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BRUSH CREEK, KANSAS CITY, MISSOURI

Hydraulic Model Investigation

by

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13. ABSTRACT *(Maximum 200 words)*

Brush Creek drains approximately 29.4 square miles of urban area in the central portion of the Kansas City, MO, metropolitan area. Diverse development covers the entire area. Within the study reach, State Line Road to Woodland Avenue, the channel is crossed by a number of bridges that present varying degrees of flow restriction.

Although several previous studies by the US Army Engineer District, Kansas City, identified a severe flood hazard along Brush Creek, a damaging flood in the Plaza area had never been experienced prior to September 1977. On 12 and 13 September 1977, the Kansas City metropolitan region experienced flooding of catastrophic proportions. The Plaza area was devastated with 5 to 6 ft of water in shops and restaurants adjacent to Brush Creek.

As a result of the September 1977 flood, the Kansas City District was asked to study the flooding problem. A number of structural and nonstructural measures were identified that could reduce the flood hazard. These plans called

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for bridge modifications, channel widening, and channel deepening. Water-surface computations were made but did not provide the desired accuracy for a design water-surface profile.

A physical model study was authorized. The study was conducted using a fixed-bed model constructed at a scale of 1:35 to study the various flood control measures. Approximately 3 miles of natural and improved channel from State Line Road to Woodland Avenue were reproduced.

Testing of the project began with reproducing prototype high-water marks obtained during the September 1977 flood. Various alternatives concerning bridges and channel modifications were examined. Many of the existing bridges were very restrictive to the flow. Flood conditions were improved by either removing or replacing these existing bridges with less restrictive bridges. The Volker Park conduit was replaced with an open channel, which also reduced flooding.

The model was reconstructed to incorporate proposed channel modifications developed by the Corps of Engineers. This plan was called the Corps BCP-9 Plan. These modifications called for bridge and channel widening and overall channel deepening in the reach from the beginning of the Plaza to downstream of Troost Avenue. These modifications significantly lowered water-surface elevations caused by the various floods.

Hydrograph tests were conducted on the existing conditions and BCP-9 Plan. These tests showed that any proposed modifications would not increase the downstream discharge or the downstream flooding potential.

The model was again reconstructed to proposed modifications requested by the city of Kansas City. This plan, called the Park Plan, was located between Roanoke Parkway and downstream of the Paseo. The Park Plan used wider and deeper channel sections than the BCP-9 Plan. Several pools were formed by small dams throughout the channel. Drop structures were required at two locations in the channel. The Park Plan water-surface elevations were generally comparable to those of the BCP-9 Plan.

PREFACE

The model investigation reported herein was authorized by the Headquarters, US Army Corps of Engineers (USACE), on 30 January 1987 at the request of the US Army Engineer District, Kansas City (MRK), through the US Army Engineer Division, Missouri River (MRD). The model tests were accomplished during the period December 1987 to April 1989 in the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) under the general supervision of Messrs. F. A. Herrmann, Chief of the Hydraulics Laboratory; and R. A. Sager, Assistant Chief of the Hydraulics Laboratory; and under the direct supervision of Mr. G. A. Pickering, Chief of the Hydraulic Structures Division, Hydraulics Laboratory; and Mr. J. F. George, Chief of the Locks and Conduits Branch, Hydraulic Structures Division. The tests were conducted by Messrs. H. O. Turner, Jr., and J. E. Myrick, and the plates were prepared by Mr. Mike Ott, all of the Locks and Conduits Branch. This report was prepared by Mr. Walter Linder, MRK, and Mr. Turner and edited by Mrs. Marsha C. Gay, Information Technology Laboratory, WES.

Tom Muncey, USACE; Bill Todsen, Warren Mellema, Fred Snyder, Donald Sedrel, and Richard Maskil, MRD; Paul Barber, Walter Linder, Jon Conley, Charles Jacques, Jerry Holloway, John Holm, John Hoyt, Scot Loehr, Phil Rotert, Pat Gibson, and Paul Speckin, MRK; Terry Dobson, Anita Gorman, Keith Graham, Gurnie Gunter, John Laney, Zain Obedin, Kevin Pistilli, Mac Andrew, and Donald Hurlburt, Kansas City, MO; Phillip Gibson of Continental Construction Engineers; and Al Groves of Groves and Associates, Kansas City Parks and Recreation consultant, visited WES during the course of the model study to observe model operation and correlate 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

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
cubic feet	0.0283168	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	25.4	millimetres
miles (US statute)	1.609347	kilometres
square miles	2.589998	square kilometres

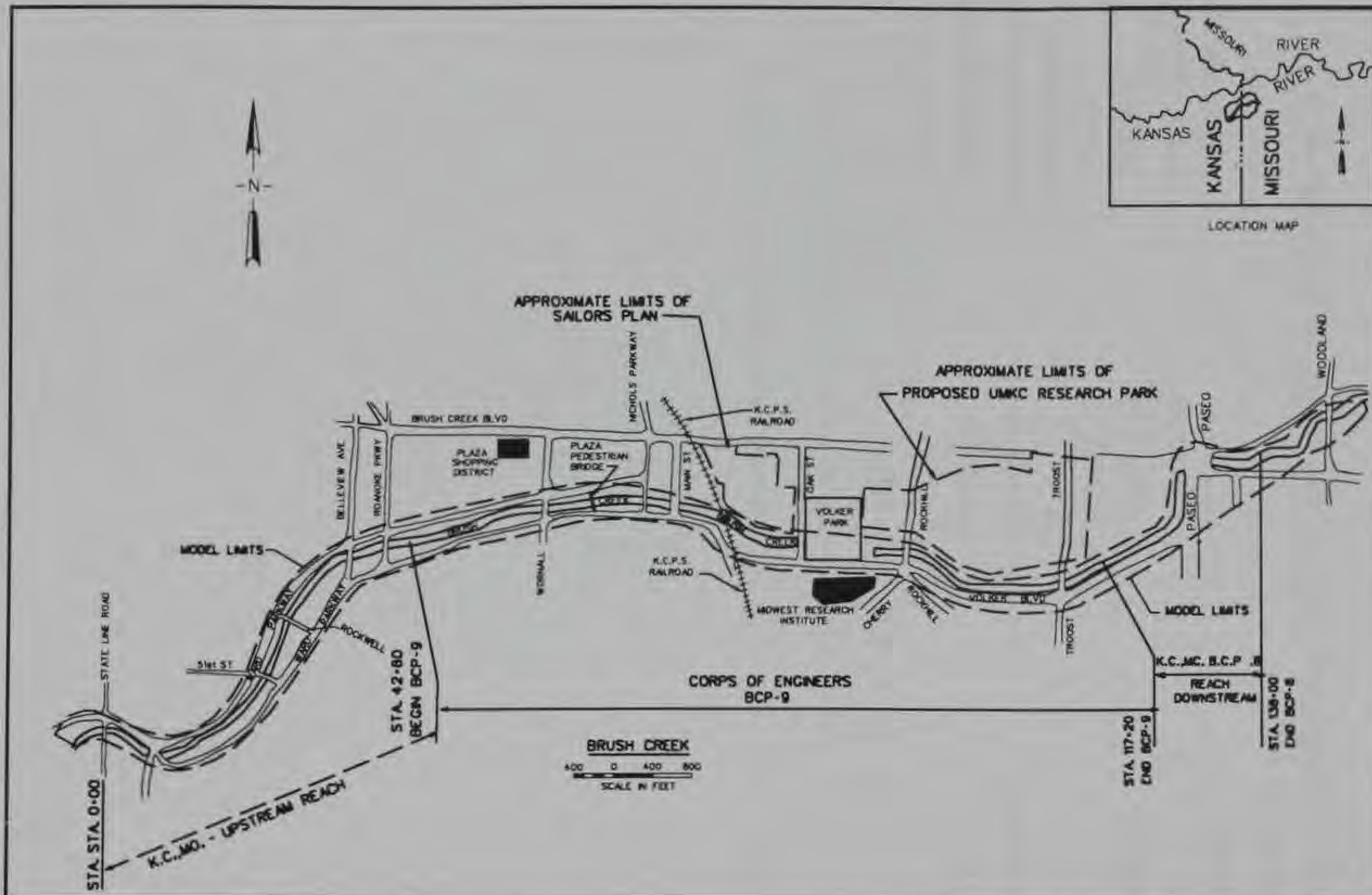

Figure 1. Vicinity map

BRUSH CREEK, KANSAS CITY, MISSOURI

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. Brush Creek (Figure 1) drains approximately 29.4 square miles* of urban area in the central portion of the Kansas City metropolitan area. Forty-three percent of the basin lies in Kansas and 57 percent in Missouri. Diverse development covers the entire area. The stream channel on both sides of the Kansas-Missouri State line has been straightened and improved over most of its length. Drainage from residential areas has been either channelized into concrete-lined ditches or emptied into large underground storm sewers. Much of the ground surface in the basin has been paved over with streets, rooftops, sidewalks, parking lots, and other impervious surfaces. Because of the urbanization that has taken place, the stream has a high potential for flash flooding.

2. Parts of Brush Creek in Prairie Village, KS, have been channelized with gabion sidewalls and concrete bottom paving. Brush Creek is entrained in a conduit beneath Prairie Village Shopping Center, and Rock Creek passes through a conduit beneath Mission Shopping Center. Low banks are either earth or rock wall remnants with rock outcrops along the bottom as the stream nears the Kansas-Missouri State line. Brush Creek flows through the Mission Hills Country Club for some distance above the state line. Downstream of the state line, the channel has an earth bottom for about 2,000 ft. The banks are low and nearly vertical and show evidence of bank erosion with each flood event. Adjacent overbank areas are grassed with isolated mature trees. Downstream of the earth channel, the bottom is paved with concrete for a distance of 3.8 miles. The remaining 6,500 ft to the junction with the Blue River is earth channel.

3. The paved bottom varies from 60 to 80 ft wide. A small low-flow

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

channel is centered on the paved bottom. On each side of the paved bottom are low, nearly vertical masonry rock walls generally 3 to 4 ft high, except for the right bank near Troost Avenue where the wall extends to a height of over 20 ft. Most adjacent overbank areas have grass-covered gentle slopes. A few short reaches are steep with some brush and trees, particularly the right bank below Main Street. Depth of the channel varies from 10 to 20 ft. Channel slopes vary from about 17 ft per mile above Troost Avenue to about 23 ft per mile below Troost Avenue. City streets parallel the stream and curb-to-curb distance varies from 180 to 400 ft.

4. The channel is crossed by a number of bridges that present varying degrees of flow restriction. Within the study reach, State Line Road to Woodland Avenue, these include a railroad bridge, 11 street bridges, 2 pedestrian bridges, and 2 conduits. Bridge and conduit locations are provided in Table 1. A 418-ft-long triple-barrel conduit passes under the Paseo-Brush Creek Boulevard intersection. Another triple-barrel conduit, located under Volker Park, is 840 ft long. The Paseo conduit will pass flows up through a 50-year event before overtopping the roadway. Flows greater than about a 10-year event overtop the Volker Part conduit. Several of the existing bridges also present an obstruction to high flows. These include Rockhill Road, the railroad bridge, and the 50th Street Bridge. The large center piers at Main Street and the narrow opening at Troost also create significant increases in the upstream water-surface elevations. Wornall Road was a major obstruction until its replacement in 1981.

Background

5. Although several previous studies had identified a severe flood hazard along Brush Creek, a damaging flood in the Plaza area had never been experienced prior to September 1977. On 12 and 13 September 1977, the Kansas City metropolitan region experienced flooding of catastrophic proportions. Hardest hit was the Brush Creek basin, especially below State Line Road. Of the 25 lives lost, 12 were in the Brush Creek basin, and damages in the reach below State Line Road exceeded $66 million.

6. The Plaza area was devastated with 5 to 6 ft of water in shops and restaurants adjacent to Brush Creek. Numerous parked cars were swept off the street and were deposited in the channel, many of them lodged on the upstream

side of bridge piers. The frequency of the flood was estimated to be a 200- to 500-year event on Brush Creek below State Line Road. Except for the three high-level bridges at J. C. Nichols Parkway, Main Street, and Troost Avenue, every bridge below State Line Road was overtopped by a significant amount.

7. As a result of the September 1977 flood, the US Army Engineer District, Kansas City, was asked to study the flooding problem in the Brush Creek basin to see if solutions, either Federal or non-Federal, were possible that would lessen future flood damage and loss of life.

8. A number of structural and nonstructural measures were identified that could potentially reduce the Brush Creek flood hazard. From these measures, a series of alternative plans were developed and analyzed in detail. These plans generally took two forms: (a) bridge and channel widening for the reach between upstream of the Plaza and downstream of Troost Avenue, and (b) channel deepening for the same reach. Channel deepening between Roanoke Parkway and Troost Avenue was the only plan that maximized net economic benefits and was also acceptable to the numerous public interests. This plan has been identified as BCP-9 and is the plan in which the Federal Government will cost share. The BCP-9 plan begins at sta 43+50 and ends at sta 117+20. The city of Kansas City, MO, will extend the channel deepening upstream from sta 43+50 to the vicinity of sta 2+00 near 51st Street and downstream from sta 117+20 to sta 143+00 below the Paseo. Engineering for the upstream and downstream channel deepening extensions is being accomplished by the Kansas City District with funding by the city. Figure 1 shows the project reach, identifies the Corps and city portions of the project, and model limits.

9. Design water-surface profiles were computed with the channel improvement option in the HEC-2 water-surface profile computation program. To develop design water-surface profiles, the cross sections were recoded using the actual coordinate points for the deepened section. The computations indicated the water surface was at or near critical depth at a number of locations within the study reach. Further analysis concluded that the computed profiles did not provide the required accuracy in areas of supercritical flow and at the transitions between subcritical and supercritical. An attempt was made to use a generalized water-surface profile computation program based on both the energy and momentum equations. Computations by this program produced inconsistent results and were no more reliable than the HEC-2 computations.

Purpose

10. When it became apparent that computations would not provide the desired accuracy for a design water-surface profile, a decision was made to proceed with a physical model study. The purpose of the physical model was to provide the following:

- a. Water-surface elevations for the existing and modified channel for design conditions.
- b. Assurance that the proposed design will achieve the desired degree of flood protection.
- c. Flow velocities for determining the need to protect exposed rock surfaces and hydraulic forces on retaining walls.
- d. Flow conditions through existing and proposed bridges in order to determine head losses and changes required to improve flow conditions.
- e. Information to determine open channel requirements to replace the existing Volker Park conduit.
- f. A visual concept of the project through visits to the model by local and Corps officials and through video tape presentations to other interested parties.

