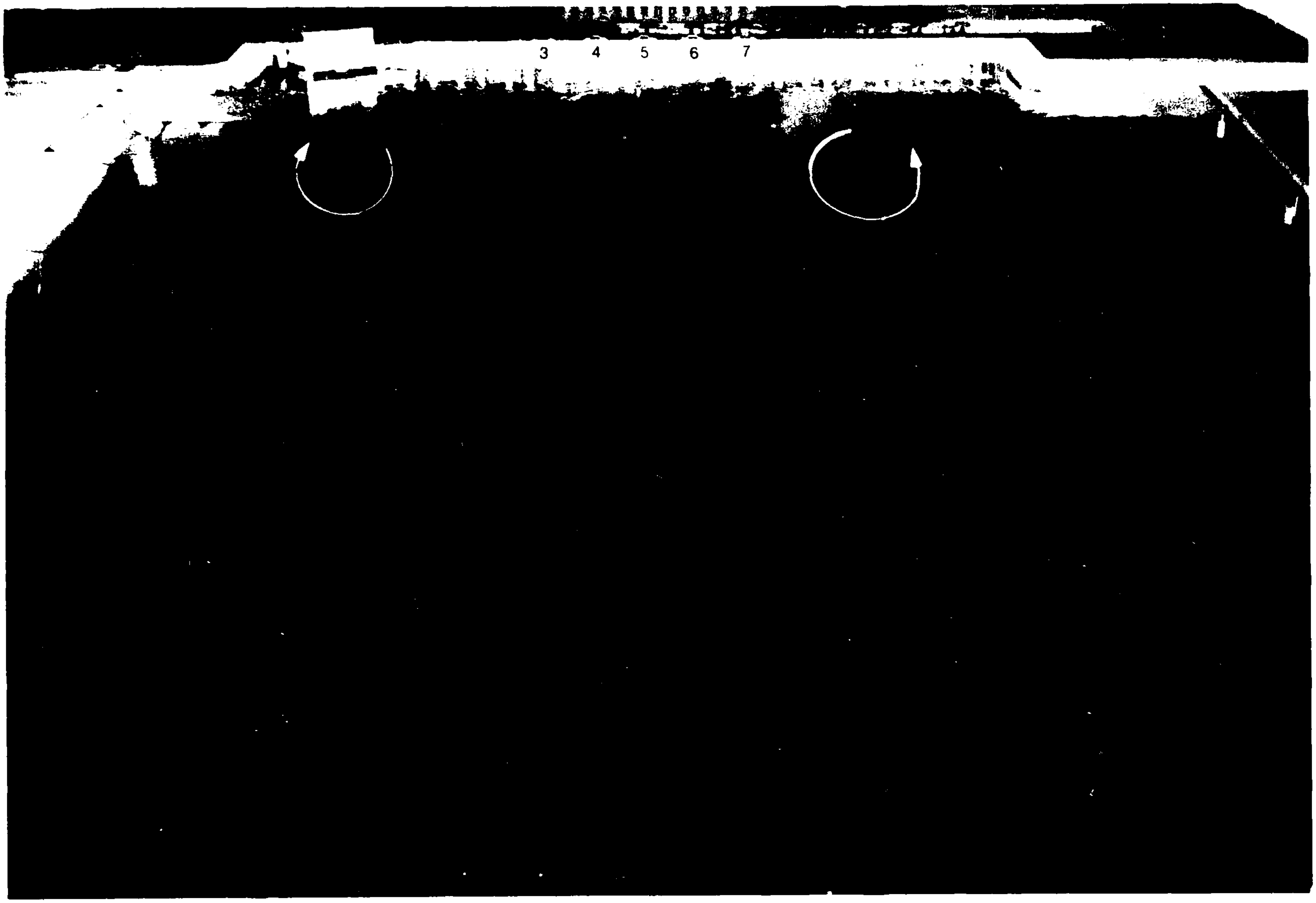


Photo 9. Pumps 3-7 operating at maximum throttled discharge and tailwater el 100

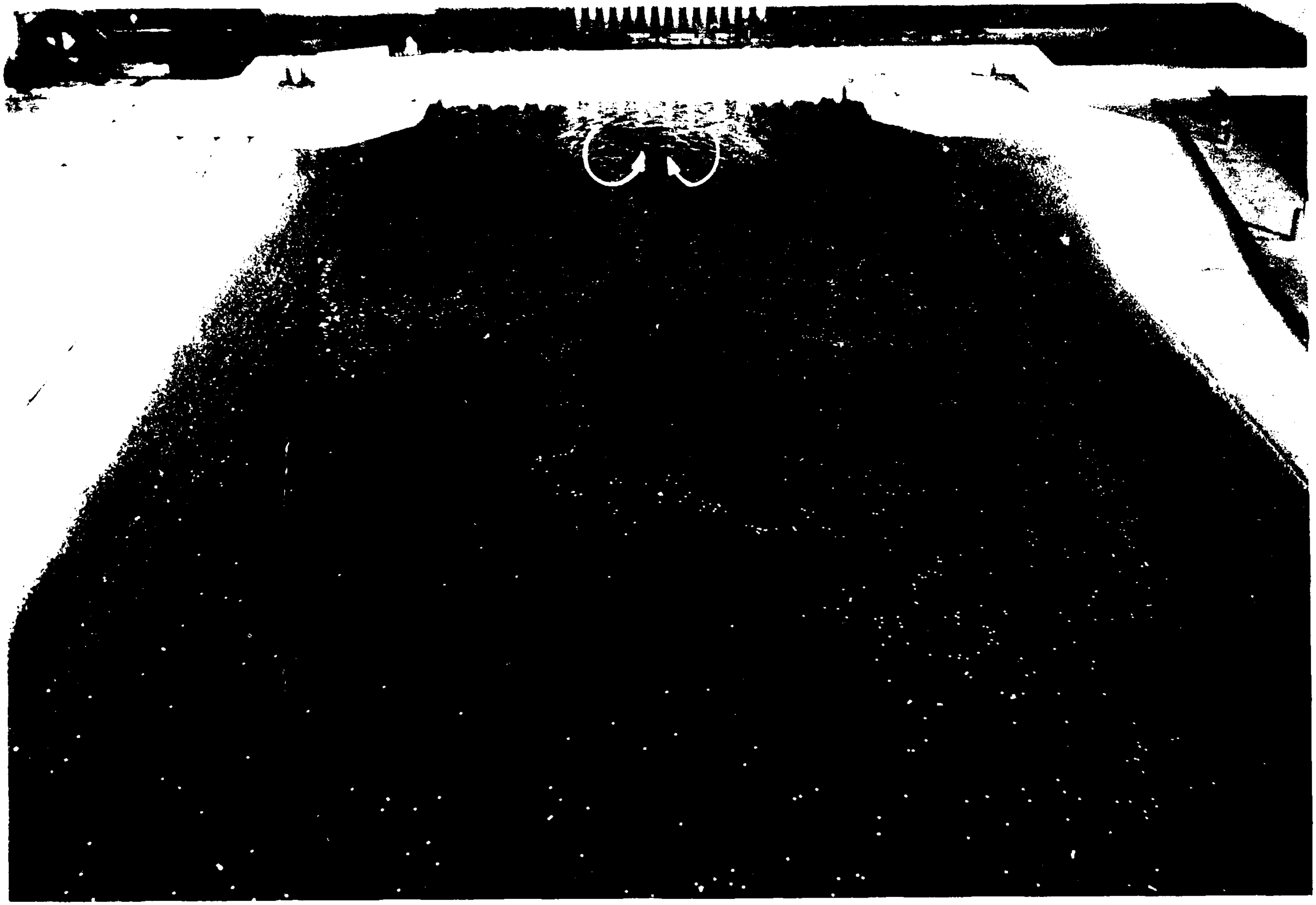


Photo 10. Pumps 1-3 and 7-9 operating at maximum throttled discharge and tailwater el 79

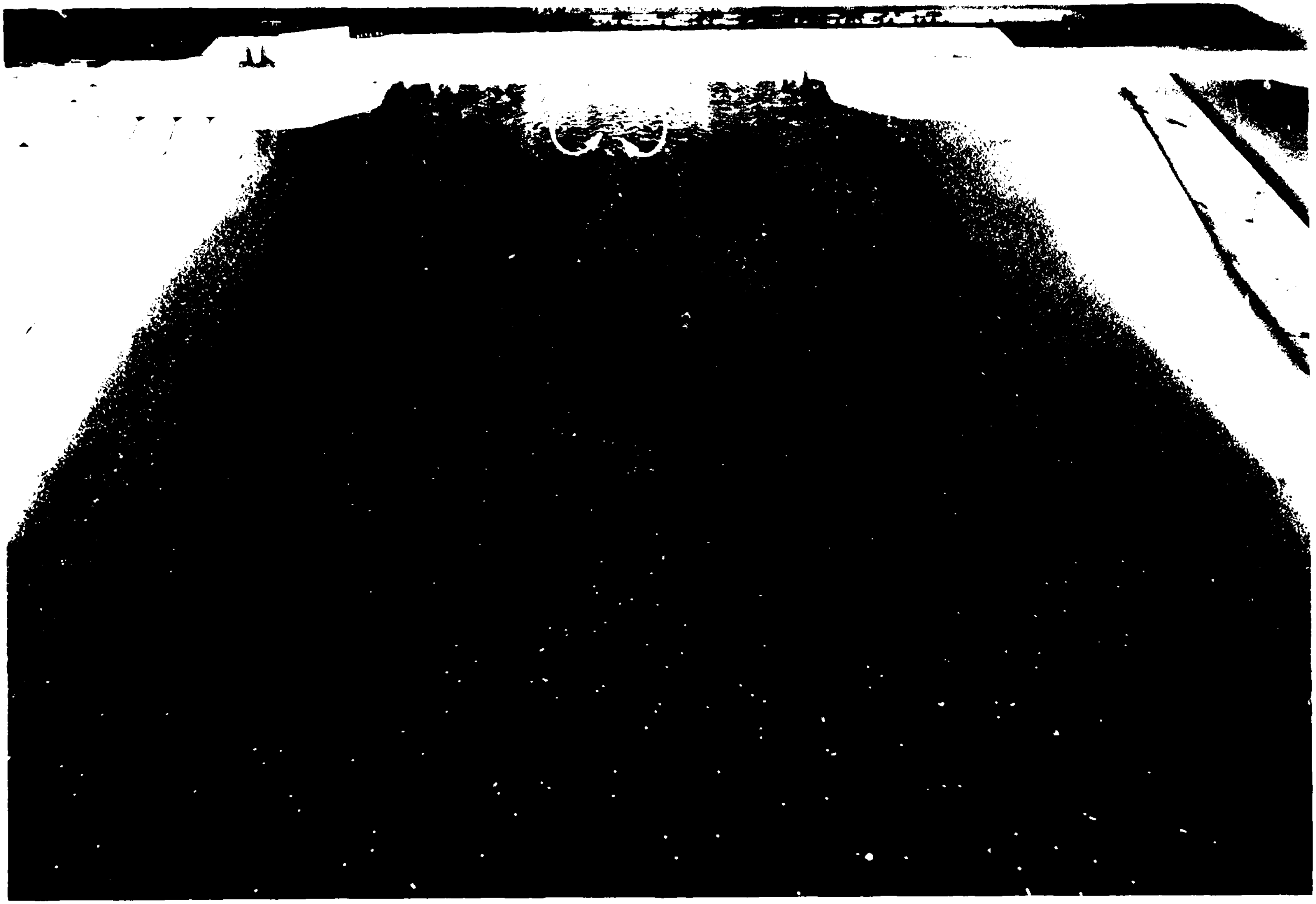


Photo 11. Pumps 1-3 and 7-9 operating at maximum unthrottled discharge and tailwater el 79

Photo 12. Pumps 1-3 and 7-9 operating at maximum throttled discharge and tailwater el 100