PART II: THE MODEL

Description

11. The investigation was conducted using a 1:35-scale model (Photo 1). The model reproduced approximately 3 miles of natural and improved channel from sta 0+00 (State Line Road) to sta 157+50 (Woodland Avenue). This provided a sufficient length of model to include the Federal project reach as well as proposed city extensions. The model flume was constructed of plastic-coated plywood and elevated to allow for slope and grade adjustments. The width of the model varied from 560 to 400 ft (prototype) in order to reproduce sufficient overbank areas and allow for planned modifications. To accurately reproduce the channel and overbank areas, prototype cross-section data were used to make sheet metal templates. These templates were placed at the proper locations and elevations and covered with sand. A thin crust of cement mortar was graded to the top of the templates. Overbank and channel side slope surfaces were left with the normal concrete mortar surface formed in construction of the model. The channel bottom was coated with an epoxy paint to represent concrete paving on the bottom. Bridges made of Plexiglas were constructed to prototype specifications and were removable to determine the impact of individual bridges or groups of bridges on the water-surface profile. Two tunnels in the model were also constructed of Plexiglas. These tunnels were installed at the proper grade and location and covered with cement mortar.

12. Table 2 shows various discharges downstream of State Line Road through the modeled reach. The appropriate amount of incremental flow was determined by Kansas City District using a modified version of the Environmental Protection Agency storm water runoff numerical model, SWMM, which also defined the discharge frequency relationships. This additional flow results from several large storm sewers that discharge into the channel and overbank flow from adjacent streets and low areas that carry surface runoff in excess of the storm sewers' capacities. The additional flow was introduced into the model at four locations:

- a. Downstream of Roanoke Avenue where a storm sewer enters from the left bank.
- b. Upstream of the Volker Park conduit where storm sewers enter from both banks just inside of the conduit and also from the left bank downstream of the railroad bridge.

c. Upstream of Troost Avenue where a storm sewer and overbank flows enter from the left bank at Harrison Street.

d. Upstream of the Paseo conduit where a storm sewer enters from the right bank a short distance upstream of the conduit.

13. The additional flow was introduced into the model through plastic pipes that were buried in the overbank and discharged into the channel. Adding the total increment of additional flow at these points would have resulted in a high-velocity jet from the model storm sewers. To compensate for this, lengths of perforated pipe were placed on the overbank to represent surface inflows. The flow was divided between the model sewers to represent storm inflow and the parallel perforated pipe to represent surface inflows.

Model Appurtenances

14. Water used in the operation of the model was supplied by a circulating system. Discharges were measured with electronic flowmeters. Steel rails graded to specific elevations were placed along both sides of the flume to serve as supports for measuring devices and to provide a convenient means of establishing stations and elevations in the model. Water velocities were measured with an electronic velocity meter. Water-surface elevations were measured with point gages. Different designs along with different flow conditions were recorded photographically. Hydrograph discharge data were obtained by using sonic distance meters to measure the water height upstream of a 60-deg V-notch weir.

Scale Relations

15. The equations of hydraulic similitude, based on Froudian relations, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for transferring model data to prototype equivalents are listed in the following tabulation. Because of the nature of the phenomena involved, certain model data can be accepted quantitatively, while other data are reliable only in a qualitative sense. Measurements in the model of discharges, water-surface elevations, velocities, and resistance to displacement of riprap material can be transferred quantitatively from model to prototype by means of these scale relations.

Characteristic	Dimension*	Scale Relations Model:Prototype
Length	L_r	1:35
Area	L_r^2	1:1,225
Velocity	$L_r^{1/2}$	1:5.916
Discharge	$L_r^{5/2}$	1:7,247.2
Time	$L_r^{1/2}$	1:5.916
Volume	L_r^3	1:42,875
Weight	L_r^3	1:42,875

* Dimensions are in terms of length.

PART III: TESTS AND RESULTS

Existing Conditions

Model verification

16. The ability of the model to simulate prototype conditions was verified by reproducing the September 1977 flood and comparing water-surface elevations in the model with recorded elevations of high-water marks in the prototype. The old Wornall Road Bridge (Photo 2) was used in the verification tests to represent prototype conditions at the time of the September 1977 flood. Wornall Road Bridge was replaced in 1981 with a new bridge (Photo 3) that was less restrictive to the flow. Plate 1 shows the 1977 flood high-water marks and the center-line water-surface profile from the model.

Flow conditions

17. After verification of the model was completed, tests were conducted to observe and document flow conditions with existing conditions. These tests were conducted with the existing (new) Wornall Road Bridge (Photo 3) in place. Results of the tests pertinent to each component of the project are discussed in order of its position, beginning at the upstream end and proceeding downstream.

18. Flow conditions observed at the State Line Road Bridge (Photo 4), the first bridge reproduced, indicated that the elevation of State Line Road is such that even a 10-year-frequency flow would overtop the roadway to the right (south) of the bridge (Photo 5a). It was also observed that the bridge would be overtopped with the 100- and 500-year-frequency flows (Photos 6a and 7a, respectively). During a major flood event, a significant amount of flow bypasses the bridge opening and reenters the channel further downstream. Water-surface profiles (Plate 2) showing the various degrees of restriction caused by the different bridges and tunnels were obtained for the 10-, 100-, and 500-year flood events using the discharges listed in Table 2. Flow conditions for the 10-, 100-, and 500-year frequency events are shown in Photos 5, 6, and 7, respectively.

19. The Ward Parkway Bridge (Photo 8) created an obstruction to the flow with nearly a 10-ft drop in water surface through and downstream of the bridge with the 100- and 500-year flow events. The 10-year flow safely passed underneath the Ward Parkway Bridge (Photo 5a). However, flows of 100 and

500 years were obstructed by the bridge (Photos 6a and 7a, respectively). Under these conditions, water flowed over and around the bridge and re-entered the channel downstream.

20. The low-water crossing (Photo 9), formerly 51st Street, has been barricaded to prevent vehicular traffic. Channel paving begins here and extends downstream. A conduit through the low-water crossing passes only very low flows. At higher flows, the low-water crossing becomes submerged, as shown in Photo 5b with the 10-year flood. Other flows are shown in Photos 6b and 7b. Upstream water-surface elevations were not influenced by the low-water crossing because it quickly became submerged and presented no major blockage to the flow.

21. The 50th Street Bridge, also called Rockwell Road (Photo 10), is a masonry arch type with two openings. This bridge was very restrictive to flows and resulted in 4 to 5 ft of head loss for all flows observed. The capacity of the bridge was very limited with flow overtopping the right approach embankment at approximately the 2-year frequency. Photo 5b shows flow overtopping the right embankment for a 10-year event. The right approach embankment also acted as a critical depth control for right overbank flows with a hydraulic jump forming on the downstream overbank for the full range of flows observed.

22. The bridges at Belleview and Roanoke (Photos 11 and 12, respectively) formed the next obstruction to flow. These bridges were analyzed together since Roanoke is only 290 ft downstream of Belleview. Test results indicated that approximately 5 ft of head loss occurred through the two bridges at the higher discharges. As shown in Photo 5c, the 10-year flood flow through and downstream of the bridges was at near critical depth with supercritical flow present in places. An undular hydraulic jump occurred downstream with characteristic large water-surface fluctuations.

23. The new Wornall Road Bridge (Photo 3) has streamlined piers and unconfined openings underneath and is less restrictive to flow conditions than the old Wornall Road Bridge (Photo 2). While the new bridge has less head loss, conditions downstream create a backwater effect and the new bridge becomes submerged at the 100- and 500-year discharges (Photos 6c and 7c, respectively).

24. The Plaza footbridge (Photo 13), located 400 ft downstream of Wornall Road, is an open-span pedestrian bridge supported by abutments on each

side of the channel. Portions of this bridge also became submerged at the 100- and 500-year discharges (Photos 6d and 7d, respectively).

25. The J. C. Nichols Parkway Bridge (Photo 14) also has streamlined piers and unconfined openings underneath. This bridge passes the 100-year flow. However, the roadway on the left side was overtopped at the 100-year flow (Photo 6d).

26. The Main Street Bridge (Photo 15) presents a narrow flow opening, but the elevations of the bridge and roadway were high enough that they were not overtopped even with the 500-year flow (Photo 7d). However, the Kansas City Public Service (KCPS) Railroad bridge (Photo 16) was very restrictive for all flows (Photos 5d, 6d, 7d), due to the low steel elevation and the bridge abutments located in the channel. The combined effects of both these bridges raised upstream water-surface elevations in the vicinity of the Plaza approximately 4 ft.

27. The head loss measurements of the Volker Park conduit (Photo 17) and Rockhill Road Bridge (Photo 18) were considered together due to their proximity. Rockhill Road Bridge is only 330 ft downstream of the Volker Park conduit exit. These two structures combined for a total head loss of 5 ft with the 500-year frequency flood. Flow conditions for this reach are shown in Photos 5e, 6e, and 7e. The Volker Park conduit is a triple-barrel conduit 840 ft long with each barrel being 22 ft wide by 15 ft high. Overtopping of the conduit occurred at flows less than the 10-year flood. The Rockhill Road Bridge is a masonry arch type with two 35-ft openings. A pedestrian bridge is also located just upstream. Because of this arrangement, the capacity of the bridge is very limited with flow overtopping the bridge during 100- and 500-year frequency events.

28. Troost Avenue Bridge (Photo 19) presents another major restriction to channel flow due to its narrow span opening. Because of the high roadway and bridge deck elevations, no overtopping occurred, resulting in all the flow being forced through the bridge opening. The flow conditions for Troost Avenue Bridge and downstream areas, including the Paseo conduit, are shown in Photos 5f, 6f, and 7f. At the 500-year flood (Photo 7f), stages were increased as far upstream as the KCPS Railroad bridge due to the effects of Troost Avenue Bridge. The flow transitioned from subcritical to supercritical under the Troost Avenue Bridge and remained supercritical downstream to around sta 120+00, where a hydraulic jump formed due to backwater effects from the Paseo conduit.

29. The Paseo conduit (Photo 20) is a triple-barrel conduit 418 ft long. Each barrel is 22 ft wide by 15 ft high. Flow entering the conduit makes a 90-deg clockwise turn and exits. Flows greater than the 50-year flood event overtopped the Paseo intersection, resulting in major flooding in this vicinity. Flows for the 10-, 100-, and 500-year frequencies are shown in Photos 5f, 6f, and 7f, respectively.

30. Downstream of the Paseo conduit, the flow was near critical depth with an undular jump occurring for the lower flood flows (Photo 5g). At higher flows (Photos 6g and 7g), this undular jump became submerged due to the curved channel alignment and constriction of the Woodland Bridge (Photo 21). Upstream of Woodland Bridge, very large eddies and lateral flows formed at the higher flows.

Velocity measurements

31. Velocity measurements were obtained for the 10-, 50-, 100-, and 500-year flood events. These data measurements were recorded near the bottom, middepth, and near the surface at the channel center line and along the right and left sides of the main channel. A wide variation in velocities occurred between areas of supercritical and subcritical flows. In the supercritical flow area downstream of Troost, surface velocities ranged from a maximum of 30 ft/sec for the 50-year flood to 34 ft/sec for the 500-year discharge. Bottom velocities in this vicinity were about 4 ft/sec lower than the respective surface velocities. In subcritical regions, velocities were as low as 3 to 4 ft/sec, but generally varied from 8 to 15 ft/sec. Velocity measurements for the flood frequencies and locations are provided in Table 3.

Proposed Development Activities

32. The effects of two proposed developments adjacent to Brush Creek were evaluated. These developments, shown in Figure 1, are the Sailors Plan and the University of Missouri-Kansas City (UMKC) Research Park.

Sailors Plan

33. An office complex known as the Sailors Development will be constructed on the left bank between the KCPS Railroad and Oak Street (Figure 1). A low floodwall (Sailors Floodwall) is proposed along the designated left bank floodway boundary to protect this area. The Sailors Floodwall was installed in the model. This increased the 100-year flood stages approximately 1 ft in

the short reach between the entrance to the conduit and the railroad bridge. Between the KCPS Railroad bridge and Main Street Bridge, the stage was increased an average of 0.5 ft. The increase in stage between the conduit and the railroad bridge was due to velocity head recovery from the downstream UMKC perimeter road and to the sudden expansion of the flow on the left bank at Oak Street where the floodwall turns away from the channel and parallels Oak Street to high ground. An additional increase in stage did not occur upstream of the railroad bridge as the effect of the floodwall became part of the total loss through the railroad bridge. Water-surface profiles in this vicinity are shown in Plate 3.

The University of Missouri-
Kansas City Research Park

34. The UMKC plans to construct a complex of buildings adjacent to the left bank between Locust Street and Troost Avenue (Figure 1). The area will be filled to raise ground elevations to the level of the 500-year flood in the left bank area between Rockhill Road and Troost Avenue.

35. The UMKC perimeter road lowered the 100-year flood profile an average of 0.7 ft between Troost Avenue and Rockhill Road. Upstream of Rockhill Road, water-surface elevations were 0.1 to 0.2 ft lower. This lowering of the water surface was the result of redirecting the overbank flow into the channel where much of the total energy head was converted to velocity head. Water-surface profiles in this vicinity are shown in Plate 4.

Existing bridge and Volker Park conduit

36. A series of tests were conducted to determine the incremental effects of the various bridges and the Volker Park conduit. Each bridge between Roanoke and Troost was sequentially removed, water-surface elevations were measured for a distance upstream until the profile matched existing conditions, then the bridge was replaced and the next downstream bridge removed. After all the bridges were tested, the Volker Park conduit was replaced by an open channel and tested in like manner. Water-surface profiles obtained for the 100-year and 500-year flood discharges with the bridges removed and the Volker Park conduit in place are shown in Plate 5. These tests show that the narrow openings at Main Street Bridge and Troost Avenue still act as controls. Next, water-surface profiles were obtained with the Volker Park conduit removed, all the bridges removed, and enlarged openings at Main Street and Troost Avenue (Plate 6). A comparison with the profiles in Plate 2 shows how

much the water-surface elevations could be lowered without lowering the channel bottom.

Proposed Channel Modifications—Corps BCP-9 Plan

37. Structural plans to provide flood control protection were investigated and generally took two forms: (a) bridge and channel widening from immediately upstream of the Plaza to downstream of the Paseo, and (b) channel deepening plans for the same reach.

38. Plate 7 shows bed profiles of the existing channel bottom and the proposed BCP-9 deepening, as well as additional upstream deepening proposed by the City of Kansas City, MO. Photo 22 shows the Corps BCP-9 plan. The channel deepening will, for the most part, be inside the existing walls adjacent to the concrete bottom paving. Excavation will vary from 0 ft downstream of Troost Avenue to a maximum of about 8 ft in the vicinity of the KCPS Railroad bridge. The edges of the cut will be vertical and will require structural facing in the prototype. The channel bottom will be paved throughout the entire deepened reach to prevent erosion and degradation of underlying poor-quality limestone and shale.

39. Existing bridges that will remain in place are Wornall Road (Photo 3), the Plaza footbridge (Photo 13), J. C. Nichols Parkway (Photo 14), and Troost Avenue (Photo 19). Protection of pier footings adjacent to channel deepening will be required at each of these bridges. The KCPS Railroad bridge and its encroaching abutments will be removed. Main Street Bridge will be removed and replaced with a new Main-Brookside connection (Photo 22b). The Volker Park conduit will be replaced with an open channel. A new bridge will be built for Oak Street as shown in Photo 23. The existing masonry arch bridge (Photo 18) at Rockhill Road will be replaced (Photos 22c and 24). The existing pedestrian bridge (Photo 18) located just upstream of Rockhill Road will also be removed.

40. The new Main-Brookside connecting bridges will be located in the vicinity of the existing KCPS Railroad bridge. Throughout this area, it was necessary to relocate the channel alignment to the left. The realignment started in the vicinity of the J. C. Nichols Parkway and ended near the entrance to the existing Volker Park conduit. The maximum amount of shift will be about 25 ft to the left at Main Street.

41. Since final prototype designs were unavailable for the replacement bridges, concept design bridges were used in the model. A concept design for the new Main-Brookside Bridge was provided by a consulting engineering firm engaged by the city of Kansas City. Concept design bridges were also used for the replacement bridge at Rockhill Road (Photo 24) and the new bridge at Oak Street (Photo 23). Span lengths for these bridges were based on the shape of the modified channel with a minimum of pier obstruction. Bridge deck thickness was determined from the span lengths and the deck surface was set to match the existing roadway elevations.

42. Flow conditions for the Corps BCP-9 plan are shown in Photos 25 and 26 for the 10-year and 500-year flows, respectively. Both the Rockhill Road and Oak Street Bridges were overtopped by the 500-year flood with this design concept. The 100-year flood submerged the low steel of the Rockhill Road Bridge about 1 ft and cleared the low steel of the Oak Street Bridge. Water-surface profiles for the various flood frequencies are shown in Plate 8. Water-surface elevations in the reach between Belleview and Roanoke were controlled by the restricted bridge openings at both Belleview and Roanoke.

43. Between Roanoke and Main Street in the high-damage reach of the Plaza, the reduction in water-surface elevations was primarily the result of enlarging the channel in the vicinity of Main Street. However, additional deepening was still needed to avoid flooding in the Plaza area. The water-surface elevations between Main Street and Oak Street did not create adverse impacts because the new Sailors' development on the left bank included a floodwall adjacent to the channel (Photo 22b). Shallow overbank flooding occurred across Volker Boulevard on the right bank, but was not high enough to flood the Midwest Research Institute (Figure 1). The lower water-surface profile between the upstream end of the existing conduit and just downstream of Rockhill Road will benefit the portion of the UMKC Research Park between Rockhill Road and Locust Street. Further lowering of the water surface between sta 98+00 and Troost Avenue would require replacement of the Troost Avenue Bridge and enlargement of the cross section. Ground levels on the right bank are far above the water surface and not subject to flooding. The low area on the left bank is subject to flooding but will be protected by fill and the UMKC perimeter road. Additional fill will tie to high ground along the downstream side of Rockhill Road.

44. Velocity profiles (Plate 9) in the channel were obtained at

intervals throughout the project reach for the 10- and 500-year flood frequencies. Flow velocities were measured near the bottom and surface along the channel center line and right and left sides of the channel. The velocity profiles shown in Plate 9 represent the highest of the three bottom and three surface velocities at each station where velocities were measured. The highest velocities were located near the upstream end of the channel deepening where flow was near critical and downstream of Troost Avenue where the flow was supercritical. Since the flow was concentrated more in the deepened portion of the channel, velocities for the 10-year frequency discharge were slightly higher than those for the 500-year flood. At the 10-year discharge, bottom velocities were greater than 15 ft/sec for nearly 70 percent of the project reach. Except for a small area in the vicinity of Rockhill Road, bottom velocities at the 10-year discharge were greater than 10 ft/sec throughout the entire project. At the 500-year flood, bottom velocities were greater than 10 ft/sec throughout the entire project and approached 30 ft/sec in the supercritical flow below Troost Avenue. These high bottom velocities for relatively frequent flood flows confirm the need for channel bottom paving as unprotected rock would experience excessive erosion. The unprotected rock and expected erosion would create an extremely rough bottom and an unacceptable increase in design water-surface elevations.

45. Standing waves were present at various locations for all discharges, which indicates the flow was near critical depth. If the flow depth was less than critical, a small change in channel roughness or a minor disturbance could cause a large change in water-surface elevation. It was observed that the flow appeared to be at or near critical depth at two locations just downstream of the transition to the deepened channel. The Froude numbers at sta 53+50 and 59+25 were computed for the 10- and 500-year flood discharges and are presented in the following tabulation:

	Froude Number	
Station	10-year Flow	500-year Flow
53+50	1.16	1.18
59+25	1.45	1.05

Computation of the Froude number was based on the relationship $F = V/(gd)^{1/2}$ where V is the average of actual velocity measurements in the cross section in feet per second; g is the acceleration of gravity in feet per second per second; and d is a depth in feet determined by dividing the flow area by the width of the water surface.

46. These Froude numbers are slightly greater that one, which indicates that the flow was barely supercritical. Therefore, only a relatively small increase in water-surface elevations would be expected should the flow change from supercritical to subcritical due to a change in flow conditions. While an unexpected increase in design water-surface elevations would be undesirable, an increase due to the flow changing from supercritical to subcritical at these stations would occur in a reach where the measured water-surface profiles were substantially below preliminary estimates. Except for the supercritical reach between Troost Avenue and Paseo, flow depths for the remainder of the project reach were greater and the velocities were lower.

Protection at upstream
end of channel deepening

47. The Corps BCP-9 project begins at sta 43+50 with a 4.5-ft lowering of the channel bottom. Several alternatives were investigated as to how this change in bed elevation should be handled. Initially, a slope of 1V on 30H starting at sta 42+69 was used (Photo 22a). Flow conditions at the 10-year and 500-year frequency are shown in Photos 25a and 26a, respectively. Acceptable flow conditions were produced; however, this long transition would have required a large area of protection on the upper side slopes.

48. The next modification involved extending the deepened channel upstream to the Roanoke Parkway Bridge. A transition slope of 1V on 3H, shown in Photo 27, was installed. Flow conditions for the 10-year and 500-year flows are shown in Photo 28. The 1V on 3H slope was changed to a vertical drop (Photo 29). Flow conditions for the 10-year and 500-year flows are shown in Photo 30. Flow conditions were unacceptable with either configuration. Also, the vertical drop would hinder equipment access to the deepened channel. In addition to the attempts made to improve entrance conditions into the BCP-9 project, a 66-in. storm drain on the left bank at sta 42+65 would also require extensive modification to help improve flow conditions in this vicinity.

49. In order to avoid modification of the storm drain on the left bank near sta 42+50, the beginning of the drop was moved downstream to sta 43+00 and the channel invert sloped over a distance of 50 ft to the deepened channel (Photo 31). The side slopes from the channel bottom through this transition reach were 1V on 3H. Satisfactory flow conditions were obtained with this

modification. Flow conditions, shown in Photo 32, for the 10-year and 500-year floods revealed overbank lateral flow into the deepened channel. The existing topography of the left overbank assisted in redirecting the flow back into the modified channel.

50. A low berm on the right bank extending downstream from the right abutment of the Roanoke Bridge (Photo 33) was installed to confine the flow and allow re-entry at the transition structure. Flow conditions shown in Photo 34a for the 10-year flood show that the berm did not allow floodwaters passing through the Roanoke Bridge to escape to the right overbank. However, with the 500-year flow (Photo 34b), floodwaters passed over the north side of the Roanoke Parkway Bridge and re-entered the channel downstream of the transition.

Channel roughness

51. Manning's n values for the model were also determined at the two stations referenced in paragraph 45 as listed in the following tabulation:

	Computed Prototype Manning's n	
Station	10-year Flow	500-year Flow
53+50	0.019	0.017
59+25	0.016	0.023

Roughness values for the design discharge are close to anticipated conditions. Composite channel and overbank n values for Brush Creek were estimated to be between 0.020 and 0.025. The value of 0.017 at sta 53+50 is low while the value of 0.023 at sta 59+25 falls within the range of expected values. At locations where the depth is greater and velocities lower, n values would be higher than in the area of minimum depth and high velocity. The conclusion was that model n values were within an acceptable range and water-surface profiles obtained from the model will be representative of prototype conditions.

52. To determine the effect of the prototype channel bottom being rougher than expected, tests were conducted by placing expanded metal screen on the channel bottom between sta 81+00 to 87+00 and 91+00 to 100+00. This reach was selected because of better subsurface rock in this area and the possibility that channel bottom paving would not be necessary. Water-surface profiles shown in Plate 10 indicate the roughened bottom would cause an increase in the 500-year-flood water-surface elevation of 0.5 to 1.0 ft between Rockhill Road and Oak Street, and approximately a 1.5-ft increase from

Oak Street upstream to the vicinity of the Plaza footbridge. The increase in water-surface elevation for the 100-year flood was slightly greater over approximately the same reach. The effect on lower discharges was not investigated as the greatest effect was shown in the higher discharges. Therefore, by not paving the channel bottom and leaving the exposed subsurface rock unprotected, a significant increase in water-surface elevations will result. If the unpaved channel bottom was extended through the entire project reach, an unacceptably high design water surface would occur.

Overdeepening channel

53. Additional deepening between sta 55+00 and 85+00 was considered (Plate 7). The intent of this extra-deep bed profile was to place the channel bottom on sound rock and reduce the amount of channel bottom paving. The channel bottom in this plan would be paved through bridges and in areas of exposed shale. The remaining areas would be left as excavated. Tests conducted with the extra-deep bed profile indicated that supercritical flow would exist on the steep slope between sta 55+00 and 60+00 for all discharges. A hydraulic jump occurred between sta 59+00 and 60+00. Bottom velocities measured in the supercritical flow were 25.1, 28.5, and 29 ft/sec for the 10-, 100-, and 500-year floods, respectively. Table 4 provides the flow velocities and locations. The combination of high velocities and the hydraulic jump would cause unacceptable erosion on an unprotected rock surface. Therefore, the overdeepening was not recommended. Based upon these results, the initial deepened bed profile for the BCP-9 Plan shown in Plate 7 was recommended, as well as paving the channel bottom for the entire reach of deepened channel.

Upstream Flood Control

54. The city of Kansas City requested the Kansas City District to study a plan for flood control upstream of the BCP-9 Federal project (Photo 35). This plan included channel deepening upstream from the Federal Project to sta 20+60. At the present time, Brush Creek frequently overflows the right bank (south) intersection of 50th Street and Ward Parkway and floods homes along the south side of Ward Parkway. Protection of pier footings at Belleview (Photo 36a) and Roanoke (Photo 36b) adjacent to channel deepening is required at each of these bridges.

55. Deepening of the channel was then extended upstream from sta 42+69

to just below the low-water crossing (51st Street), which is the start of the paved channel. Even with the deeper channel, the 10-year flow still overtopped the intersection of 50th Street and Ward Parkway because of the very restrictive existing 50th Street Bridge. Flow conditions for the 10-year and 500-year flows, throughout the upstream extension, are shown in Photos 37 and 38, respectively. Water-surface elevations for the 10-year and 25-year flows are shown in Plate 11.

56. To alleviate some of the overbank flooding, tests were conducted to investigate modifications in the 50th Street area. These modifications included installing a low berm or dike upstream of 50th Street on the south side of Brush Creek and large culverts through the road fill just to the right of the existing bridge. These measures, individually or in combination, did not provide any significant flood protection for the affected area.

57. Protection from the 100-year flood was effected by replacing the existing 50th Street Bridge with a less restrictive one (Photo 39) and installing a low berm or dike at the corner of 50th Street and Ward Parkway. However, floods greater than 100 years still overtopped 50th Street. Channel deepening upstream of the Federal project would also require some channel widening through, between, and upstream of the Roanoke Parkway and Belleview Avenue bridges. Plate 12 shows the water-surface elevations with the new 50th Street Bridge. Channel deepening without replacement of the bridge resulted in less than 10-year protection for this area.

Impact of Channel Modification on Downstream Discharge

58. The change in discharges downstream from the Federal project that might occur as a result of the proposed channel deepening and removal of the Volker Park conduit was of great concern. Tests were conducted to evaluate any downstream discharge changes caused by the proposed channel modifications by comparing an outflow hydrograph with existing conditions and with the modified channel.

59. A hydrograph representing the accumulated flow at the downstream end of the model was introduced at the upstream end. This was done to avoid the great difficulty of reproducing individual hydrographs at each of the five inflow points in the model. The only part of the channel with proper flow was downstream of the last inflow point located near Paseo. Therefore, the

channel downstream of Woodland, which is the area of interest, received the proper discharge and all upstream areas received higher flows.

60. A V-notch weir was installed at the downstream end of the model and a time-history of weir headwater was recorded for discharge hydrographs routed through the model. The water surface in the weir was measured electronically with a sonic type distance measuring device. These distances were measured four times per second (model) and then converted to prototype discharge and time values.

61. Hydrograph tests were conducted with the 10-, 100-, and 500-year floods for both the existing conditions and the modified channel. Plate 13 provides the discharge versus time relationships for the various hydrographs used in the tests. Plate 14 shows the results obtained for the existing conditions. Plate 15 shows the results obtained for the modified BCP-9 conditions. At the 100-year flood, the peak discharge for the modified channel was about 800 cfs more than for existing conditions. A comparison of peak flows for the 500-year discharge indicated that the peak discharge for the modified channel was about 700 cfs higher than for the existing conditions. Considering the extreme and rapid fluctuation of the recorded water surface in the weir, the small difference in peak discharges was within acceptable accuracy. Therefore, a reasonable conclusion was that the channel modifications caused little change in downstream discharge.