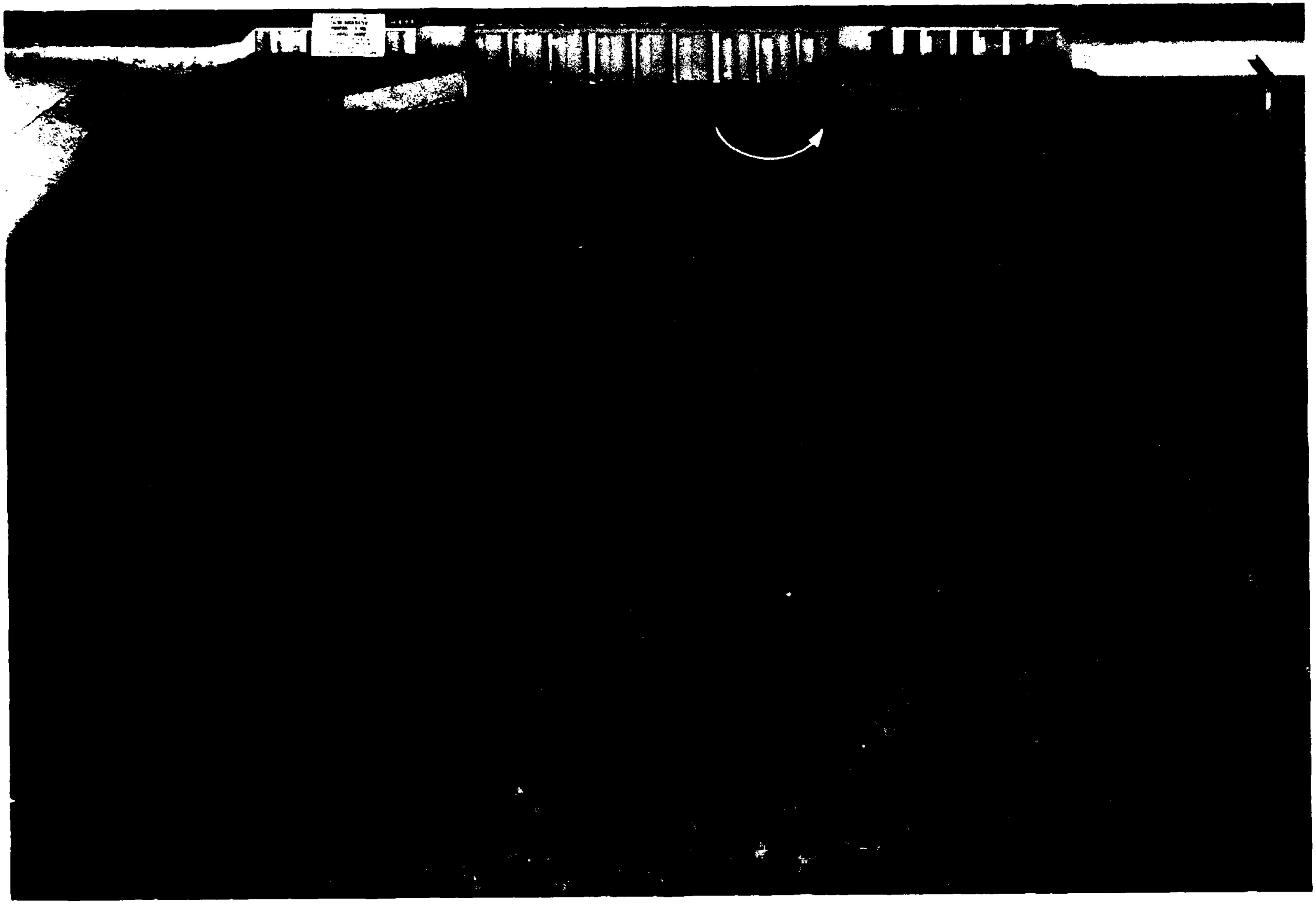


Photo 13. Operating pumps 1-5 at maximum throttled discharge and tailwater el 79

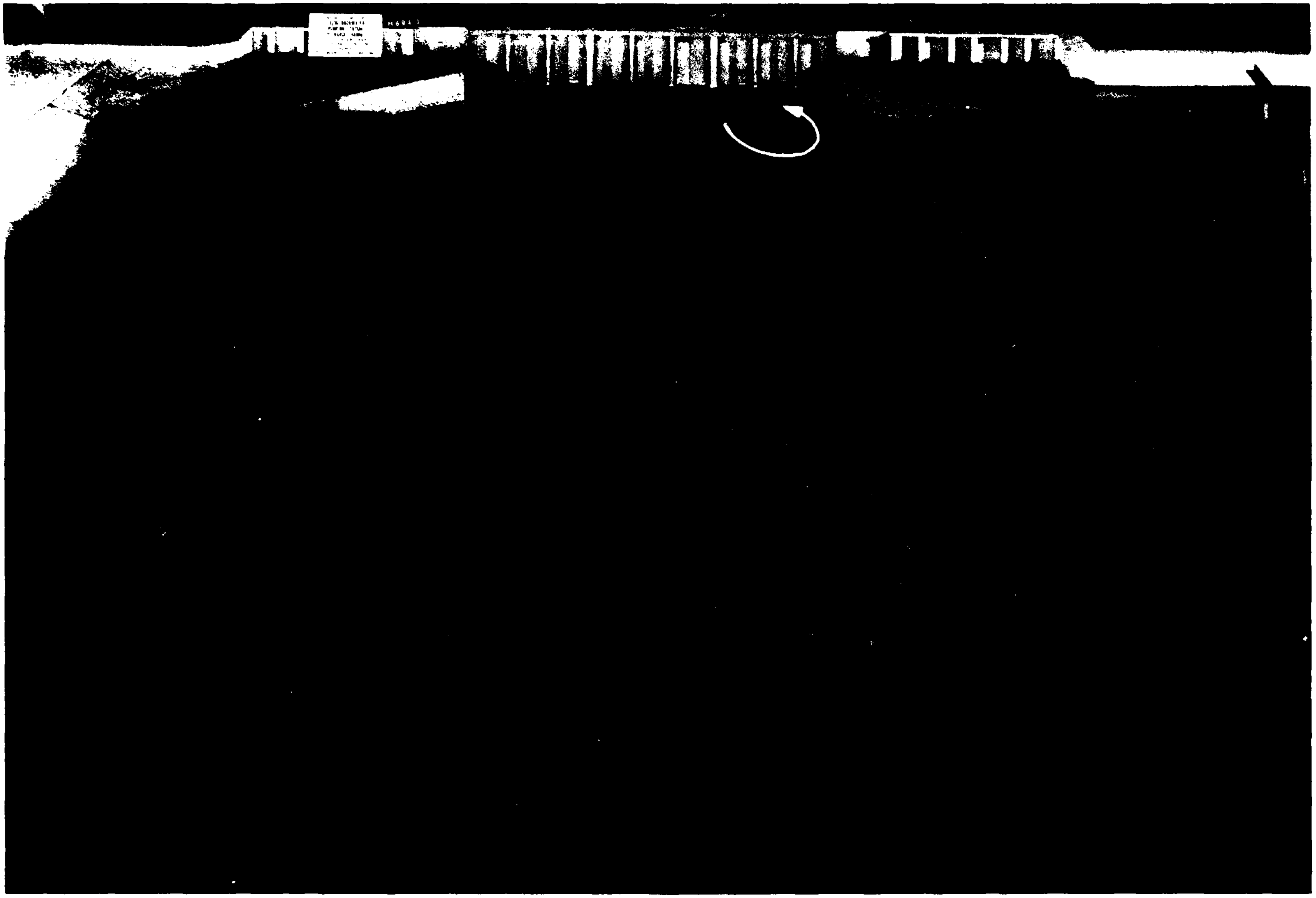


Photo 14. Operating pumps 1-5 at maximum unthrottled discharge and tailwater el 79

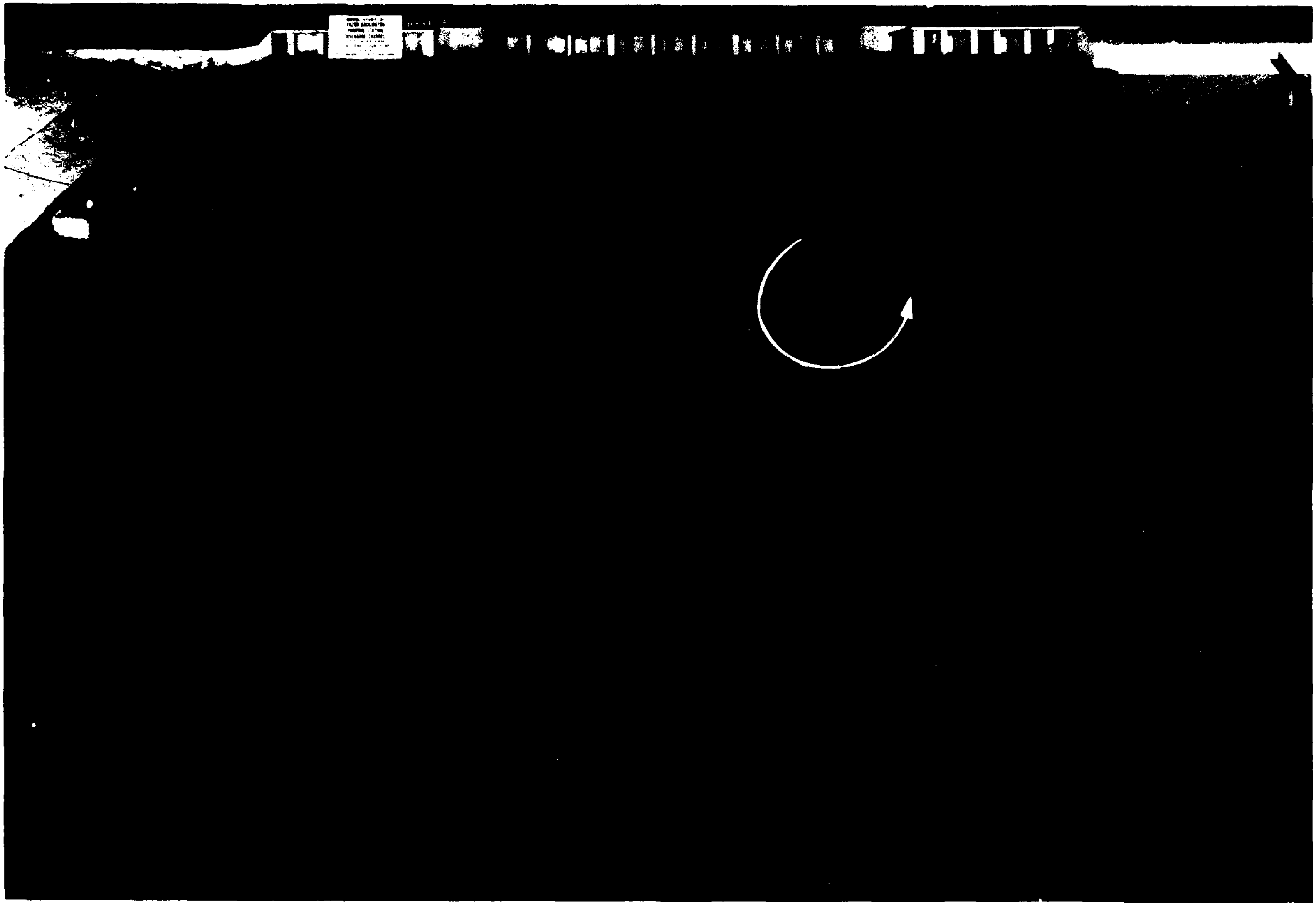
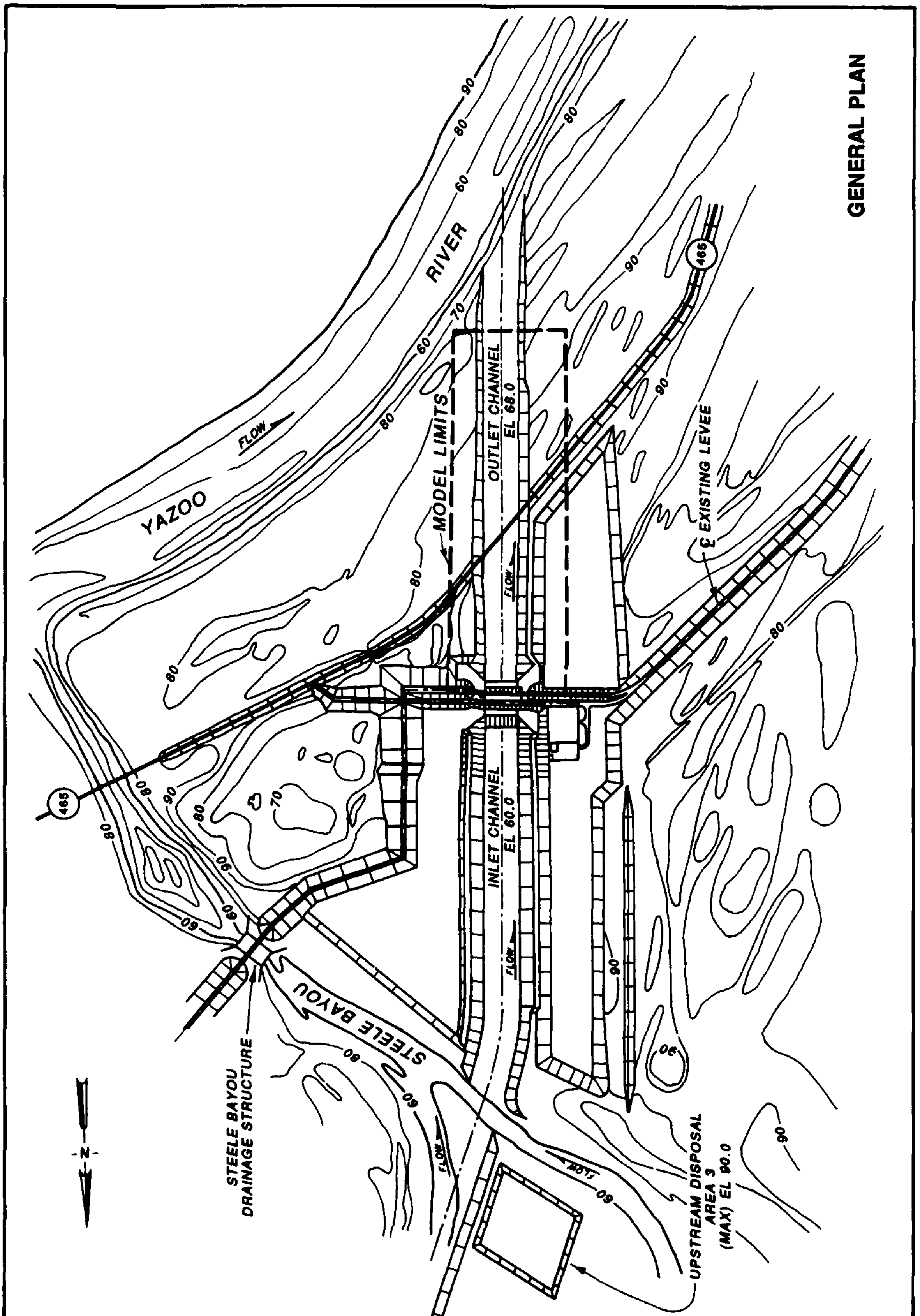
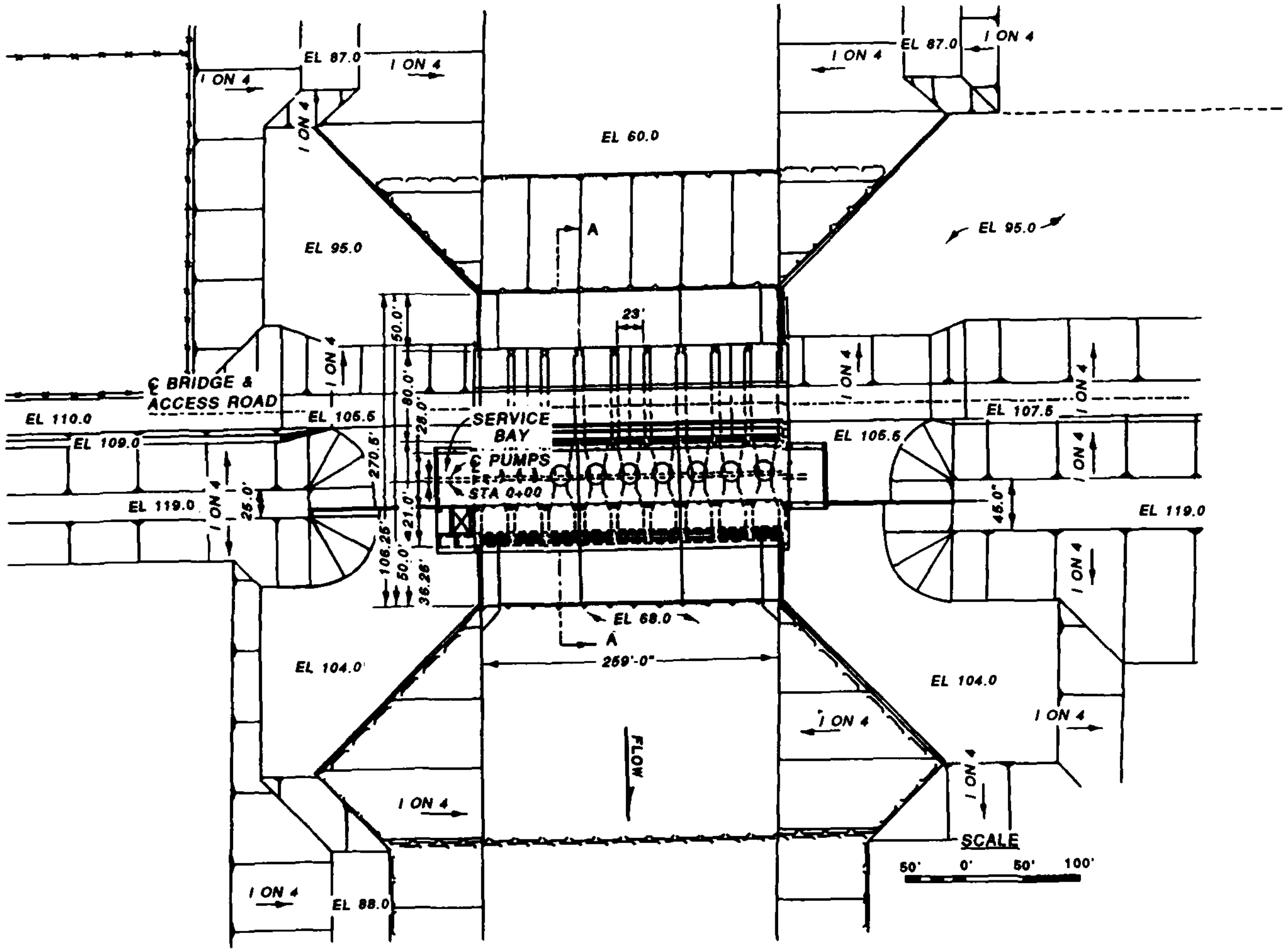


Photo 15. Operating pumps 1-5 at maximum unthrottled discharge and tailwater el 100



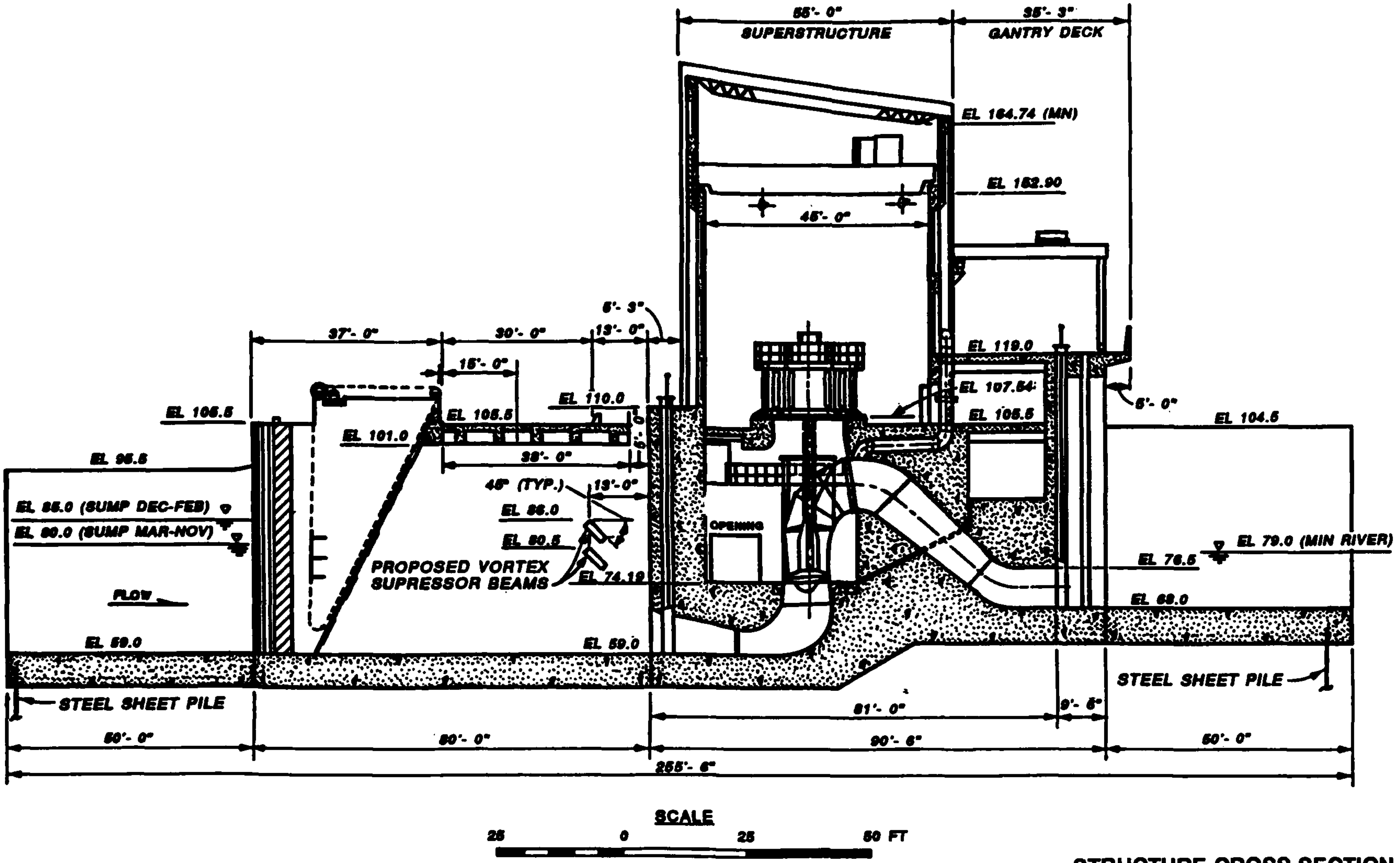
GENERAL PLAN

PLATE 2



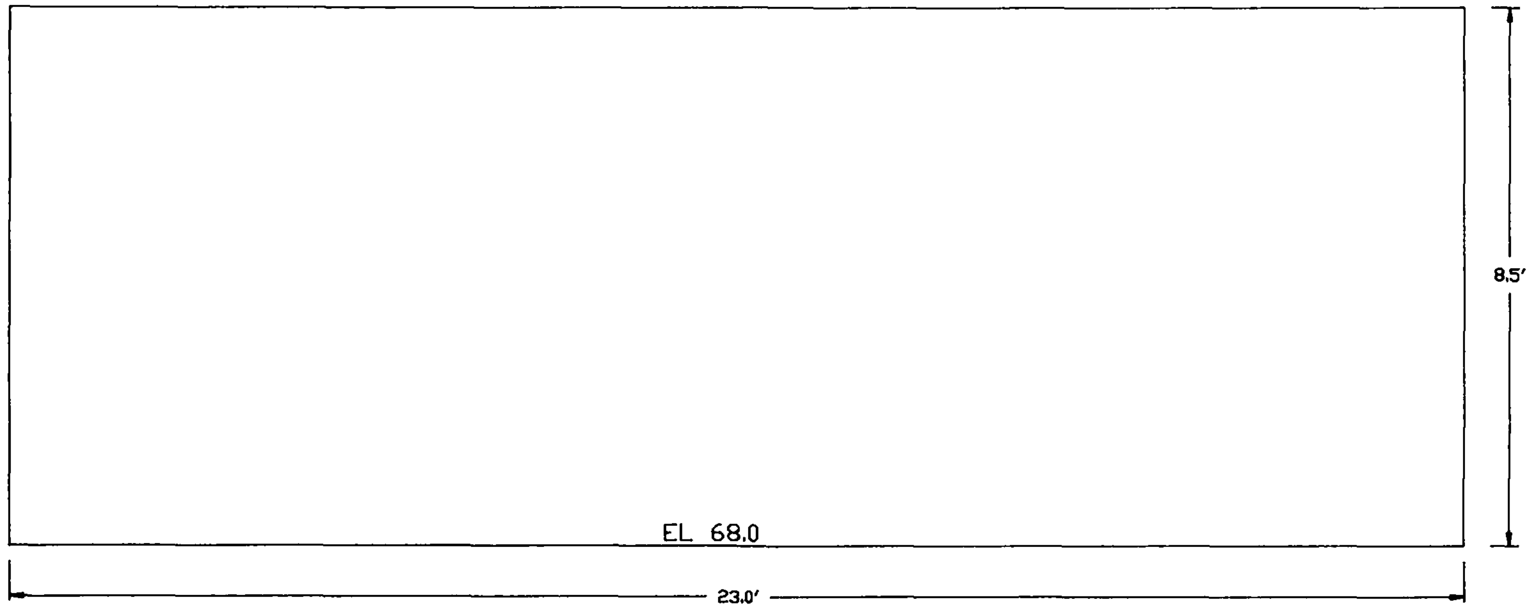
NOTE: Section A-A shown in Plate 3.