Kansas City Park Plan

Description

62. The Kansas City Parks and Recreation Department proposed a treatment of the channel deepening patterned after the channel modification of the San Antonio River. An architect was engaged to prepare a plan for enhancement of the entire reach of Brush Creek between State Line and the Blue River. The basic concept was to provide a natural-appearing stream with a series of pools and waterfalls created by low dams. Walkways would be provided adjacent to the normal water surface during low flows. The channel side slopes would consist of a combination of grassed side slopes and landscaped terraces or steps to natural ground level. The Kansas City District, in coordination with the city of Kansas City and their architect, revised the BCP-9 Plan between Roanoke Parkway and downstream of the Paseo to better fit existing terrain and

provide a basic design that would be compatible with flood control and could be further enhanced at some future date.

63. The Brush Creek model was reconstructed to represent the Park Plan as shown in Photo 40. Water-surface profiles for the Park Plan along with the BCP-9 Plan are shown in Plate 16. Comparing the 500-year profiles shows that the Park Plan was generally higher than the Corps BCP-9 flood control plan from Rockwell to Nichols and lower for those areas downstream of Nichols. However, several problem areas in the Park Plan required modification.

64. Flow conditions observed at the start of the deepened channel, just below the low-water crossing or 51st Street (Photo 41), indicated that additional modifications were required to develop a suitable transition from the existing to the deepened channel. Several modifications were tested including removal of the low-water crossing, selective grading of the overbank to direct flow into the channel, and placing berms on the overbanks. Because of the relatively flat terrain in the area and a small change of elevation in the channel, the modifications tested did not improve the flow conditions. Velocities on the overbanks indicated that paving of selected areas would prevent scour.

Irregular dams

65. The Park Plan initially incorporated five small dams located throughout the channel to form pools and waterfalls. These dams were first installed straight across the channel because no final design had been formulated. These straight dams were used to determine the overall effects of the pools. The water-surface profiles and visual observations determined that no adverse effects were caused by the dams. A thorough investigation was conducted on a concept design for dam 1. This dam (Photo 42) was located downstream of J. C. Nichols Parkway Bridge at sta 68+65 and was broken in an irregular fashion according to aesthetic considerations. The crest elevation was 814.0. Vehicle access ramps and pedestrian steps were also incorporated in the design.

66. Some concern was expressed as to what effect the irregular shape of the dam would have on flow conditions. Flow conditions for the 10-, 100-, and 500-year flows, shown in Photo 43, indicated that no adverse effects would be caused by the irregular shape. Therefore, the irregular dam concept can be used throughout the Park Plan.

67. Dam 1 was subsequently relocated downstream to sta 79+00 (Photo 44)

to prevent the relocation of a large sanitary trunk sewer. The crest remained at el 814.0. The bed profile upstream to sta 60+32 was changed to el 807.0 to reduce excavation. Water-surface elevations in the vicinity of the Plaza were acceptable when the channel bottom was smooth. However, when the channel bottom roughness was increased, the water-surface elevations in the Plaza area were unacceptable. The crest of the dam was lowered to el 813. This change provided acceptable water-surface elevations in the Plaza area with rough bottom conditions. Flow conditions for the 10-, 100-, and 500-year flows shown in Photo 45 indicate that no adverse effects are caused by the irregular shape or modifications required for the storm drain. However, because of the concentrated flow present immediately downstream of this dam, measures should be taken to provide adequate protection, such as paving the channel in this area.

68. The relocation of dam 1 to sta 79+00 made the dam at sta 91+58 unnecessary. Therefore, it was removed. The dam located downstream of Rockhill Road at sta 101+35 was modified by raising the crest from el 801 to el 804 to provide necessary pool depth at dam 1. Flow conditions were acceptable. Again, to reduce excavation, the bed profile upstream of sta 101+35 was made horizontal at el 800. This change produced no adverse water-surface elevations and flow conditions remained acceptable.

Roanoke Parkway drop structure, drop 1

69. Type 1 design. An uncontrolled hydraulic jump formed downstream of Roanoke Parkway that had great potential for scour and erosion. To dissipate the energy of the hydraulic jump, a drop structure was needed. Traditional straight drop structures, such as the Saint Anthony Falls type, could not be used because of the high design unit discharge (210 cfs/ft for a 100-year flood) required in this situation. In previous work at the US Army Engineer Waterways Experiment Station involving high unit discharge drop structures on the Santa Ana River, a general design was developed. This type of drop structure (Photo 46) was installed downstream of Roanoke to dissipate energy and improve flow conditions. Details and design information for the type 1 design drop structure are shown in Plate 17. Flow conditions at the drop structure, shown in Photo 47, indicated that the hydraulic jump was contained within the structure and energy dissipation was greatly improved over existing conditions. Downstream water-surface conditions were also improved. Although the drop structure was designed for a 100-year event, satisfactory performance was observed at 500-year discharge conditions.

70. Type 2 design. In spite of satisfactory performance of the type 1 drop structure, the parabolic curve of the trajectory did not conform to the overall aesthetics of the Park Plan. The curve was broken into steps of approximately 2 ft in height as shown in Photo 48. All other dimensions remained the same (Plate 17). Flow conditions shown in Photo 49 indicated that the stepped trajectory (type 2 design) did not perform as well as the parabolic trajectory (type 1 design).

71. Type 3 design. Because the type 2 design performed unsatisfactorily, further efforts were directed toward making the stepped trajectory perform in an acceptable manner. The general design guidance of the Santa Ana drop structures recommends a parabolic trajectory based on the equation $X^2 = KHY$, where X is the horizontal distance, H is the head on the crest, Y is the vertical downward distance, and $2 < K < 4$. Initially, the crest profile was $X^2 = 2HY$ and this parabolic profile was satisfactory, but was not in stepped form. Therefore, a longer stepped trajectory based on the equation $X^2 = 4HY$ was installed. Dimensions and elevations of the type 3 design drop structure are shown in Plate 18. Flow conditions observed indicate satisfactory performance up to the 500-year frequency flood. Therefore, a stepped parabolic trajectory based on the equation $X^2 = 4HY$ was considered acceptable.

72. Type 4 design. Although the type 3 design provided adequate energy dissipation, the roller formed by the hydraulic jump created a significant safety hazard for anyone attempting to float the stream during high flows. Therefore, the drop structure was redesigned with a series of horizontal steps 2 ft high. The steps were arched or horseshoe shaped in the upstream direction for aesthetic reasons. A shallow upstream pool was also added. This was designated the type 4 design and is shown in Photo 50. A plan view and center-line profile of the type 4 design are shown in Plate 19. As expected, flow conditions and energy dissipation were not as good as was observed with the previous design. However, the strong reverse roller was eliminated, which greatly improved safety. Flow conditions with the type 4 design are shown in Photo 51 for the 10-, 100-, and 500-year floods. A subsequent modification was made by placing blocks approximately 4 ft high on the steps at the sidewalls. These blocks directed the flow to the center of the channel and dampened the large oblique standing waves previously created. Next, the upstream pool was narrowed with straight walls on both sides of the channel in an

attempt to reduce the oblique standing waves. These walls prevented the formation of waves upstream of the drop and reduced the height of the standing waves formed by the drop structure. Therefore, straight guide walls can be used upstream of the drop to reduce the height of the oblique standing waves. The type 4 design was acceptable based on safety considerations.

Troost Avenue drop structure, drop 2

73. Type 1 design. It was observed from the various tests conducted that a hydraulic jump will develop just downstream of Troost Avenue. Because of this, a drop structure was required in this vicinity to prevent excessive erosion from occurring. Due to the higher unit discharge in this reach and because of the narrow channel width (70 ft), a drop structure identical to the Roanoke drop structure would not perform satisfactorily. The type 1 design drop structure (Photo 52) was designed for a width of 70 ft and a unit discharge of 287 cfs/ft (100-year flood). Based upon experience gained on the Roanoke drop structure, the Troost drop structure was designed with the longer $X^2 = 4HY$ parabolic trajectory. Details of the type 1 design are shown in Plate 20. Flow conditions with the type 1 design are shown in Photo 53.

74. Type 2 design. The type 2 design (Photo 54) used a stepped trajectory instead of the parabolic trajectory for reasons stated in paragraph 70. Details of the type 2 design are also presented in Plate 20. Flow conditions shown in Photo 55 indicate satisfactory performance and effective energy dissipation. Therefore, the stepped trajectory can be safely used.

75. Type 3 design. Safety considerations, as explained previously (paragraph 72), required that the Troost drop structure also be modified to prevent the formation of any strong reverse roller in the stilling basin. The type 3 design (Photo 56) had five steps approximately 2 ft high for a total drop of 10.7 ft. The steps were 20 ft long. Dimensions and elevations are shown in Plate 21. Flow conditions are shown in Photo 57 for the 10-, 100-, and 500-year floods. Flow was directed to the center of the structure by the Troost Avenue Bridge and sidewall blocks were not required. Although there was little energy dissipation, smooth flow conditions were observed for all discharges. The type 3 design is therefore recommended based on safety considerations.

Paseo intersection alignment

76. The Paseo area benefits greatly from the Park Plan modifications. Previously, flow in the channel was restricted by the Paseo tunnel, which

turned the flow some 90 deg, and flooding frequently occurred (Photos 5f, 6f, and 7f). The Park Plan calls for bypassing the existing tunnel with a straightened open channel (Photo 40d). Two new bridges will span the channel on Paseo Boulevard (Photo 58). Dam 4 initially was to be located under the downstream bridge.

77. Although flow conditions were improved, the 500-year flood still overtopped the left bank and flooded the low area in the vicinity of the Brush Creek Boulevard-Paseo intersection. This flooding was due to the location of dam 4, which restricted the flow underneath the bridges. Also, the curved alignment of the channel upstream of the Paseo bridges contributed to the problem. Relocation of dam 4 downstream to sta 131+50 improved the situation, but additional refinement was needed. The channel upstream of the Paseo bridges was straightened to remove any curvature. The combination of these modifications, shown in Photo 59, greatly improved the flow conditions in the Paseo area. Flow conditions for the 10-, 100-, and 500-year floods, shown in Photo 60, reveal that the flood impact in this area was greatly reduced when compared with previous conditions.

PART IV: DISCUSSION OF RESULTS AND CONCLUSIONS

78. Existing prototype conditions were verified in the model by reproducing the September 1977 flood. Throughout the channel, the existing bridges present varying degrees of blockage to the flow. The bridges at Main Street and Troost Avenue act as controls for the channel. These bridges have narrow span widths and high overbanks. Replacement of these obstructive bridges with less restrictive streamlined bridges would reduce flooding. Further lowering of the water surface would require enlarging several bridge openings as well as channel deepening.

79. The Corps BCP-9 Plan incorporated bridge improvements, channel widening, and channel deepening. Some of these improvements are replacement of the Main Street Bridge, removal of the KCPS Railroad bridge, removal of Volker Park conduit and replacing it with an open channel, and deepening the channel by 4 to 8 ft. These modifications greatly improved the flood control capacity of the channel.

80. The city extension, upstream of the BCP-9 Plan, will improve flood conditions in this area. However, the existing 50th Street Bridge should be replaced to reduce localized flooding.

81. The BCP-9 bed profile was acceptable. Overdeepening the channel bed to reach a better strata of rock to reduce paving was attempted. However, unfavorable hydraulic conditions were produced that would result in severe erosion.

82. Hydrograph tests were conducted with the existing conditions and BCP-9 Plan. These tests show that any proposed modifications would not increase the downstream discharge or the downstream flooding potential.

83. The Park Plan demonstrates that flood control projects can be made to conform to an existing urban environment. In this plan, the channel sections are wider and deeper than the BCP-9 Plan. Several small dams form pools throughout the channel. These dams are to be constructed with an irregular alignment to the flow. No adverse flow conditions were observed due to this irregular alignment. The Paseo tunnel was replaced with a straightened open channel. Additional straightening resulted in further improvement. Drop structures were required at two locations in the channel. These structures were designed with a stepped trajectory and performed satisfactorily. The resulting water-surface elevations obtained with the Park Plan were generally comparable to those of the BCP-9 Plan.

Table 1

Brush Creek Bridge Stations and Low Steel Elevations

Bridge	Station	Low Steel Elevation*
State Line	0+15 to 0+25	853.6
Ward Parkway	5+30 to 6+70	848.6 to 848.0
Low-water crossing	20+40 to 20+60	
Rockwell	26+68 to 26+92	840.3
Belleview	36+10 to 36+60	837.6
Roanoke	39+85 to 40+40	837.64
Wornall	56+70 to 58+35	831.8
Plaza footbridge	61+80 to 61+90	832.71
Nichols	67+00 to 67+50	831.0
Main Street	70+00 to 70+90	842.31 (old)
		844.5 (new)
Kansas City Public Service Railroad	75+70 to 75+90	824.2
Volker Park	83+30 to 91+75	
Rockhill footbridge	94+20 to 94+30	
Rockhill	94+90 to 95+30	817.2
Troost	111+60 to 112+10	828.4
Paseo Conduit	130+20 to 134+00	
Woodland	148+25 to 148+80	791.31
Volker-Ward Parkway	73+14 to 74+70	832.0
Brookside-Main	75+50 to 76+40	835.0
Oak Street (concept)	84+00 to 84+62	823.75**
Rockhill (concept)	94+90 to 95+52	817.2**

* Elevations are given in feet referred to the National Geodetic Vertical Datum.

** These elevations were used in the model and were changed in final design for construction. Additional adjustments will be made during actual construction.