STRUCTURE PLAN

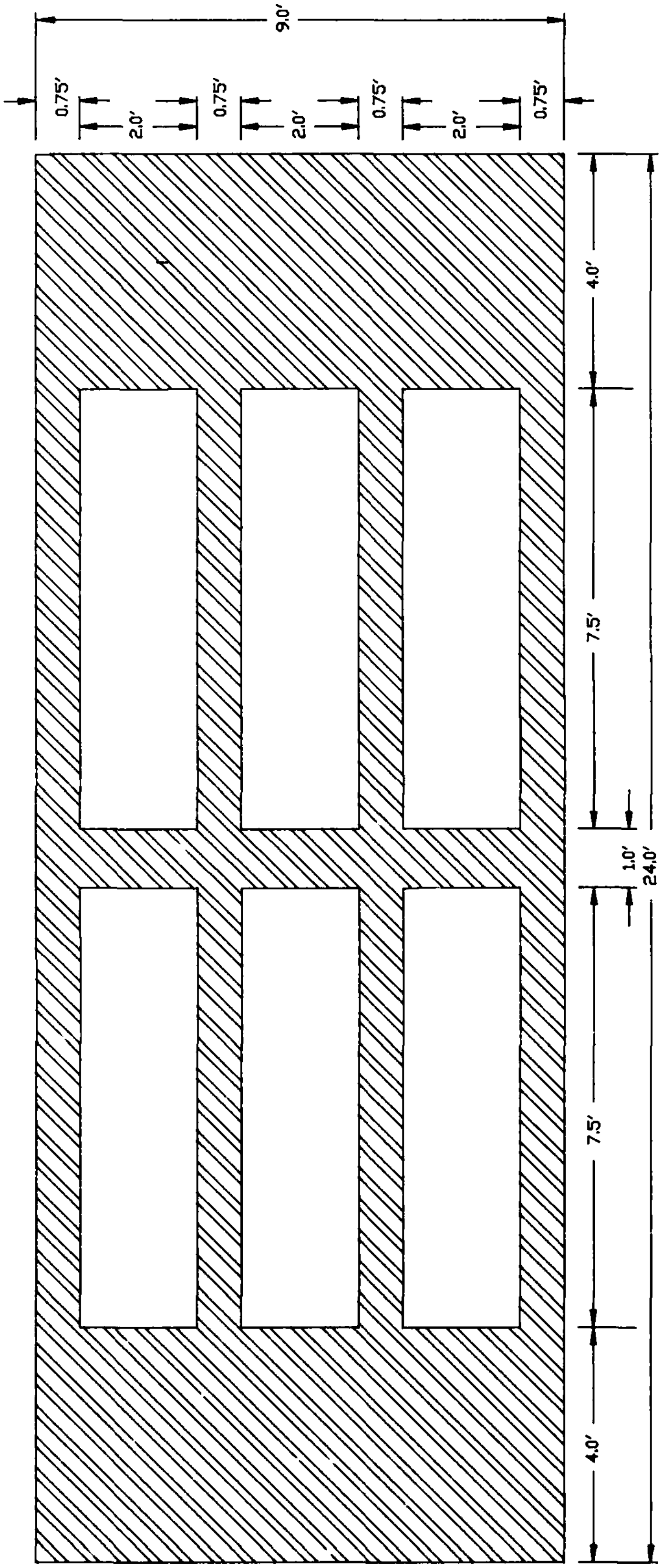


STRUCTURE CROSS SECTION
ORIGINAL DESIGN

PLATE 4

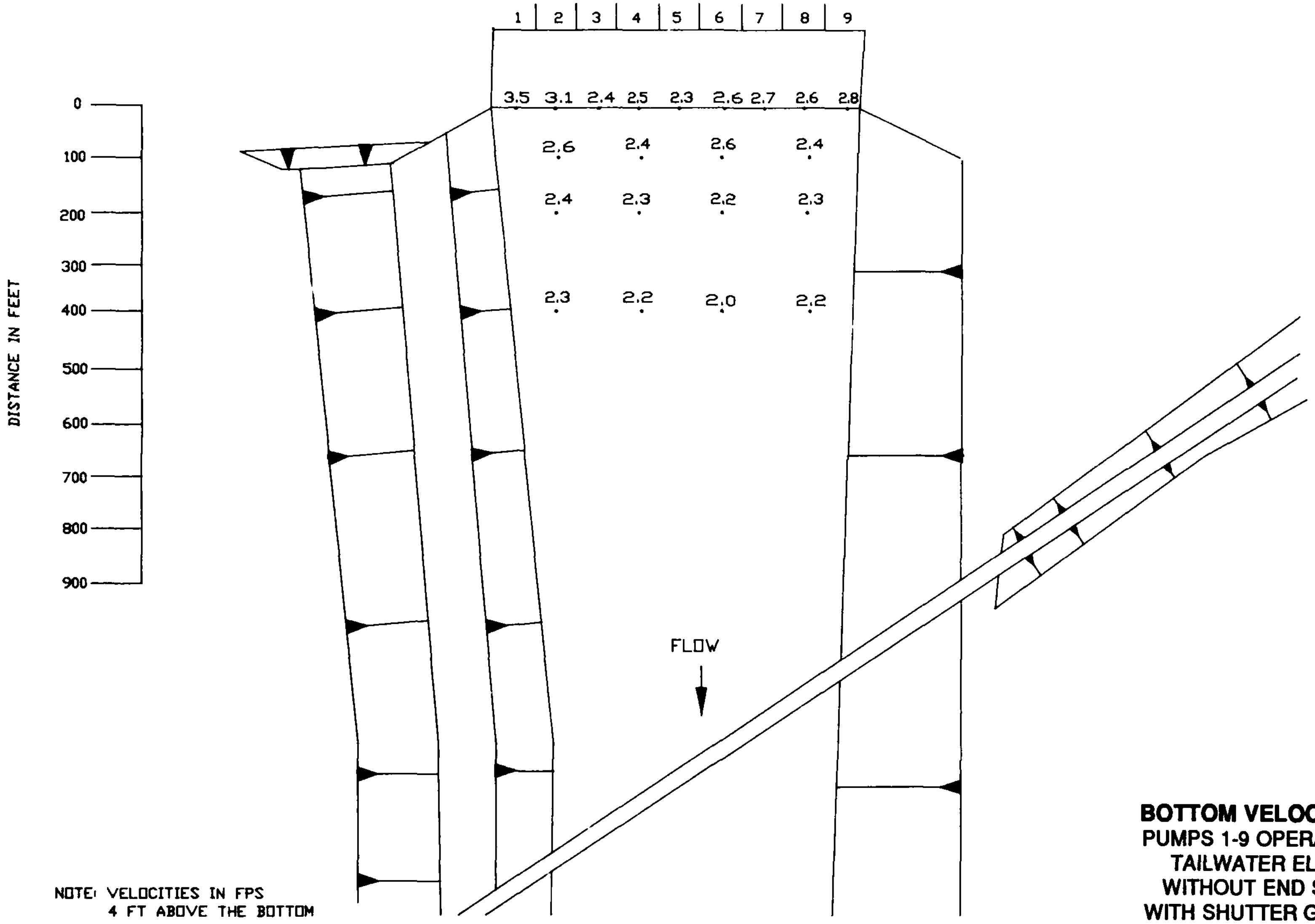


OUTLET PORT OPENING
AREA 195.5 SQ FT
MAXIMUM DISCHARGE 1,460 CFS



SHUTTER GATE
PORT AREA 15 SQ FT
6 PORTS PER GATE

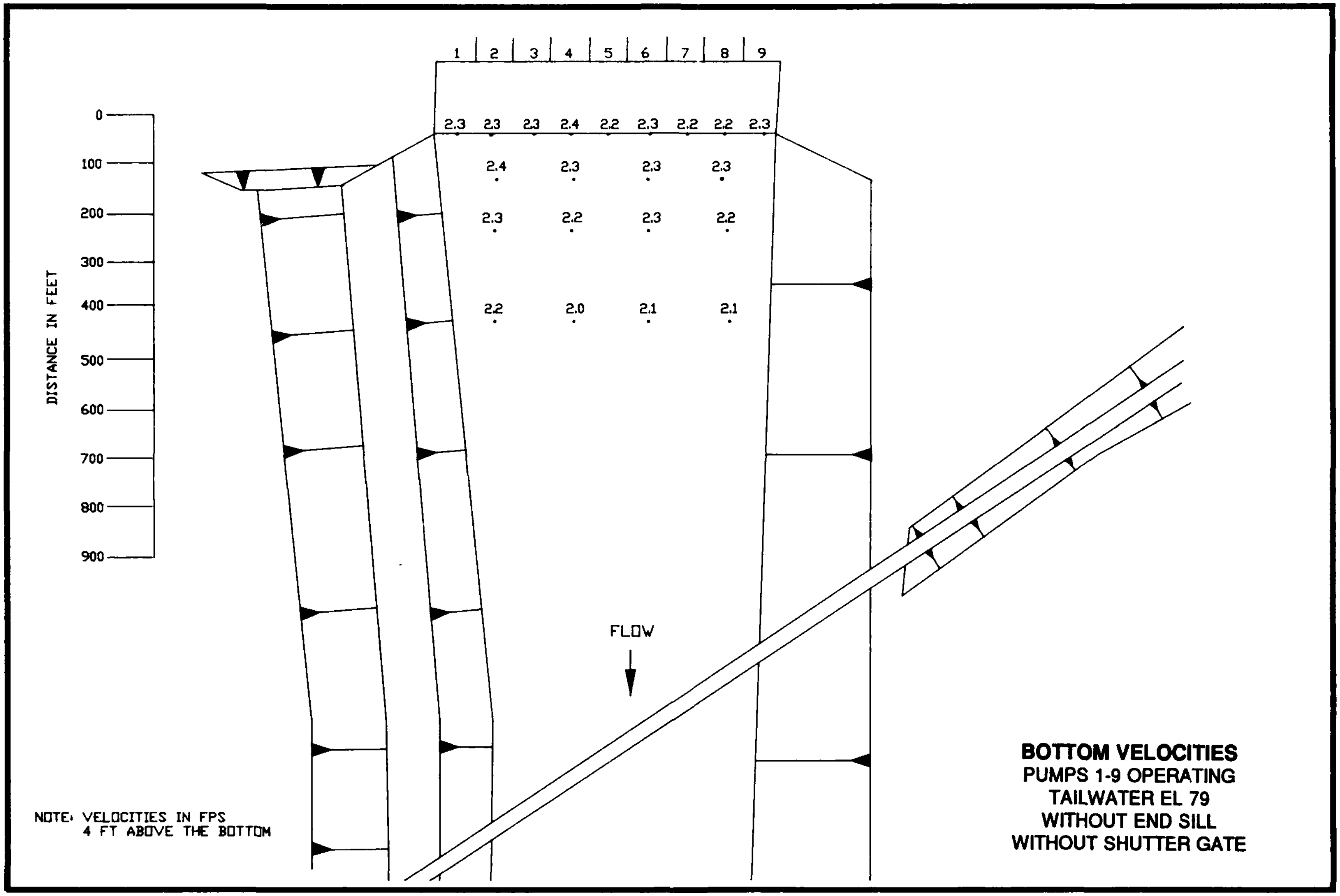
PLATE 5



NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM

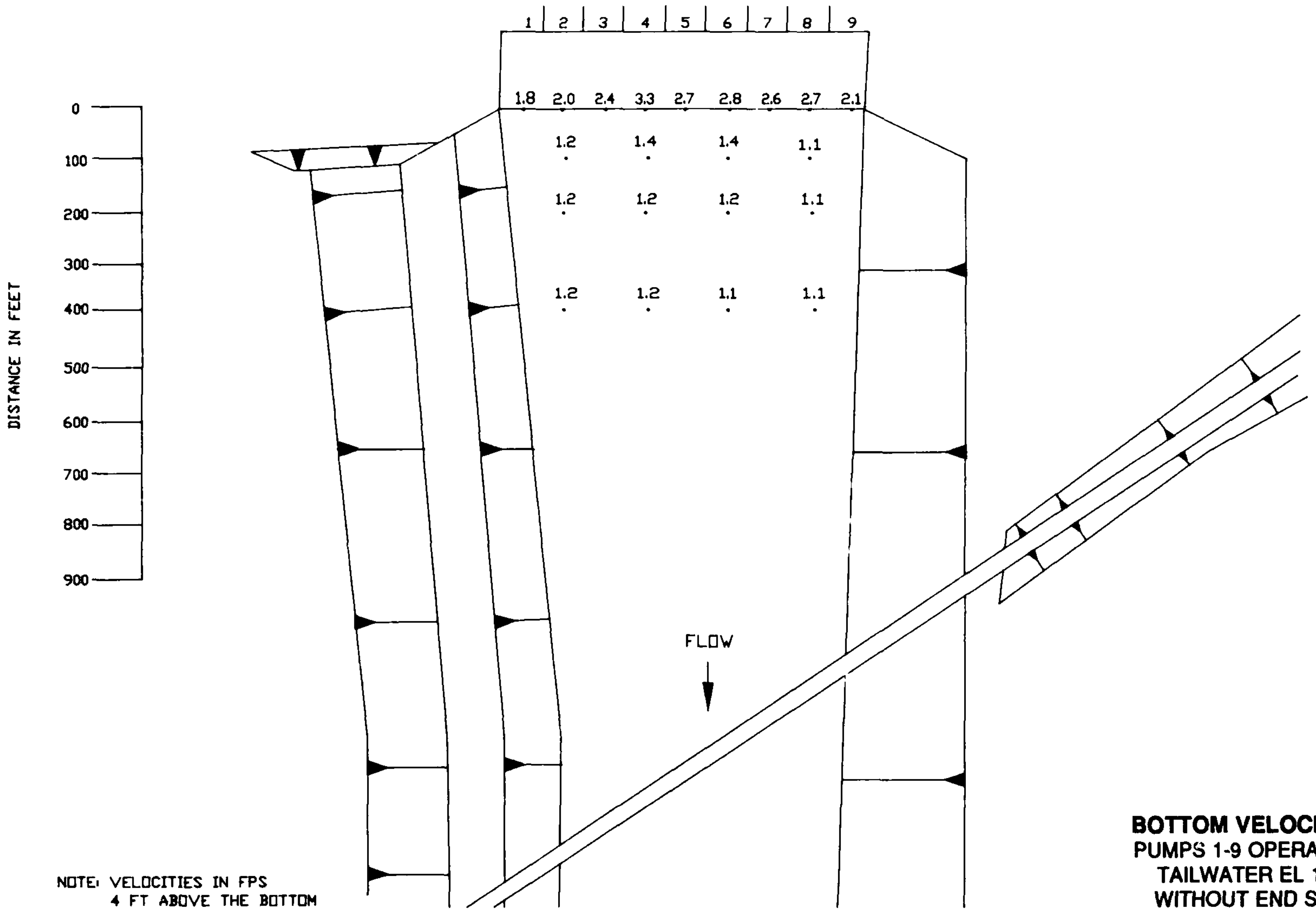
BOTTOM VELOCITIES
PUMPS 1-9 OPERATING
TAILWATER EL 79
WITHOUT END SILL
WITH SHUTTER GATES

PLATE 6



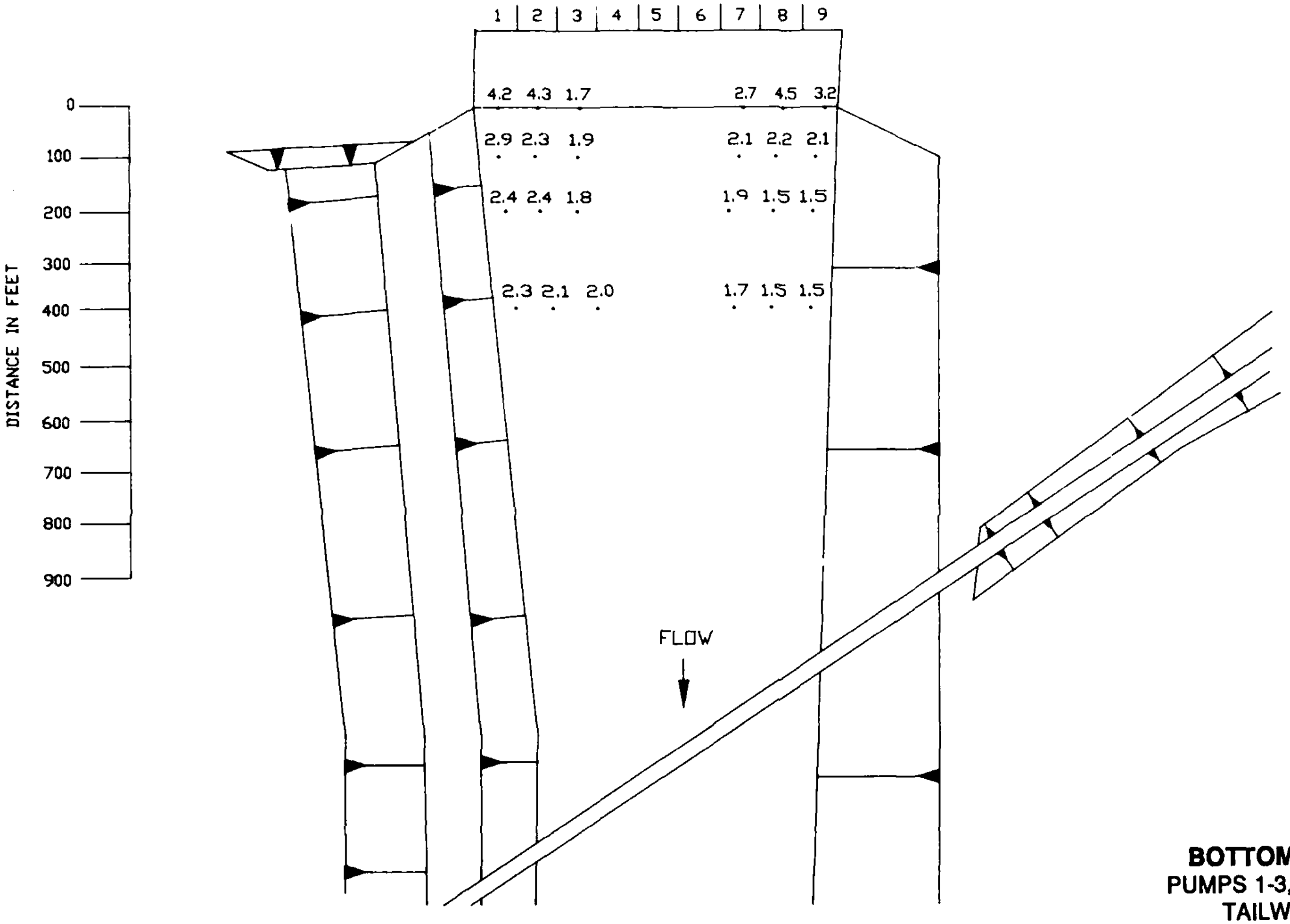
BOTTOM VELOCITIES
PUMPS 1-9 OPERATING
TAILWATER EL 79
WITHOUT END SILL
WITHOUT SHUTTER GATE

NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM



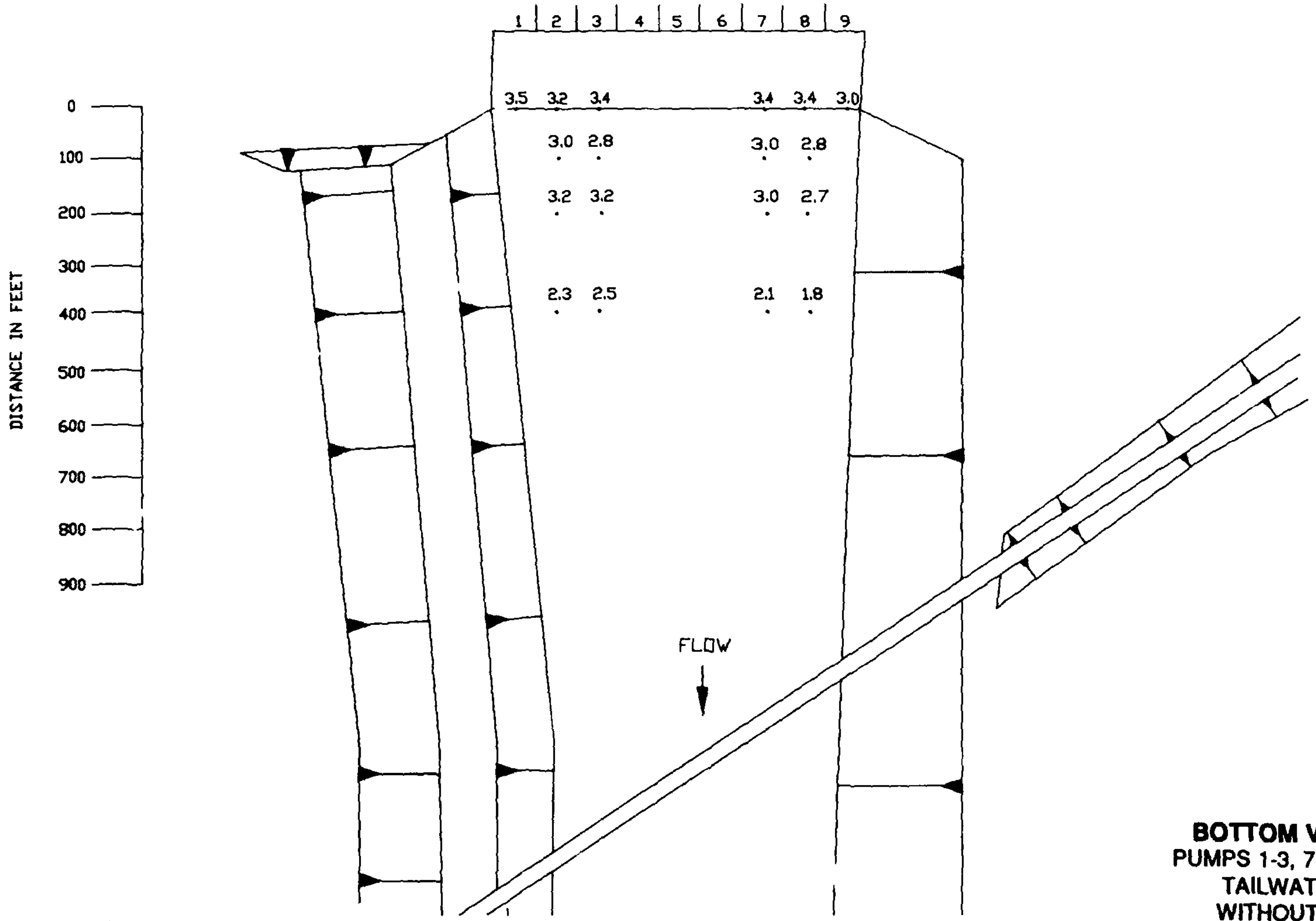
NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM

BOTTOM VELOCITIES
PUMPS 1-9 OPERATING
TAILWATER EL 100
WITHOUT END SILL
WITH SHUTTER GATES



BOTTOM VELOCITIES
PUMPS 1-3, 7-9 OPERATING
TAILWATER EL 79
WITHOUT END SILL
WITH SHUTTER GATES

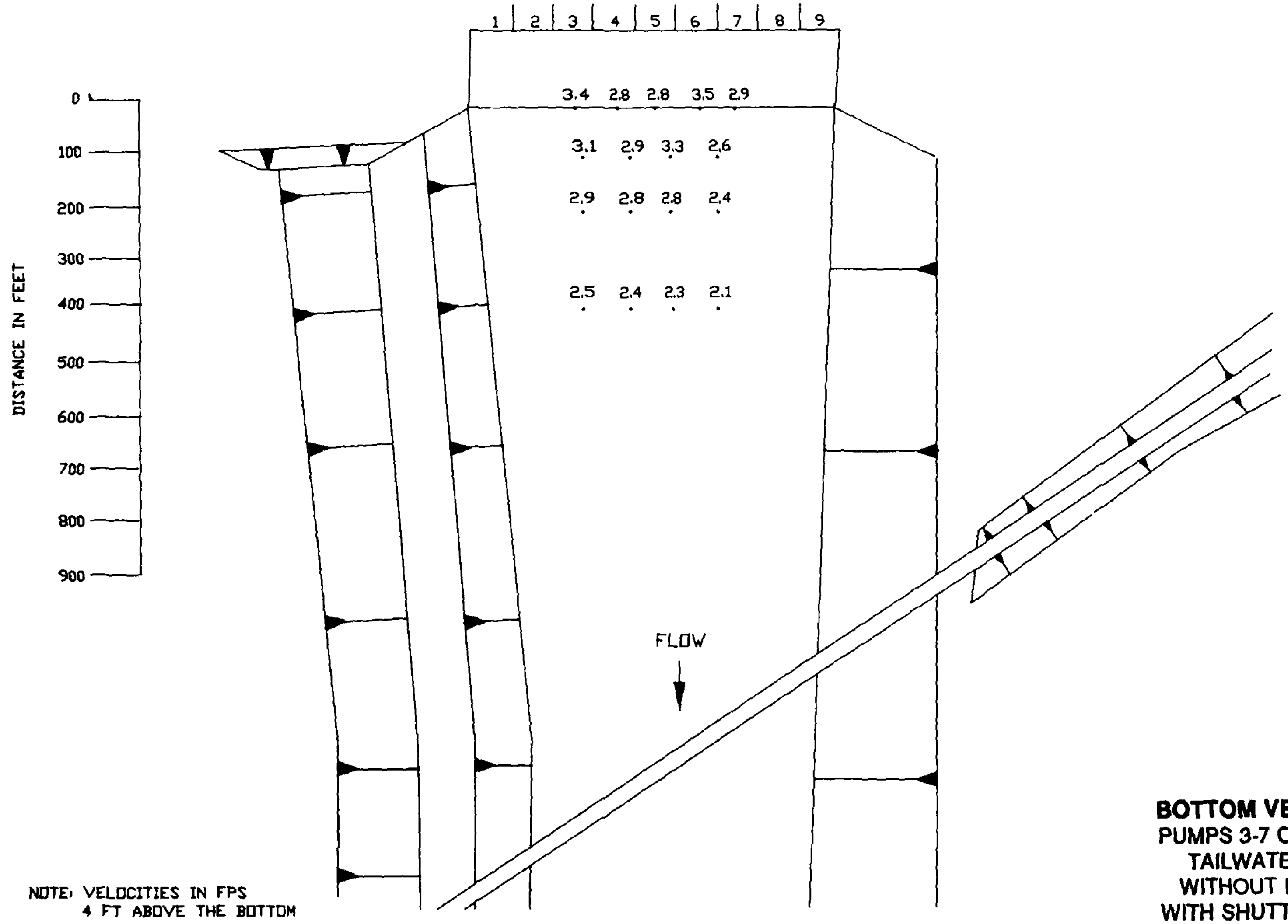
NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM



NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM

BOTTOM VELOCITIES
PUMPS 1-3, 7-9 OPERATING
TAILWATER EL 79
WITHOUT END SILL
WITHOUT SHUTTER GATES

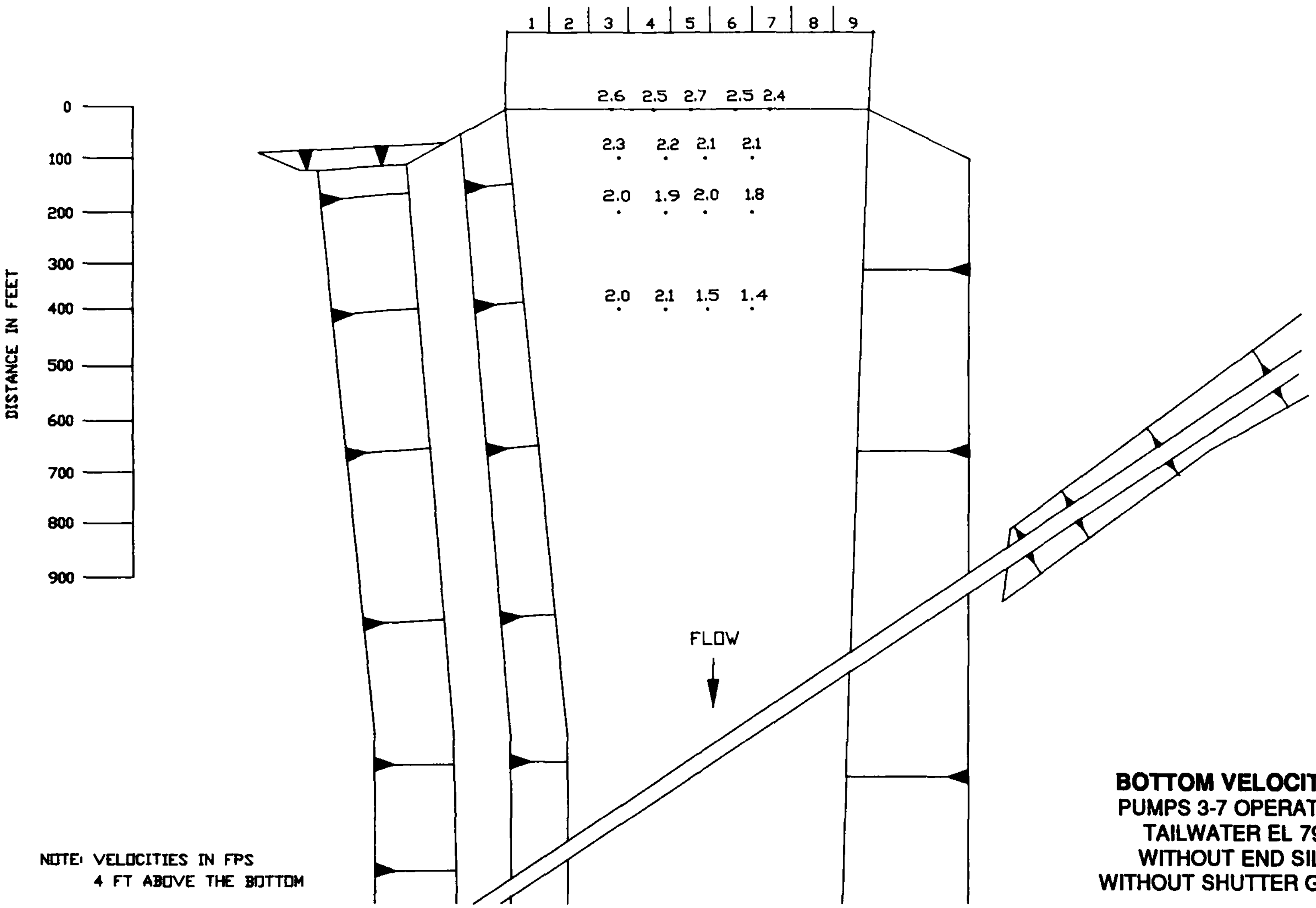
PLATE 10



NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM

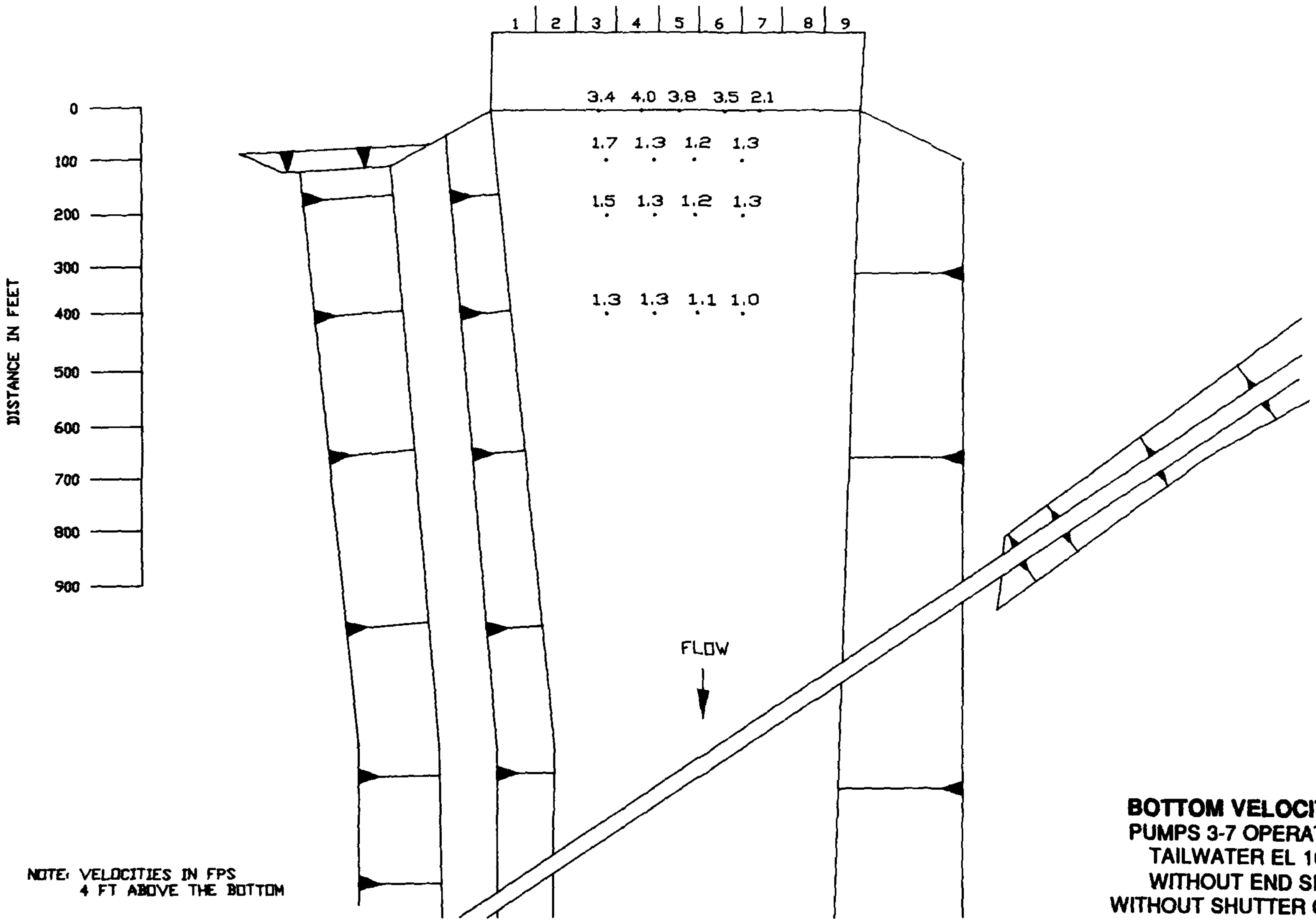
BOTTOM VELOCITIES
PUMPS 3-7 OPERATING
TAILWATER EL 79
WITHOUT END SILL
WITH SHUTTER GATES