Table 2

Incremental Lateral Inflow to Brush Creek

Location	Discharge, cfs, for Frequency, years					
	10	25	50	100	500	1977 Flood
State Line Road	8,800	11,000	12,900	14,800	19,500	17,548
Downstream Roanoke Avenue	600	800	800	900	1,200	1,057
Upstream Volker Conduit	1,700	2,200	2,400	2,900	3,800	4,221
Upstream Troost	900	1,000	1,350	1,500	1,900	2,388
Upstream Paseo	900	1,000	1,350	1,500	1,900	2,388

Table 3
Brush Creek Velocity Data
Existing Conditions

Station	Average Velocity fps
50-Year Flood	
-1+50	9.3
0+50	11.8
5+00	11.4
7+50	14.8
13+00	18.3
21+00	9.3
26+50	2.9
27+25	6.6
31+00	5.0
36+00	11.6
37+00	14.2
39+50	14.1
41+00	19.1
48+00	10.9
56+00	8.1
57+75	9.0
62+25	7.9
66+75	7.3
72+00	10.3
75+00	6.8
76+50	10.1
81+00	7.5
84+50	8.0
91+50	12.5
94+00	6.8
96+00	9.1
104+00	15.6
111+35	11.1
112+65	19.4
118+00	26.5
130+50	15.3
134+50	22.2
140+00	7.2
148+00	13.7
149+00	25.3

Station	Average Velocity fps
100-Year Flood	
-1+50	8.4
0+50	9.1
5+00	9.9
7+50	9.9
13+00	17.2
21+00	7.2
26+50	4.4
27+25	6.8
31+00	5.4
36+00	11.3
41+00	18.2
48+00	12.0
56+00	7.1
57+75	8.7
62+25	8.8
66+75	7.2
72+00	11.3
78+00	11.1
84+50	8.1
91+50	9.3
96+00	8.3
104+00	11.5
111+35	14.7
112+65	19.9
118+00	27.5
130+50	15.4
134+50	20.1
140+00	7.6
148+00	13.9
149+00	24.1
500-Year Flood	
-5+00	9.5
0+20	11.4
5+00	7.9
7+50	16.9

(Continued)

Table 3 (Concluded)

Station	Average Velocity fps
500-Year Flood (Continued)	
13+00	20.4
21+00	10.1
26+50	3.1
27+25	12.9
31+00	3.3
36+00	6.6
41+00	17.3
48+00	10.4
56+00	4.8
57+75	8.1
62+25	8.4
66+75	5.4
72+00	11.1
76+50	7.3
81+00	9.6
84+50	12.0
91+50	9.2
96+00	5.5
104+00	9.3
111+35	13.9
112+65	22.6
118+00	30.9
130+50	12.5
134+50	19.2
140+00	7.1
148+00	8.8
149+00	25.4

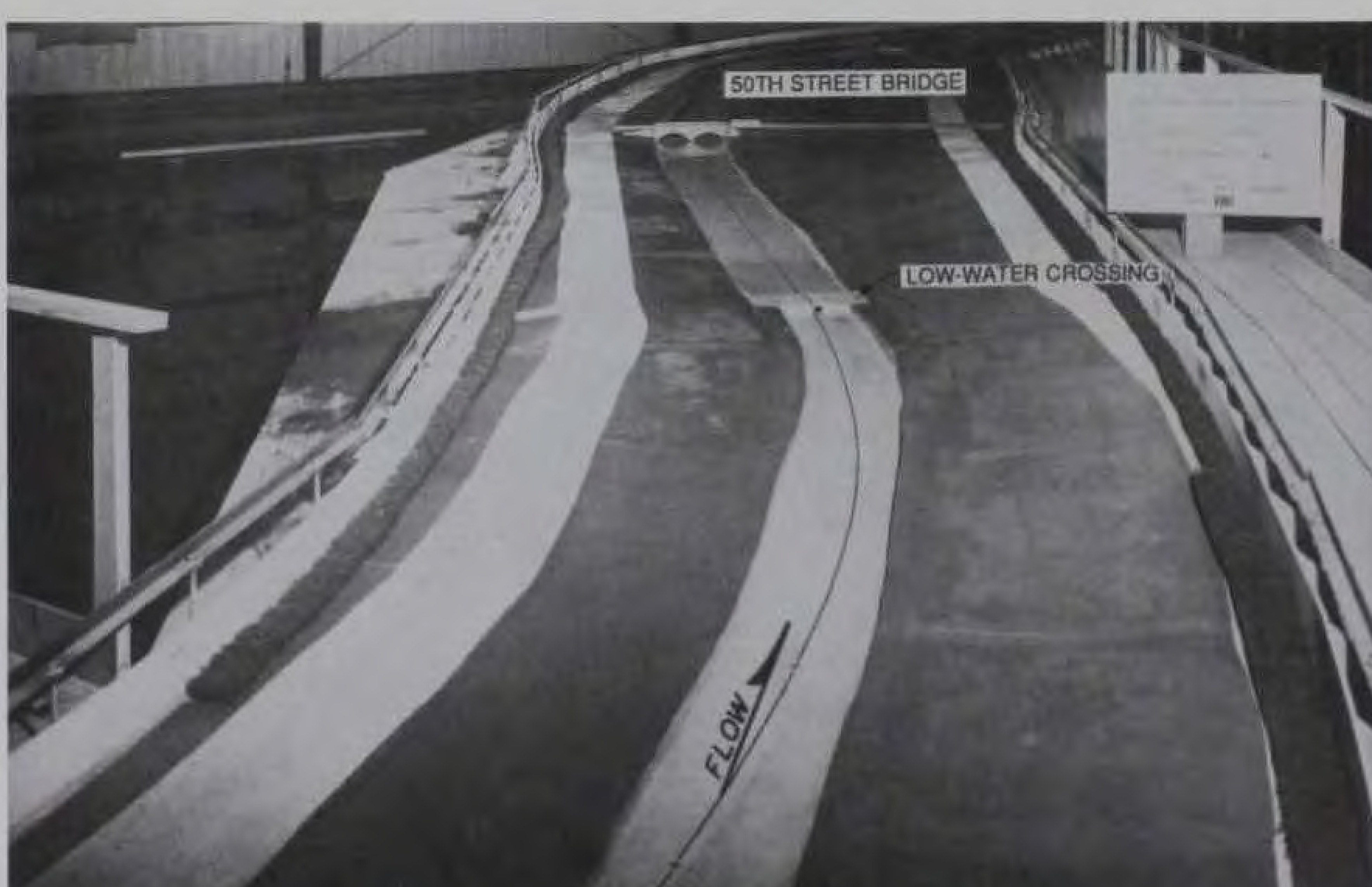
Table 4

Brush Creek Velocity Data

BCP-9 Conditions

Station	Average Velocity fps
50-Year Flood	
53+50	20.0
59+25	21.3
65+00	19.0
70+00	19.7
77+00	12.7
80+00	15.7
86+00	16.7
90+00	11.7
96+00	8.7
100+00	14.3
105+00	14.7
110+00	17.3
115+00	21.9
120+00	21.9
500-Year Flood	
41+50	24.7
43+50	21.7
44+00	23.7
44+50	20.3
53+50	20.3
59+25	18.3
65+00	16.0
70+00	11.3
77+00	10.9
80+00	11.3
86+00	15.3
90+00	10.9
96+00	12.7
100+00	15.7
105+00	13.7
110+00	11.9
115+00	29.3
120+00	18.6

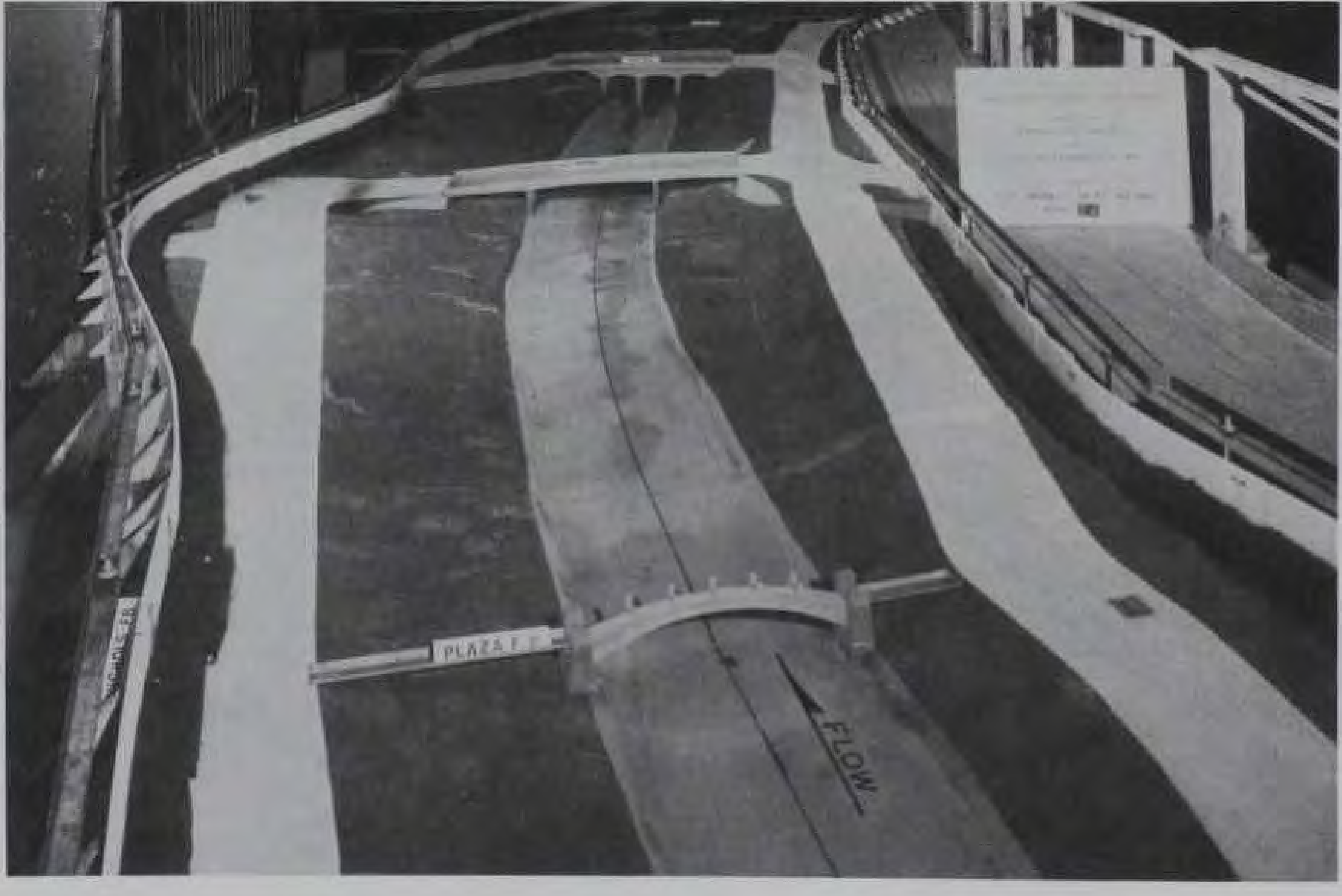
a. Sta 0+00 to sta 15+00



b. Sta 14+00 to sta 37+00

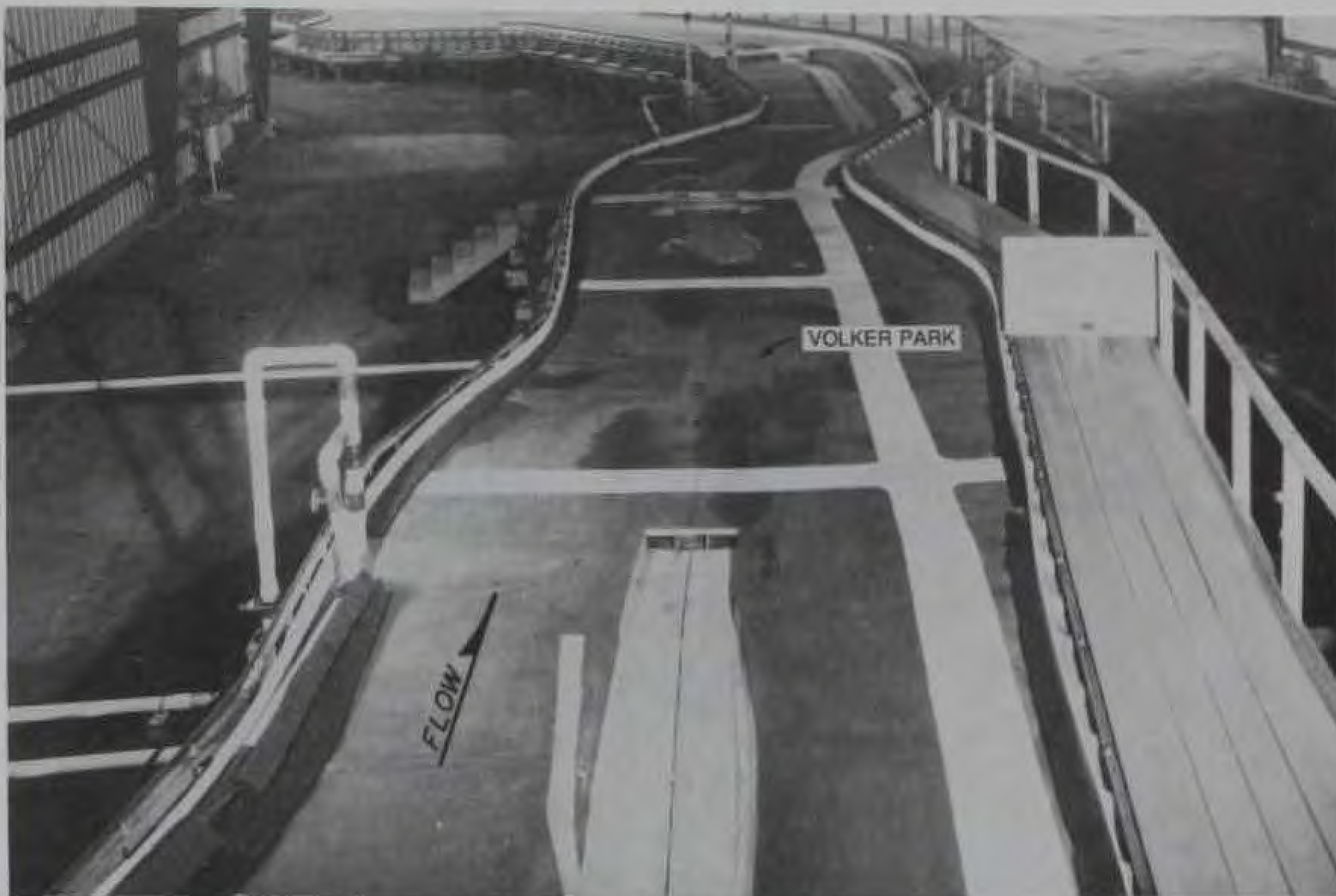
Photo 1. Existing conditions (Sheet 1 of 3)

c. Sta 35+00 to sta 61+00



d. Sta 61+00 to sta 81+00

Photo 1. (Sheet 2 of 3)



e. Sta 81+00 to sta 112+00

f. Sta 112+00 to sta 147+00

Photo 1. (Sheet 3 of 3)