PLATE 11



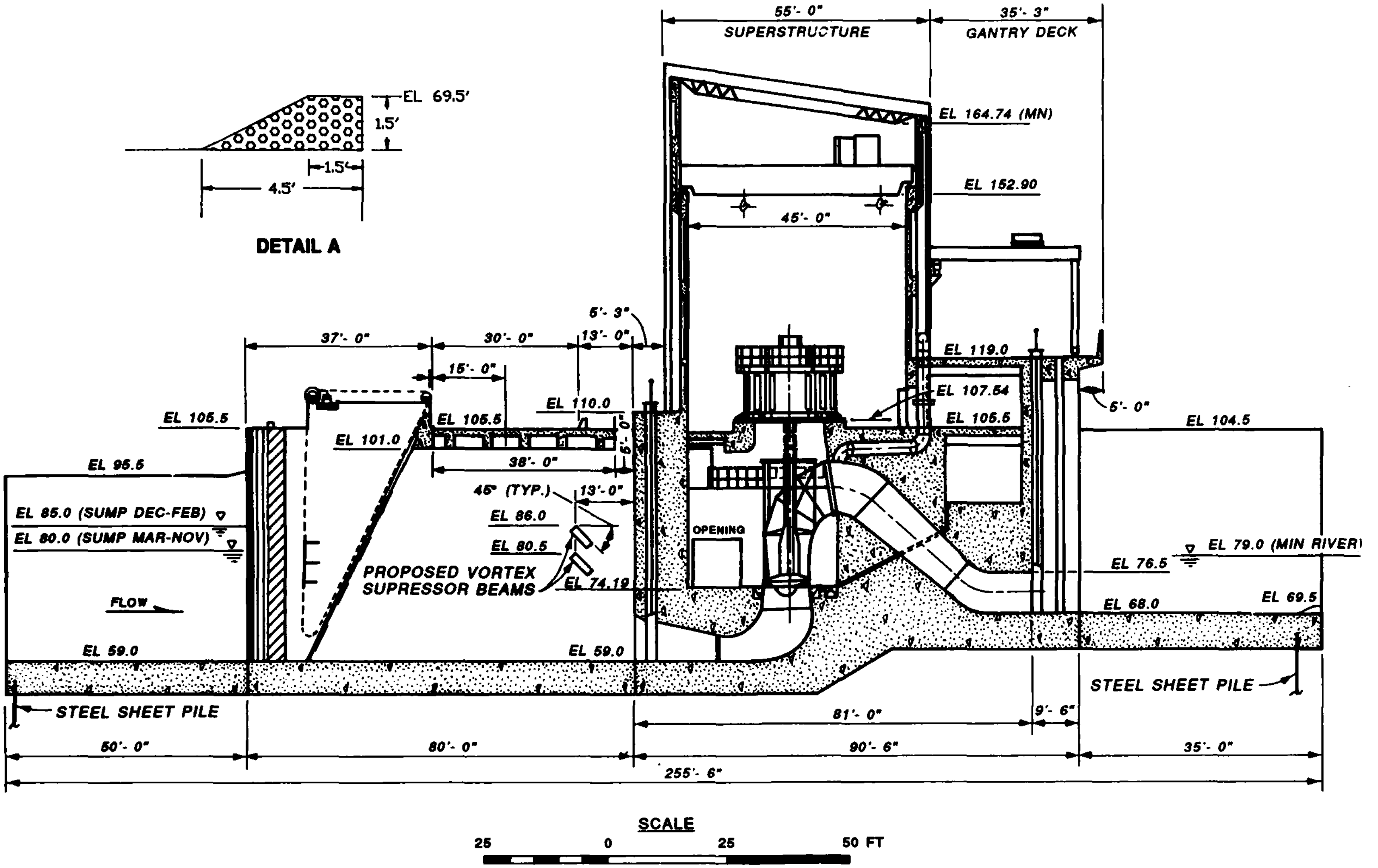
NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM

BOTTOM VELOCITIES
PUMPS 3-7 OPERATING
TAILWATER EL 79
WITHOUT END SILL
WITHOUT SHUTTER GATES



NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM

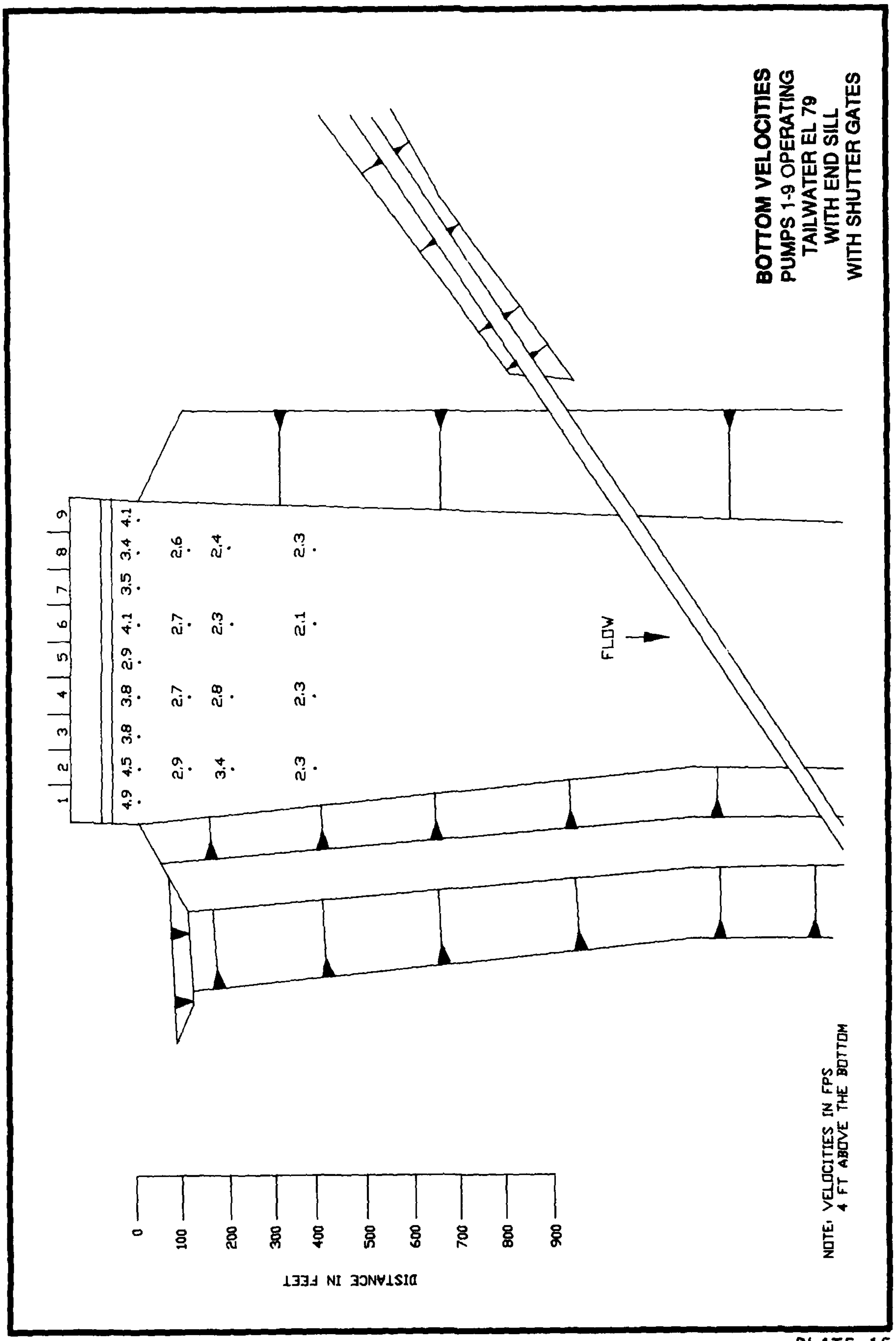
BOTTOM VELOCITIES
PUMPS 3-7 OPERATING
TAILWATER EL 100
WITHOUT END SILL
WITHOUT SHUTTER GATES



DETAIL A

SHORTENED APRON

PLATE 14

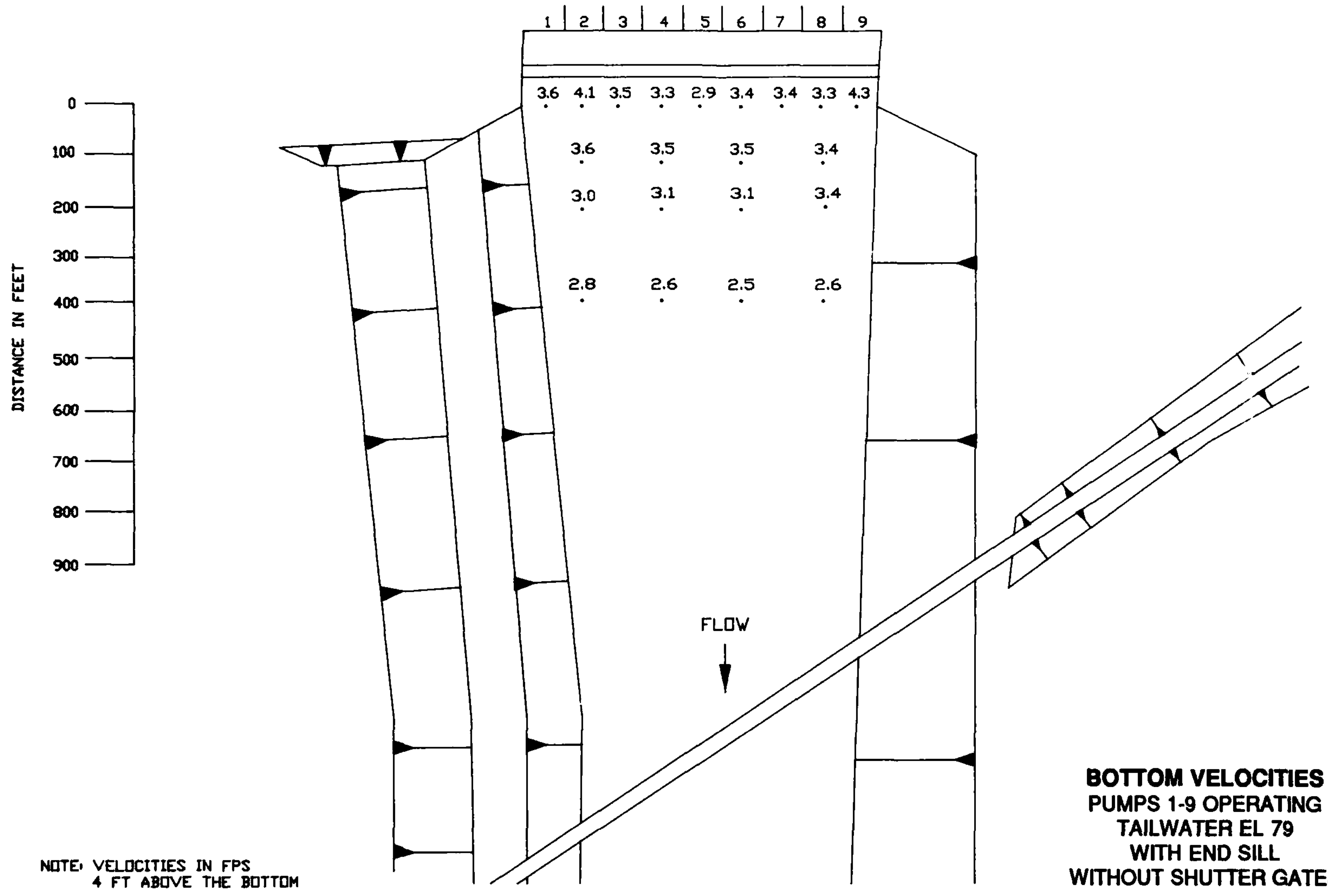


BOTTOM VELOCITIES
PUMPS 1-9 OPERATING
TAILWATER EL 79
WITH END SILL
WITH SHUTTER GATES

NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM

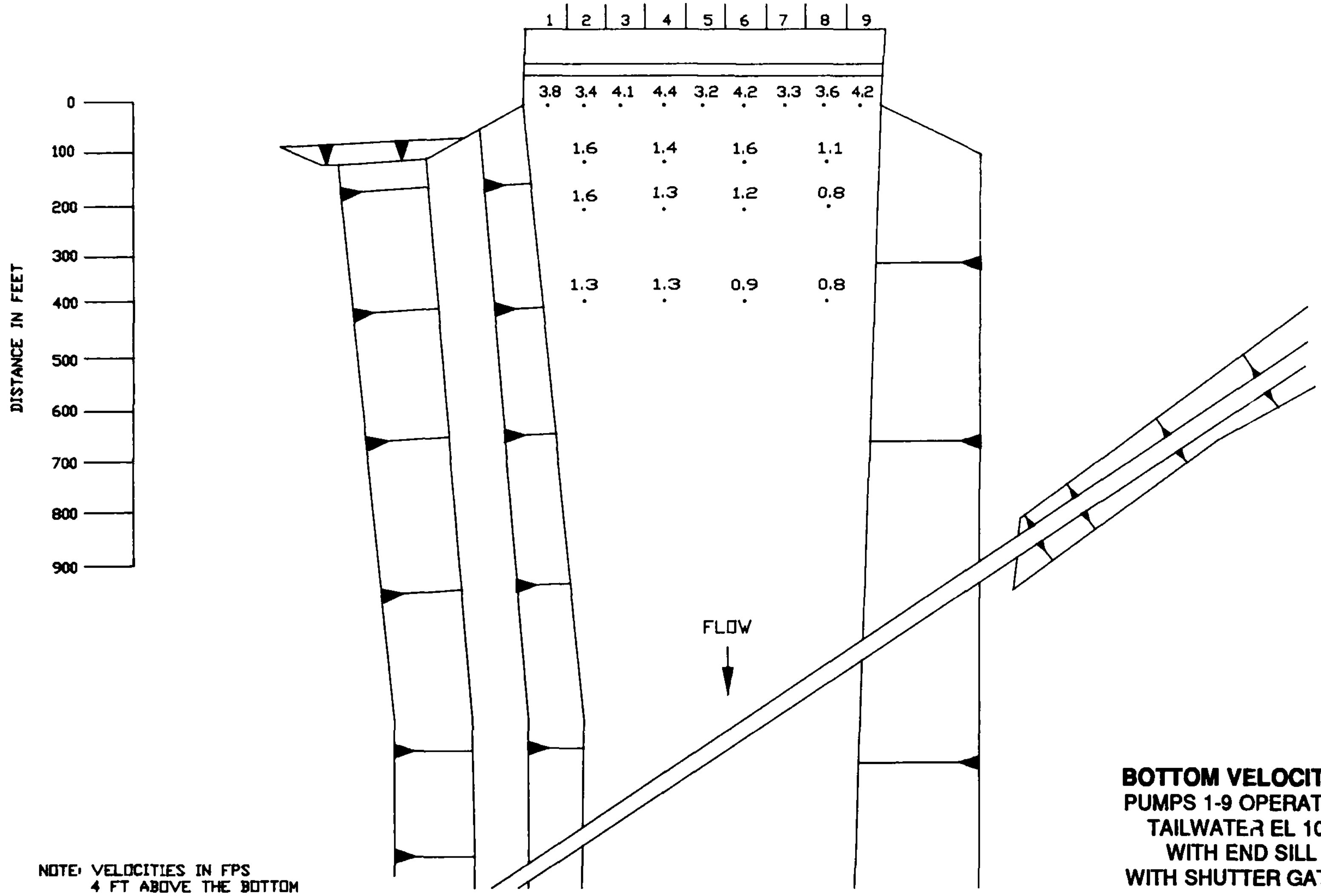
PLATE 15

PLATE 16



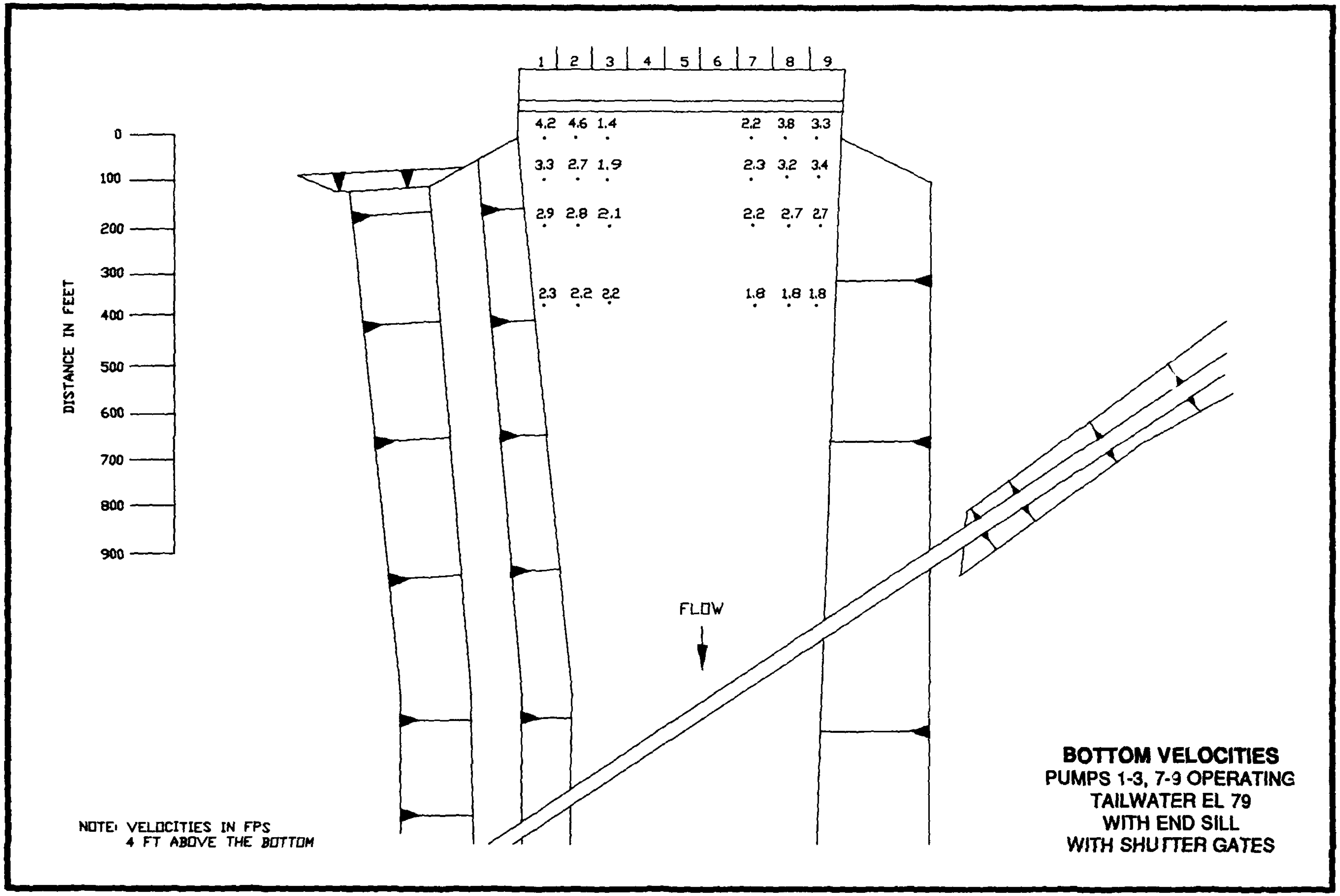
NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM

BOTTOM VELOCITIES
PUMPS 1-9 OPERATING
TAILWATER EL 79
WITH END SILL
WITHOUT SHUTTER GATES



BOTTOM VELOCITIES
PUMPS 1-9 OPERATING
TAILWATER EL 100
WITH END SILL
WITH SHUTTER GATES

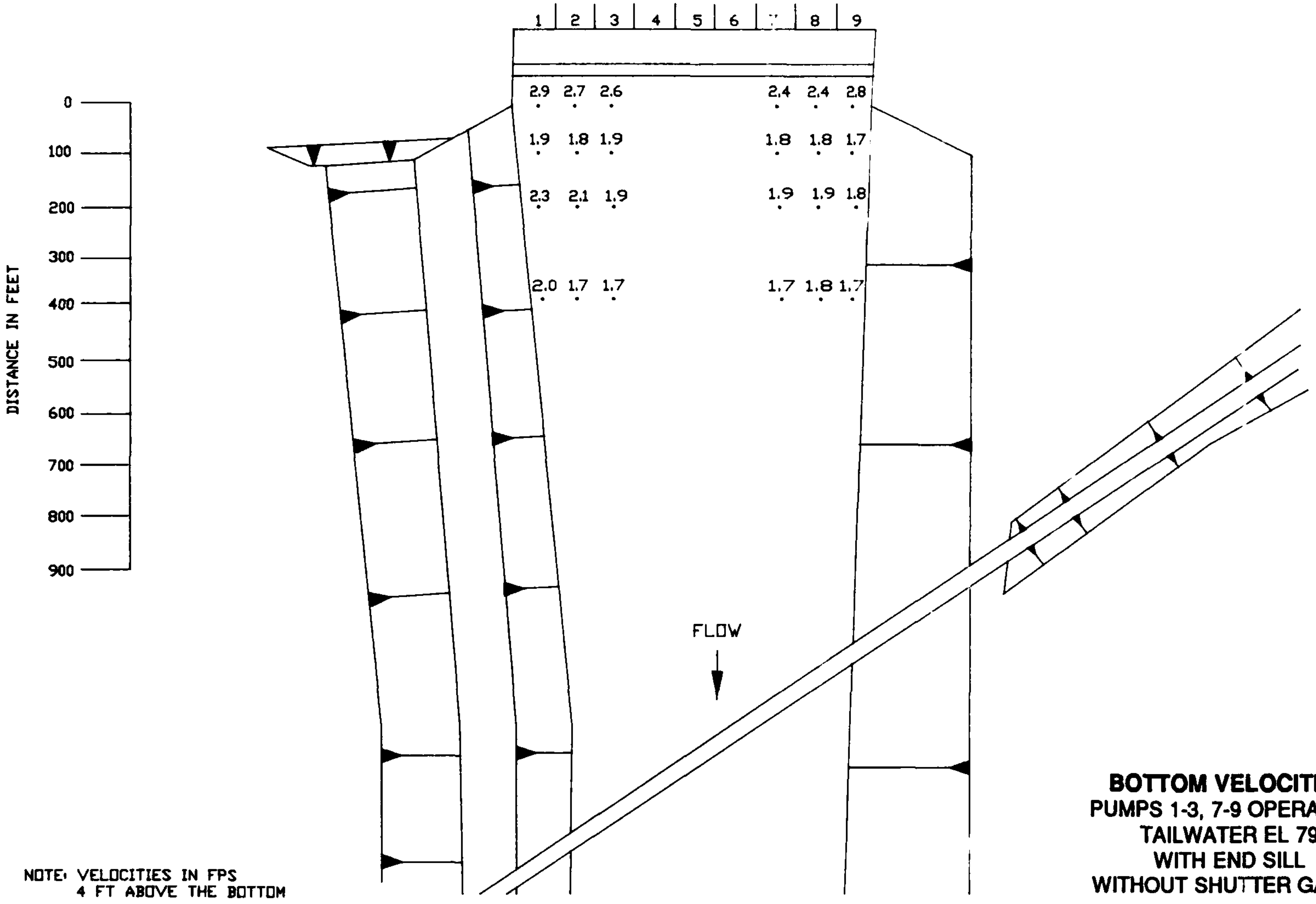
NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM



NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM

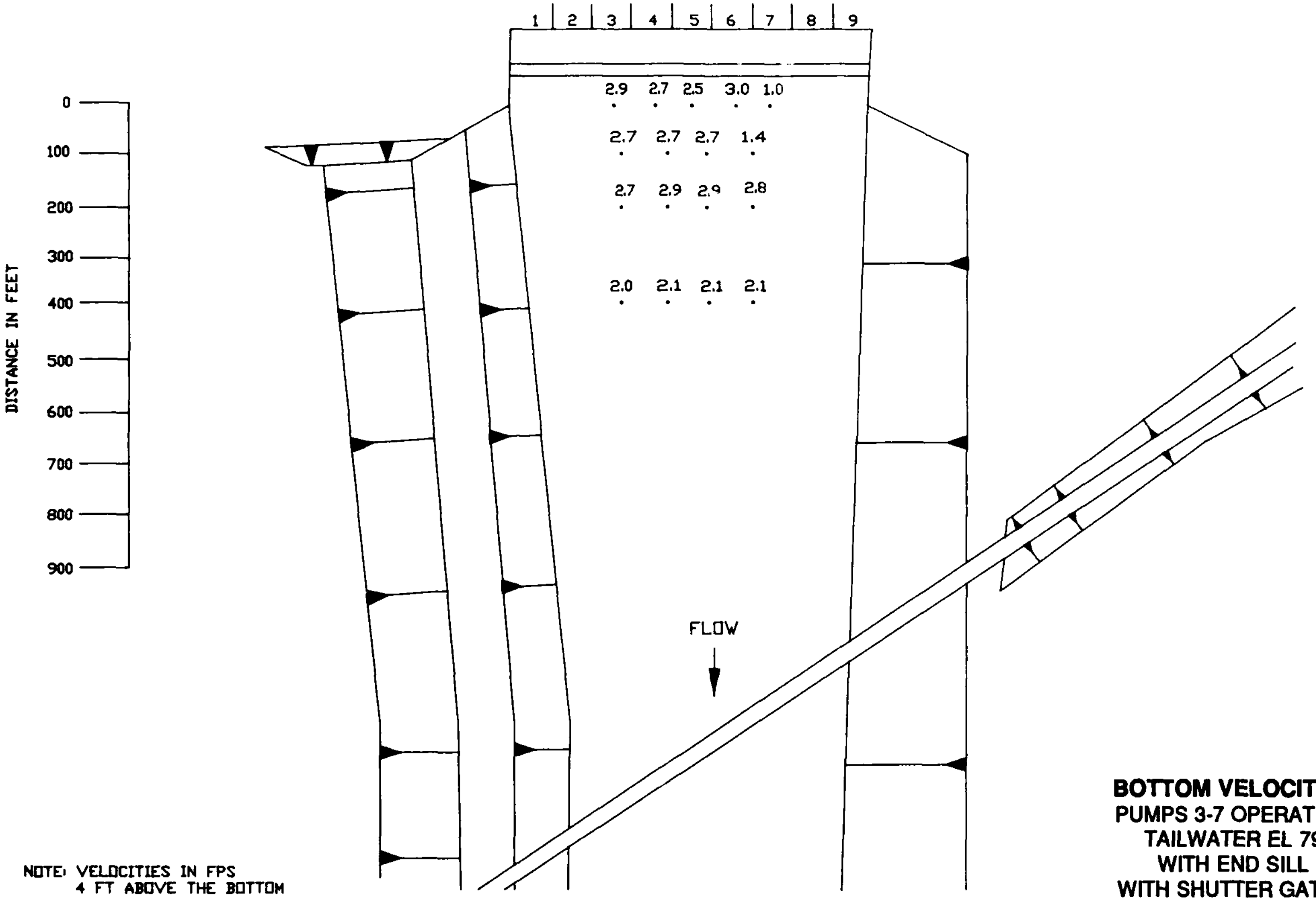
BOTTOM VELOCITIES
PUMPS 1-3, 7-9 OPERATING
TAILWATER EL 79
WITH END SILL
WITH SHUTTER GATES