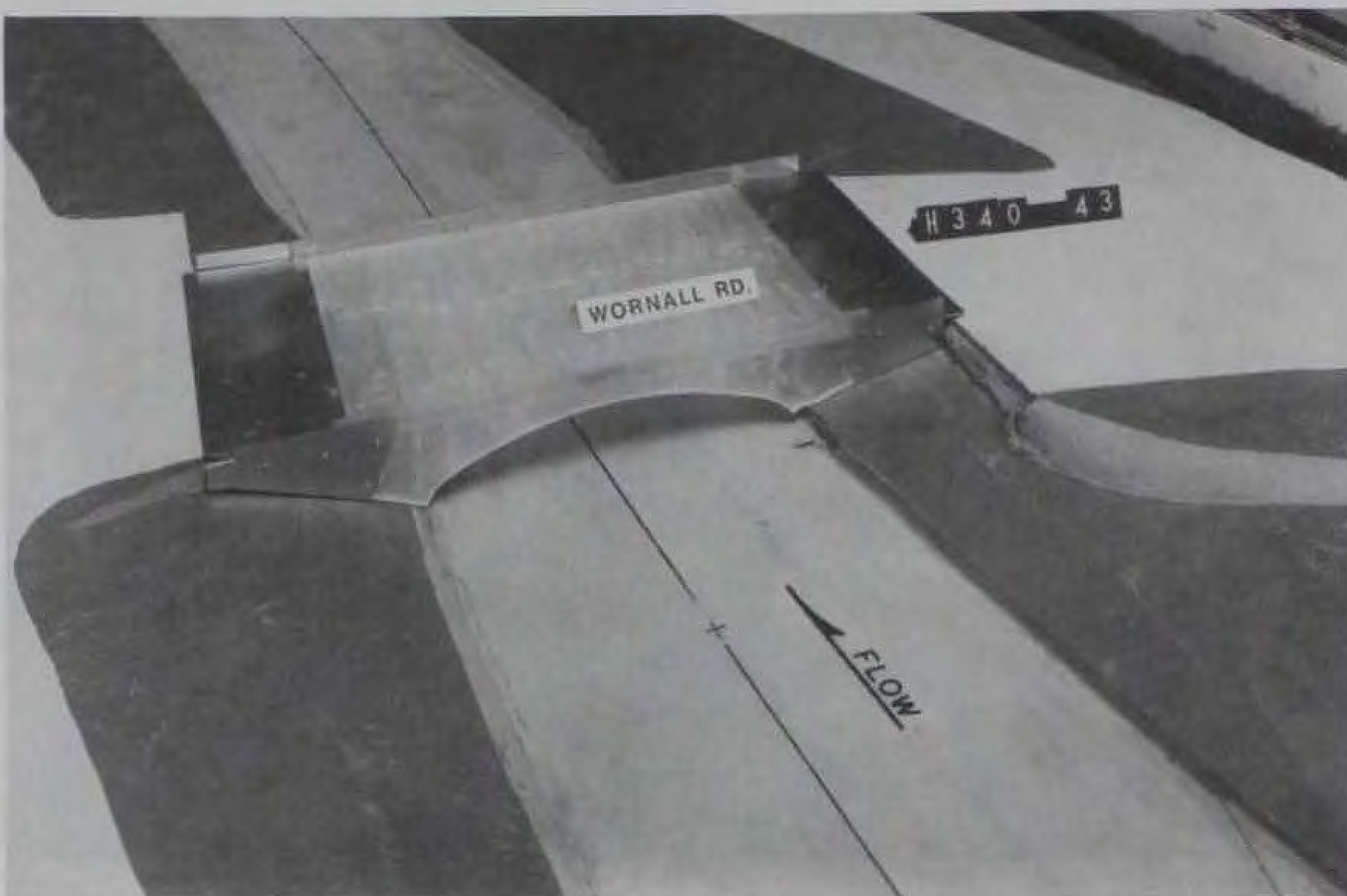


Photo 2. Old Wornall Road Bridge

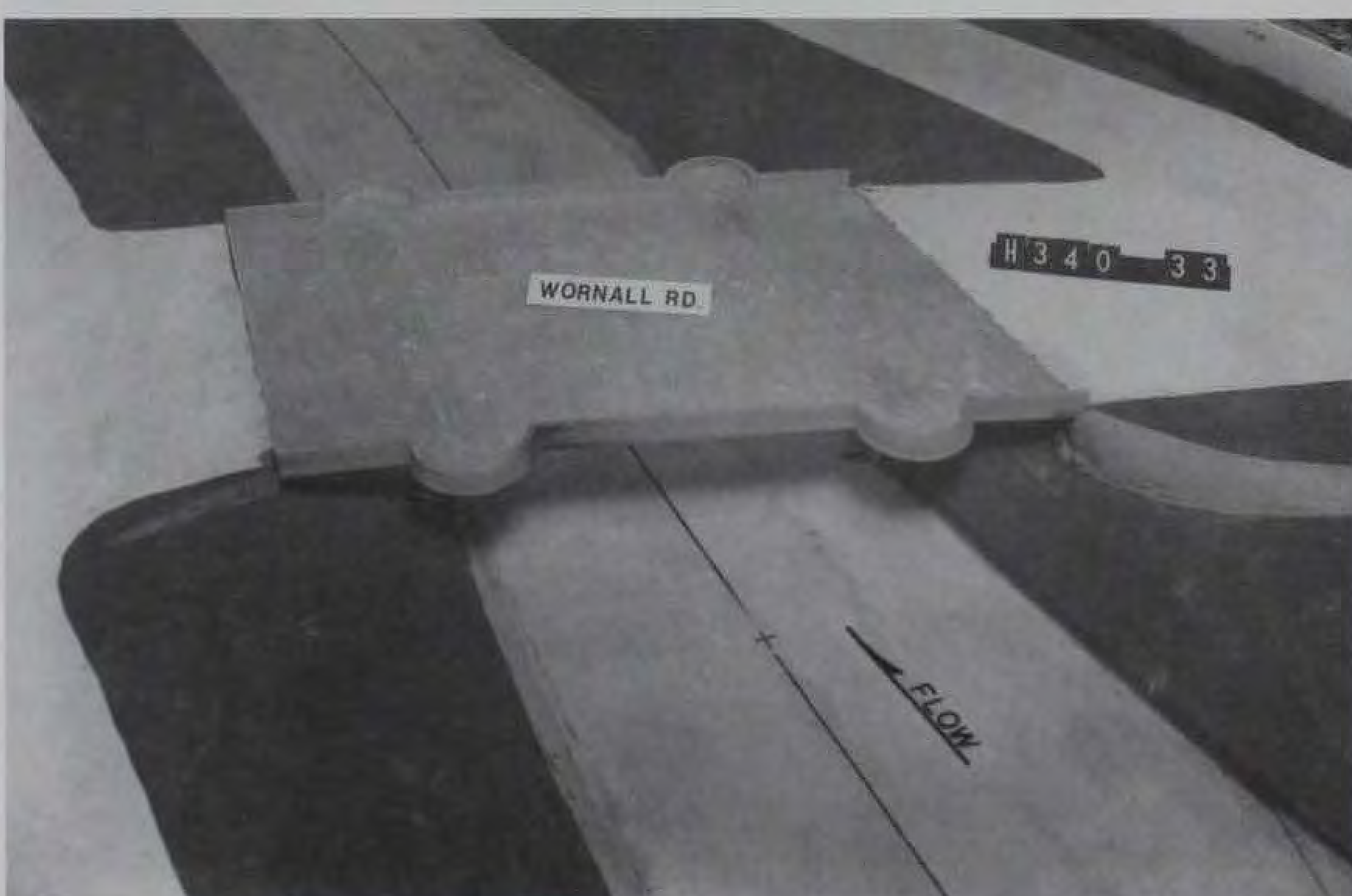


Photo 3. New Wornall Road Bridge

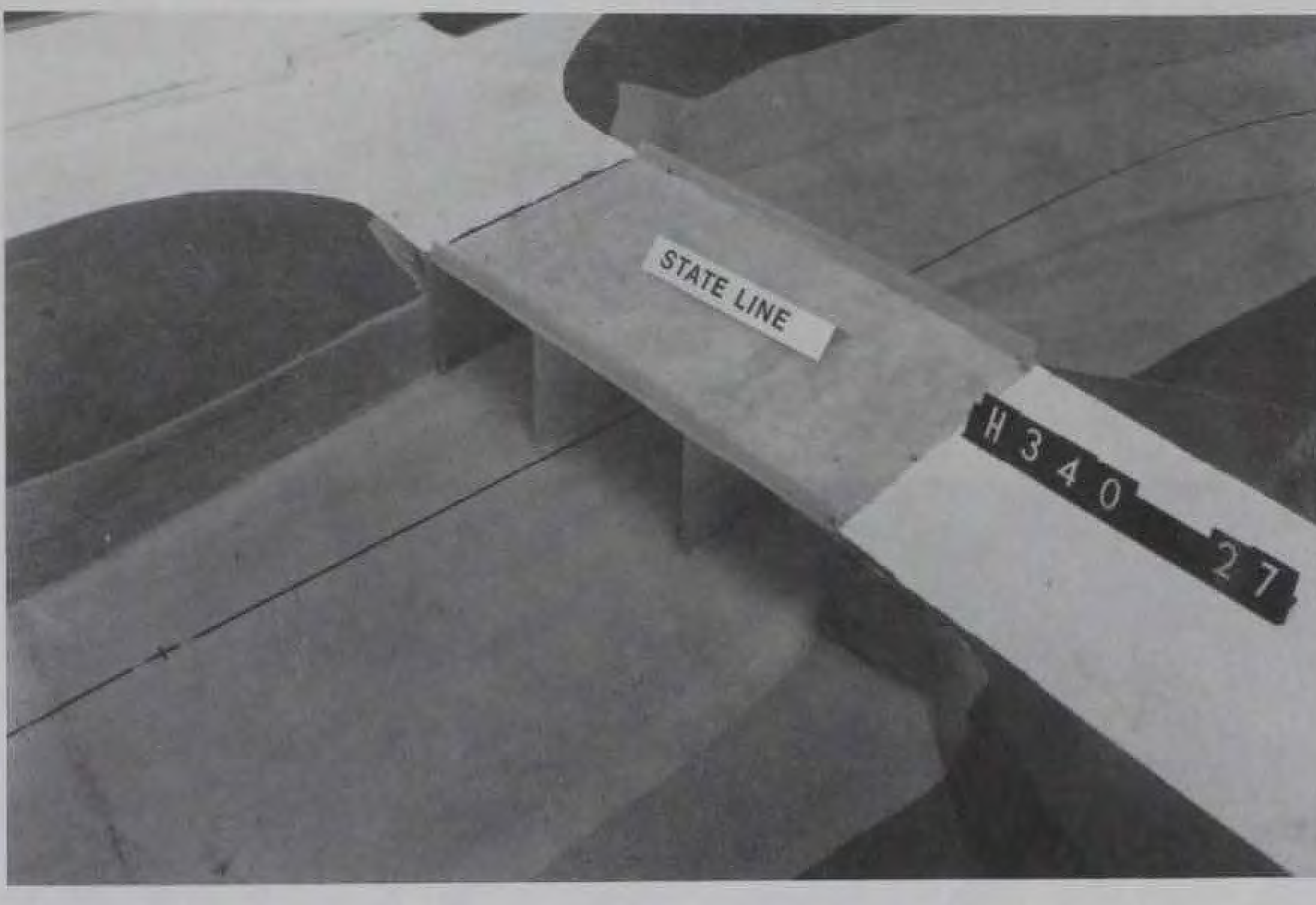
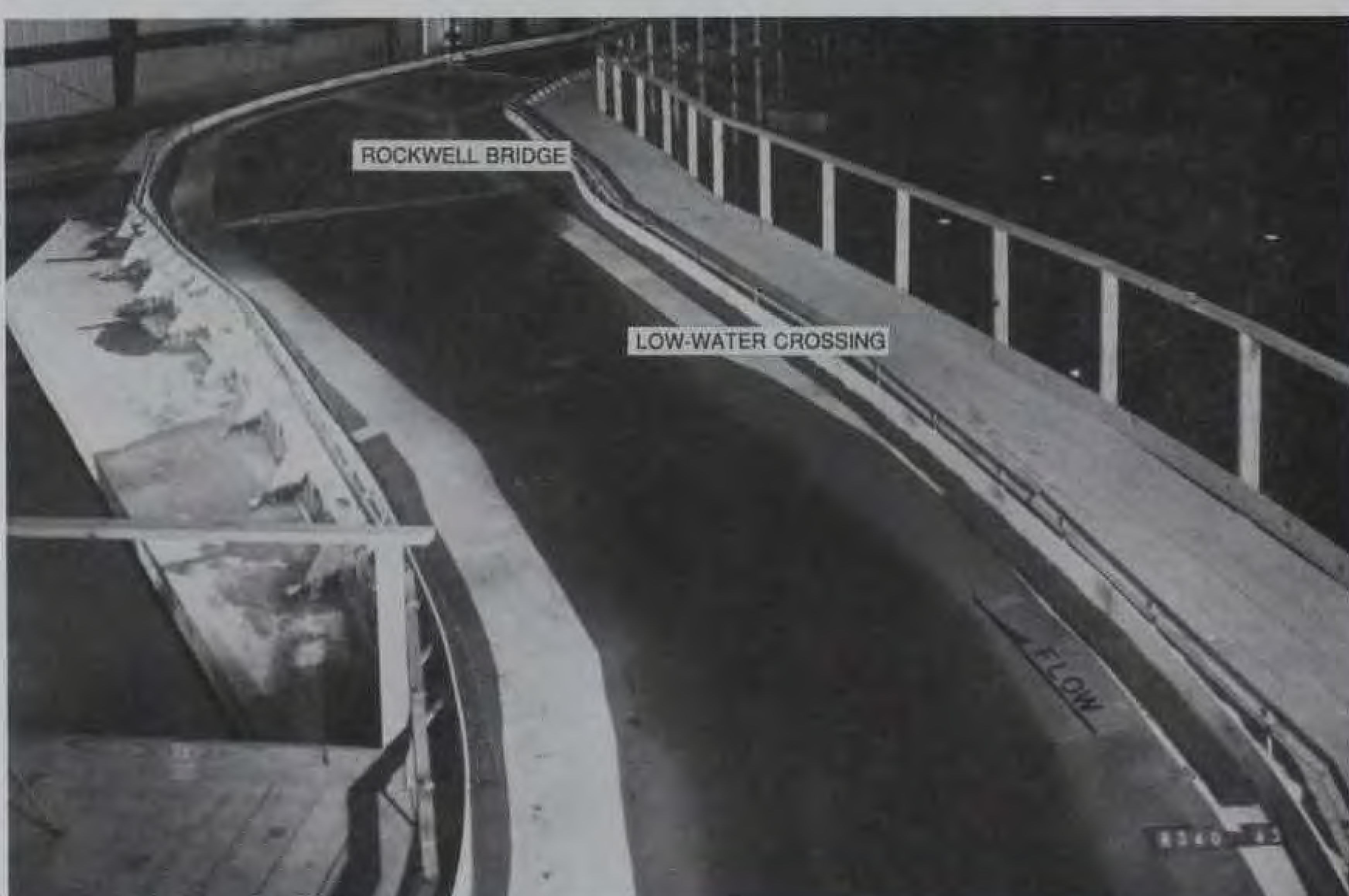