PLATE 18



NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM

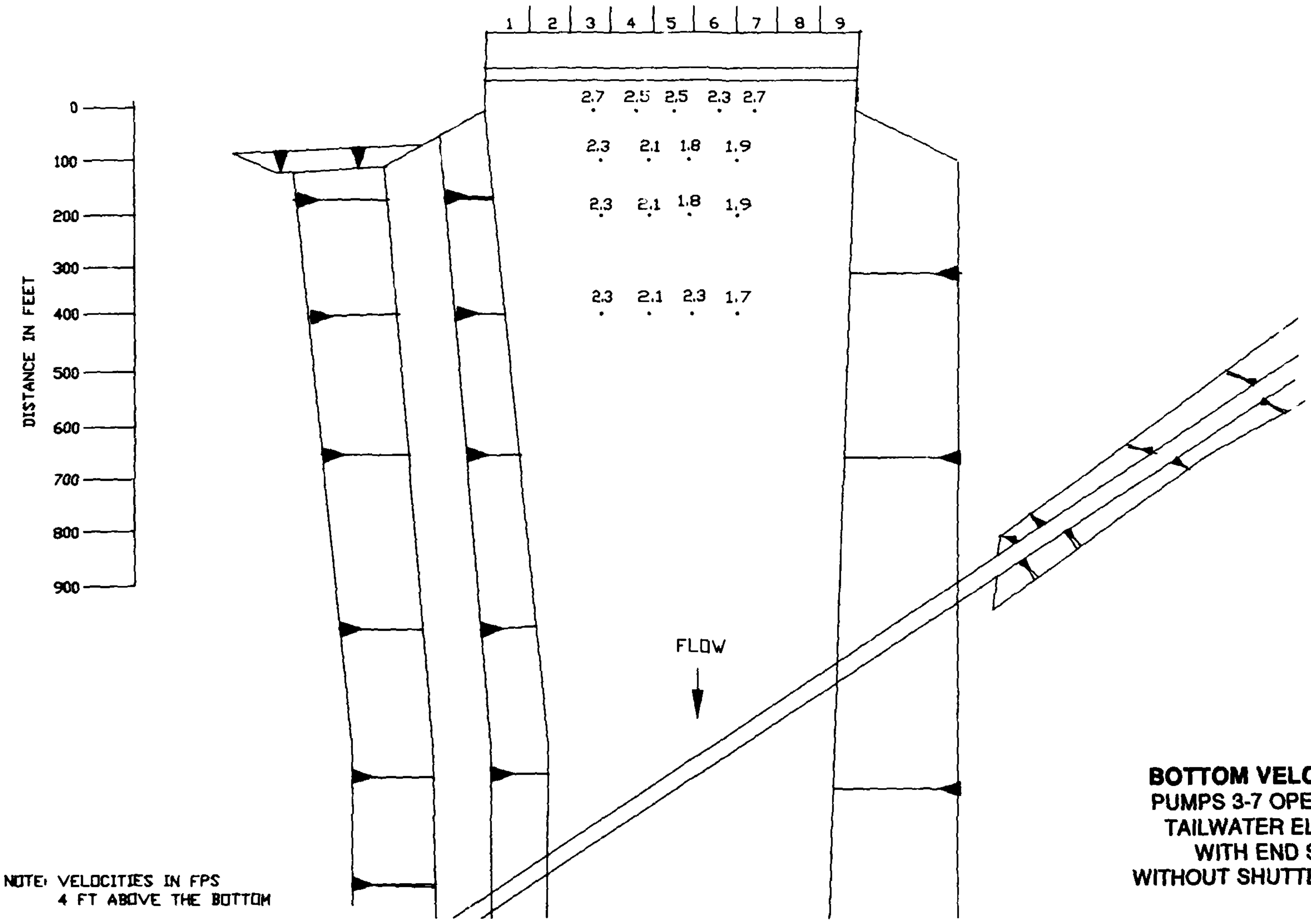
BOTTOM VELOCITIES
PUMPS 1-3, 7-9 OPERATING
TAILWATER EL 79
WITH END SILL
WITHOUT SHUTTER GATES



NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM

BOTTOM VELOCITIES
PUMPS 3-7 OPERATING
TAILWATER EL 79
WITH END SILL
WITH SHUTTER GATES

PLATE 20

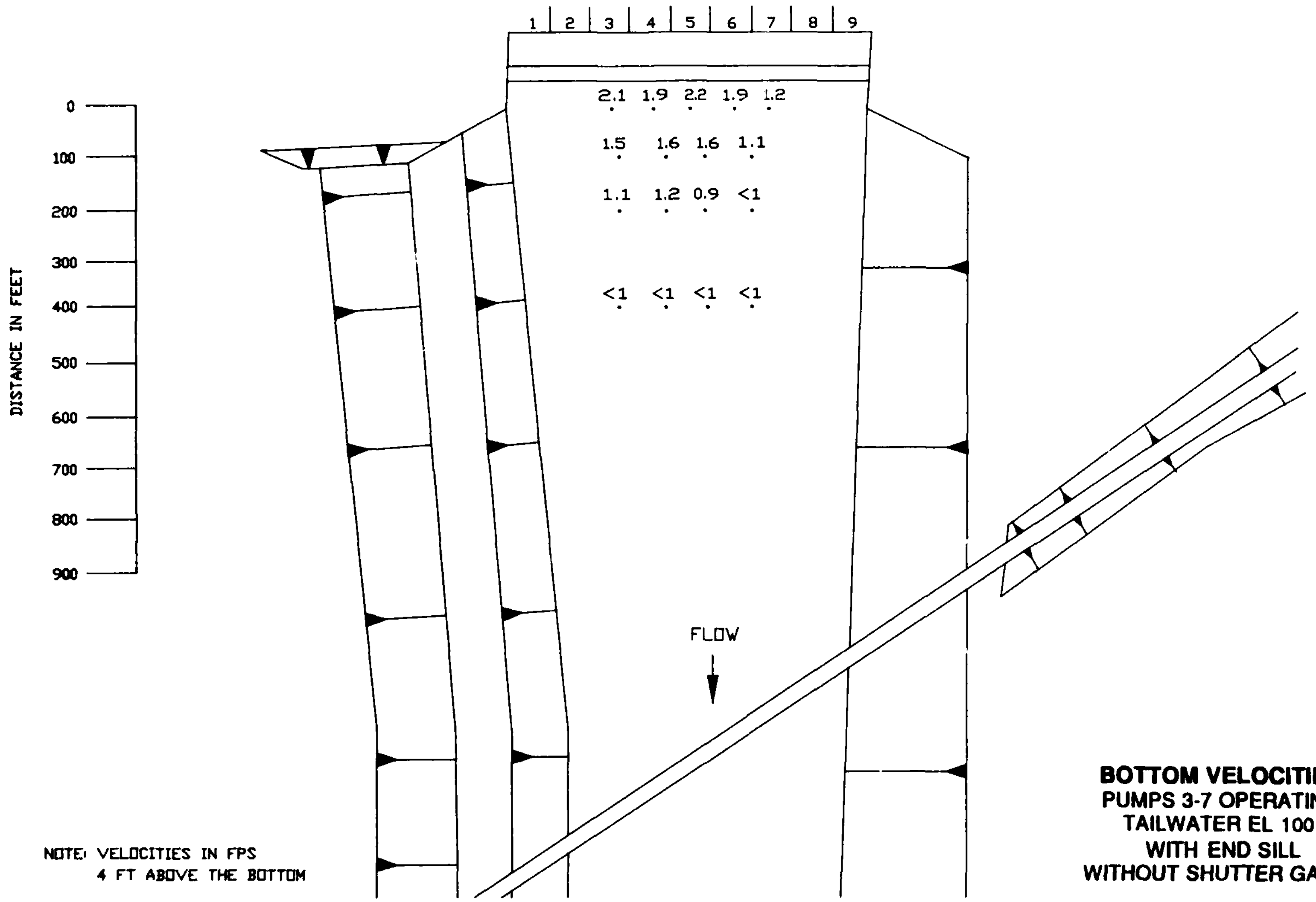


BOTTOM VELOCITIES

PUMPS 3-7 OPERATING
TAILWATER EL 79 FT
WITH END SILL
WITHOUT SHUTTER GATES

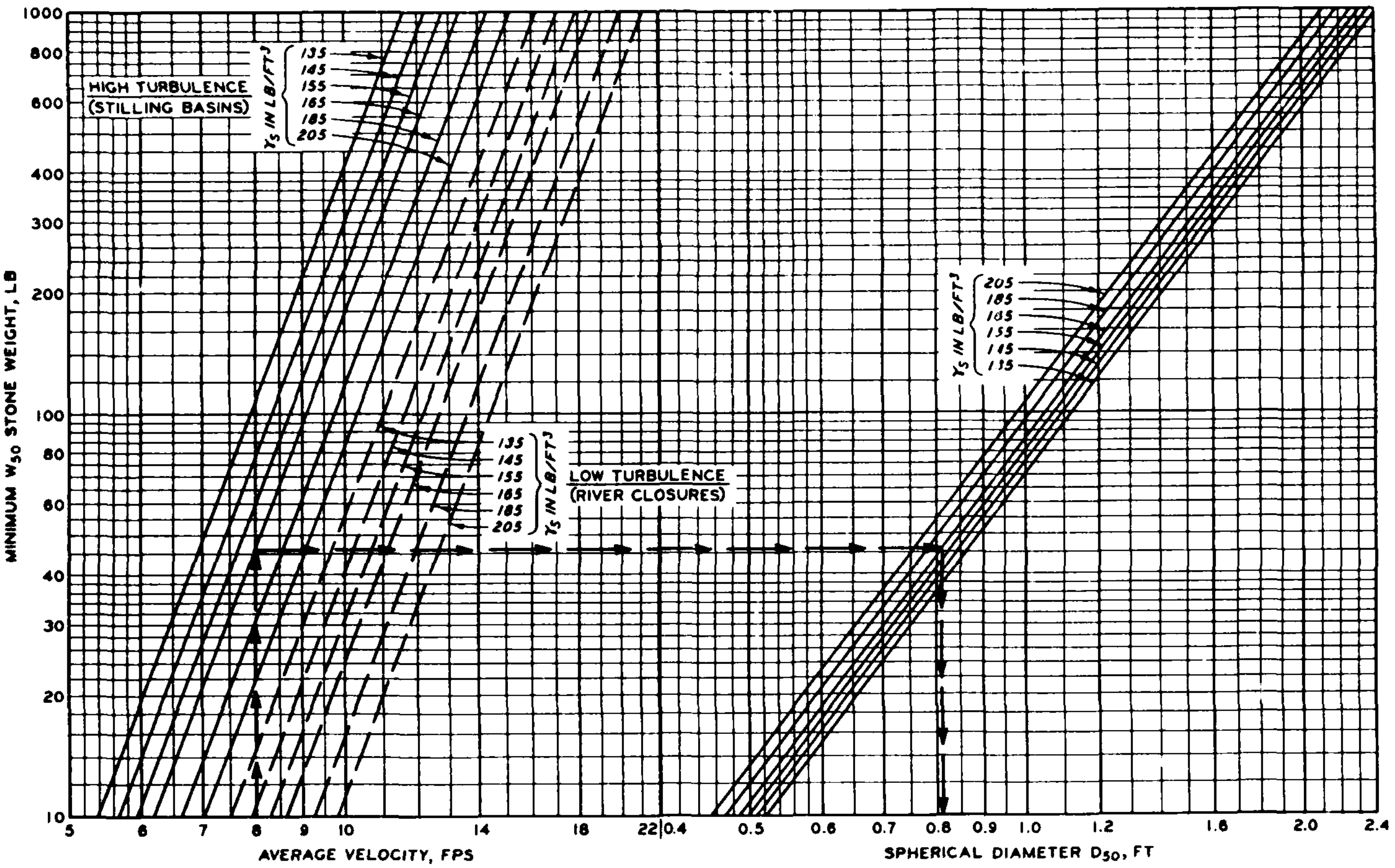
NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM

PLATE 21



NOTE: VELOCITIES IN FPS
4 FT ABOVE THE BOTTOM

BOTTOM VELOCITIES
PUMPS 3-7 OPERATING
TAILWATER EL 100
WITH END SILL
WITHOUT SHUTTER GATES



BASIC EQUATIONS

$$V = C\left[2g\left(\frac{\gamma_S-\gamma_W}{\gamma_W}\right)\right]^{1/2}(D_{50})^{1/2}$$

$$D_{50} = \left(\frac{6W_{50}}{\pi\gamma_S}\right)^{1/3}$$

WHERE:

V = VELOCITY, FPS
γ_S = SPECIFIC STONE WEIGHT, LB/FT^3
γ_W = SPECIFIC WEIGHT OF WATER, 62.5 LB/FT^3
W_{50} = WEIGHT OF STONE. SUBSCRIPT DENOTES PERCENT OF TOTAL WEIGHT OF MATERIAL CONTAINING STONE OF LESS WEIGHT.
D_{50} = SPHERICAL DIAMETER OF STONE HAVING THE SAME WEIGHT AS W_{50}
C = ISBASH CONSTANT (0.86 FOR HIGH TURBULENCE LEVEL FLOW AND 1.20 FOR LOW TURBULENCE LEVEL FLOW)
g = ACCELERATION OF GRAVITY, FT/SEC^2

STONE STABILITY
VELOCITY VS STONE DIAMETER

HYDRAULIC DESIGN CHART 712-1
(SHEET 1 OF 2)

REV 8-58, 9-70

WES 6-57

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