Photo 4. State Line Road Bridge

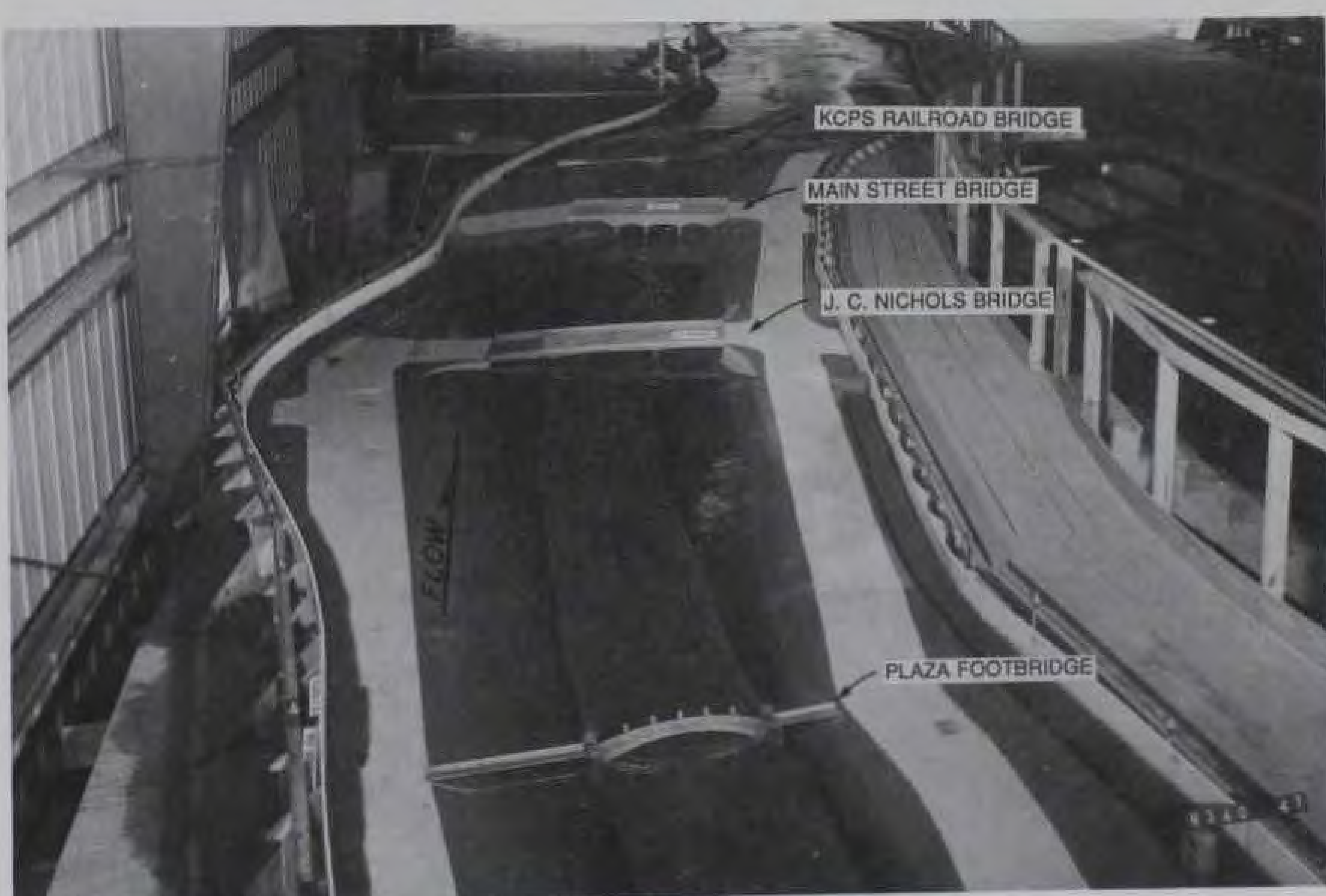
a. Sta 0+00 to sta 15+00



b. Sta 14+00 to sta 37+00

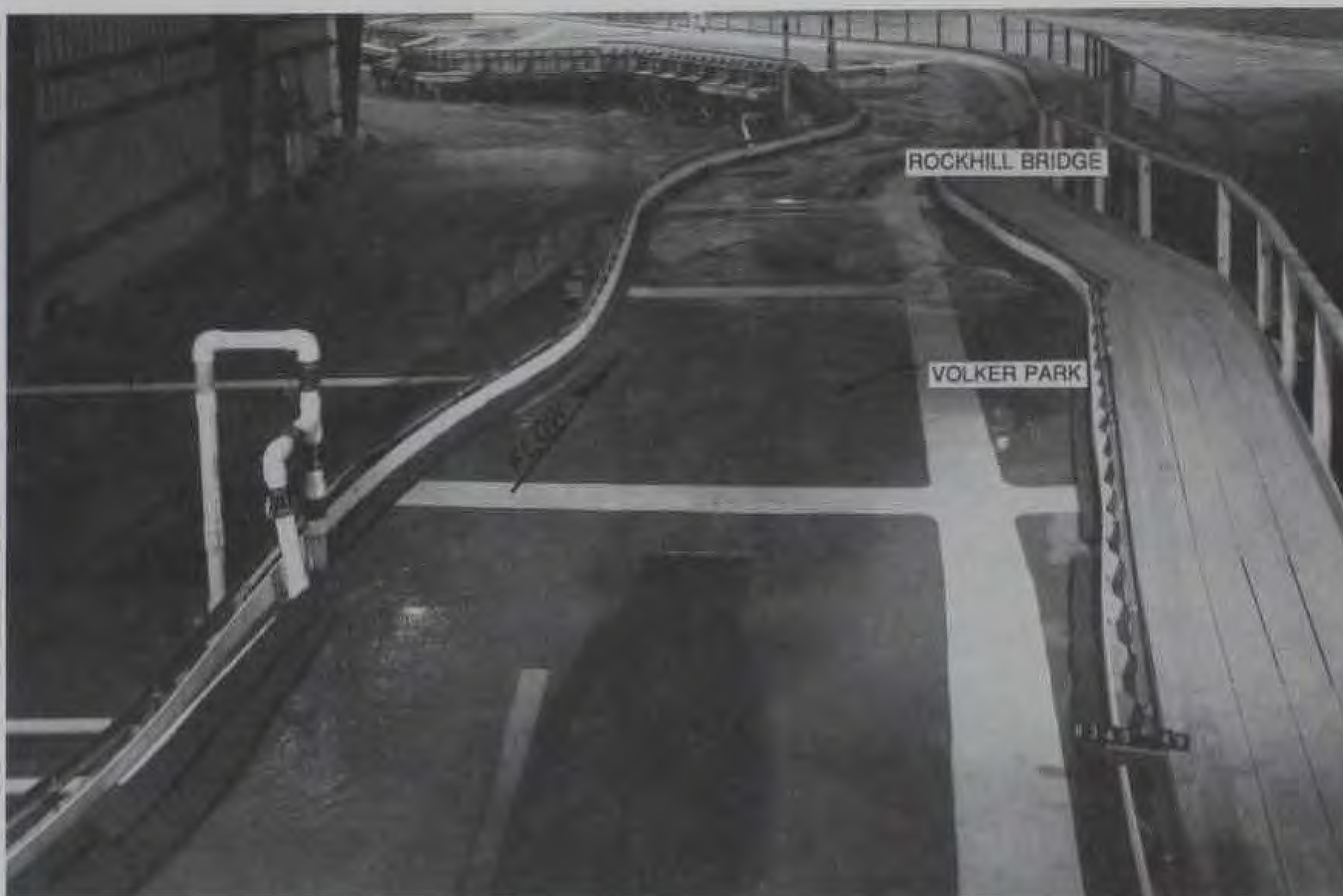
Photo 5. Existing conditions, 10-year flood (Sheet 1 of 4)

c. Sta 35+00 to sta 61+00

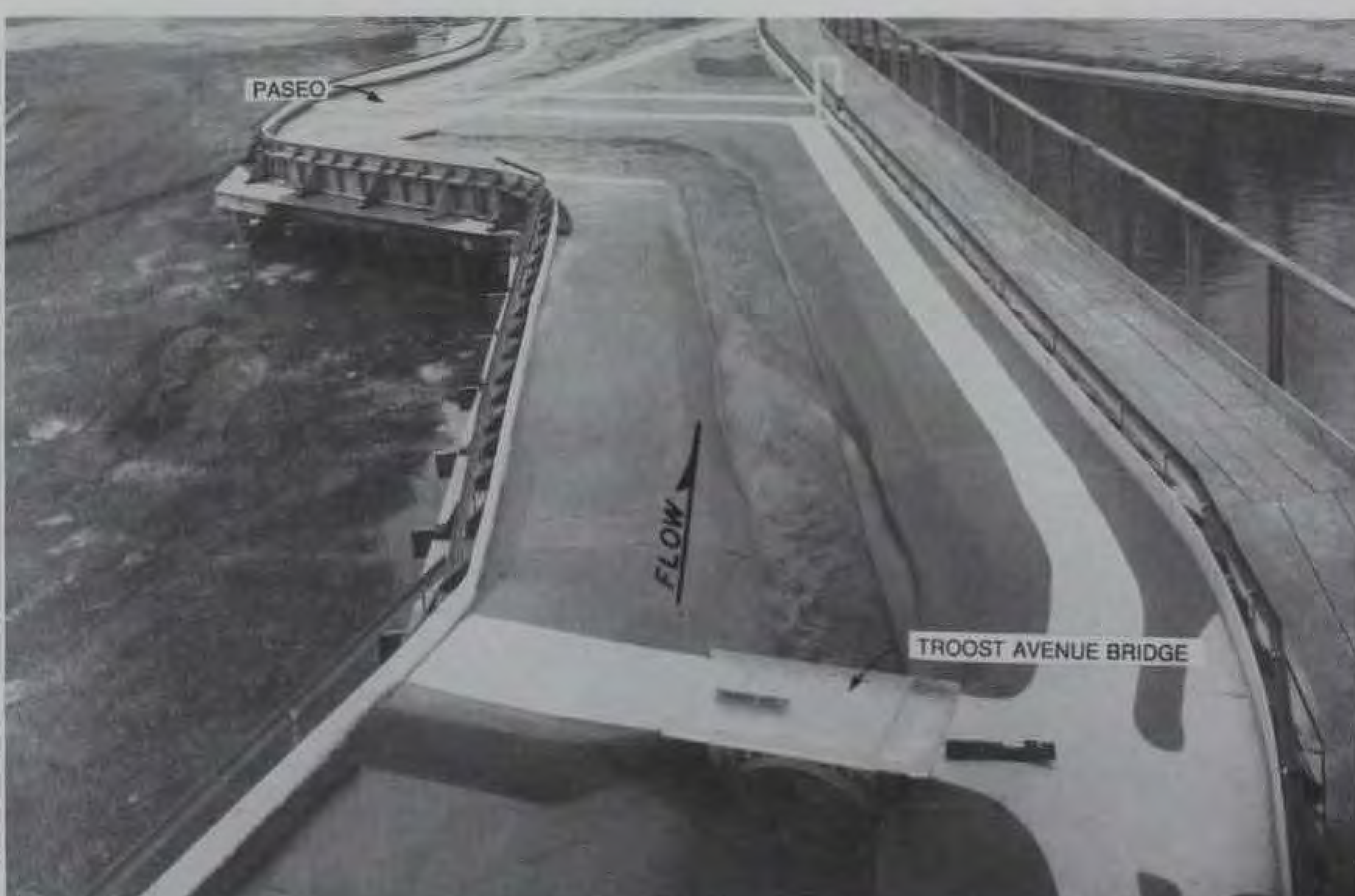


d. Sta 61+00 to sta 81+00

Photo 5. (Sheet 2 of 4)

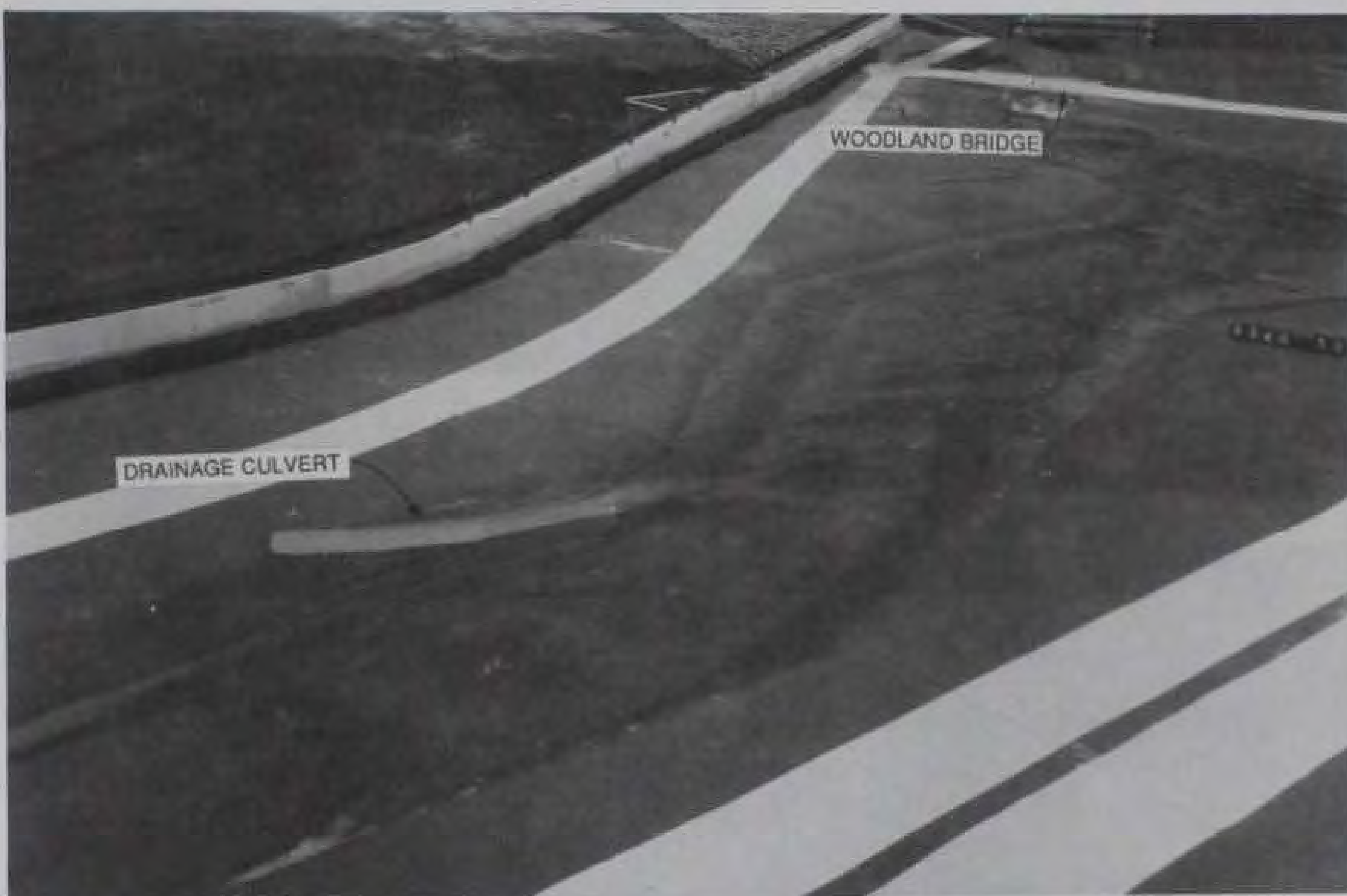


e. Sta 81+00 to sta 112+00



f. Sta 112+00 to sta 147+00

Photo 5. (Sheet 3 of 4)



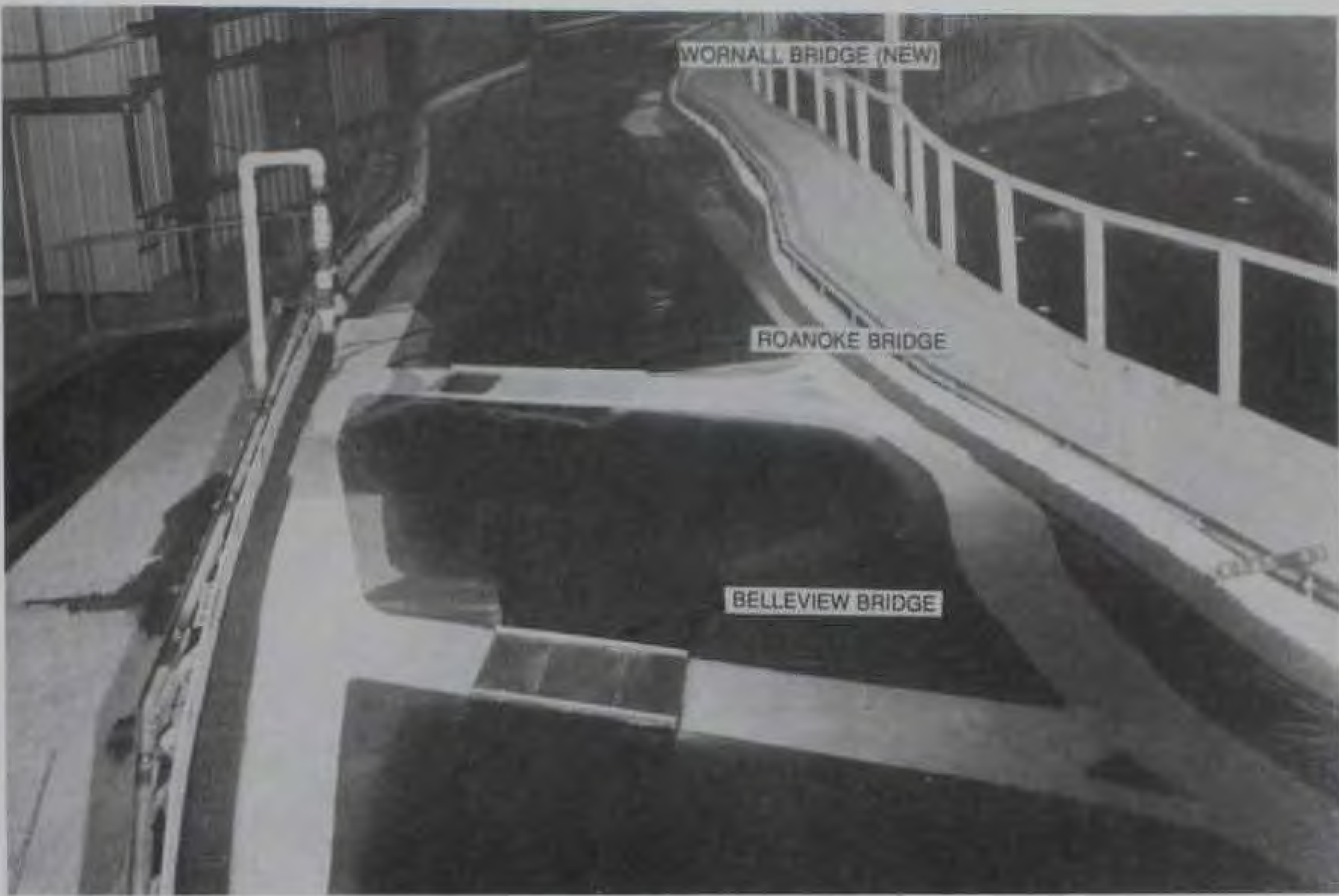
g. Sta 135+00 to sta 147+00

Photo 5. (Sheet 4 of 4)

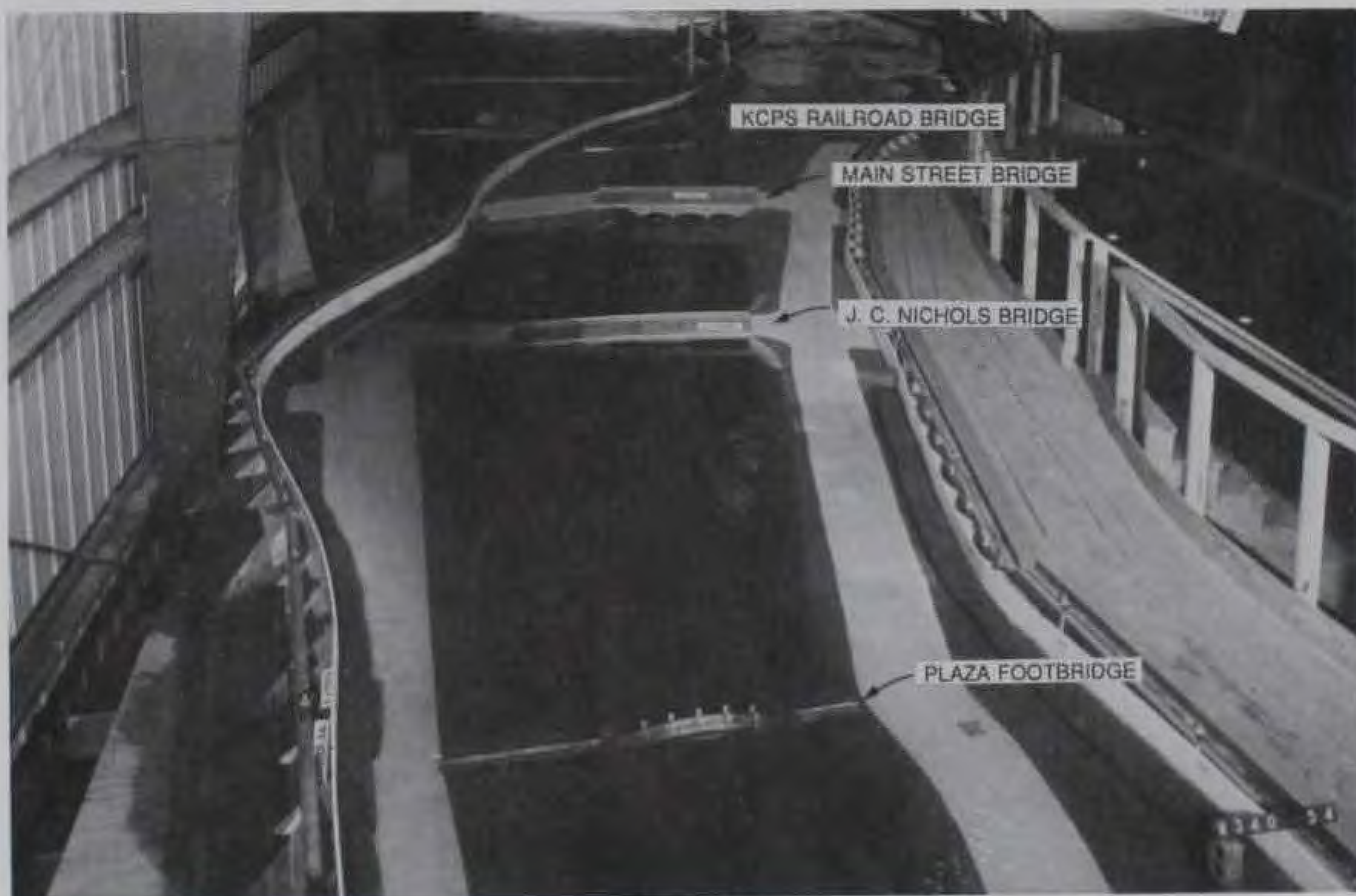
a. Sta 0+00 to sta 15+00

b. Sta 14+00 to sta 37+00

Photo 6. Existing conditions, 100-year flood (Sheet 1 of 4)



c. Sta 35+00 to sta 61+00



d. Sta 61+00 to sta 81+00

Photo 6. (Sheet 2 of 4)

e. Sta 81+00 to sta 112+00

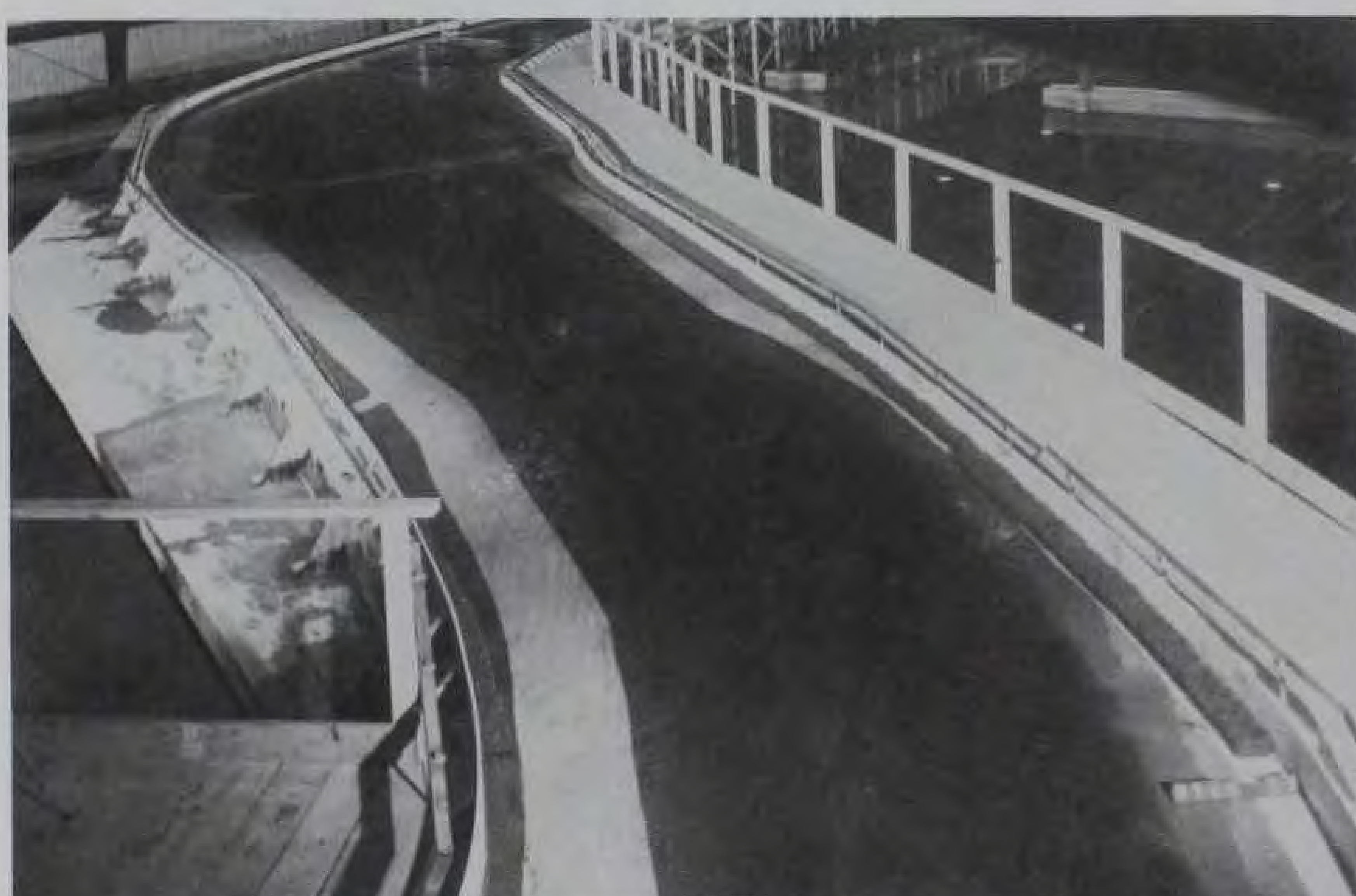
f. Sta 112+00 to sta 147+00

Photo 6. (Sheet 3 of 4)

g. Sta 135+00 to sta 147+00

Photo 6. (Sheet 4 of 4)

a. Sta 0+00 to sta 15+00



b. Sta 14+00 to sta 37+00

Photo 7. Existing conditions, 500-year flood (Sheet 1 of 4)

c. Sta 35+00 to sta 61+00

d. Sta 61+00 to sta 81+00

Photo 7. (Sheet 2 of 4)

e. Sta 81+00 to sta 112+00

f. Sta 112+00 to sta 147+00

Photo 7. (Sheet 3 of 4)

g. Sta 135+00 to sta 147+00

Photo 7. (Sheet 4 of 4)

Photo 8. Ward Parkway Bridge

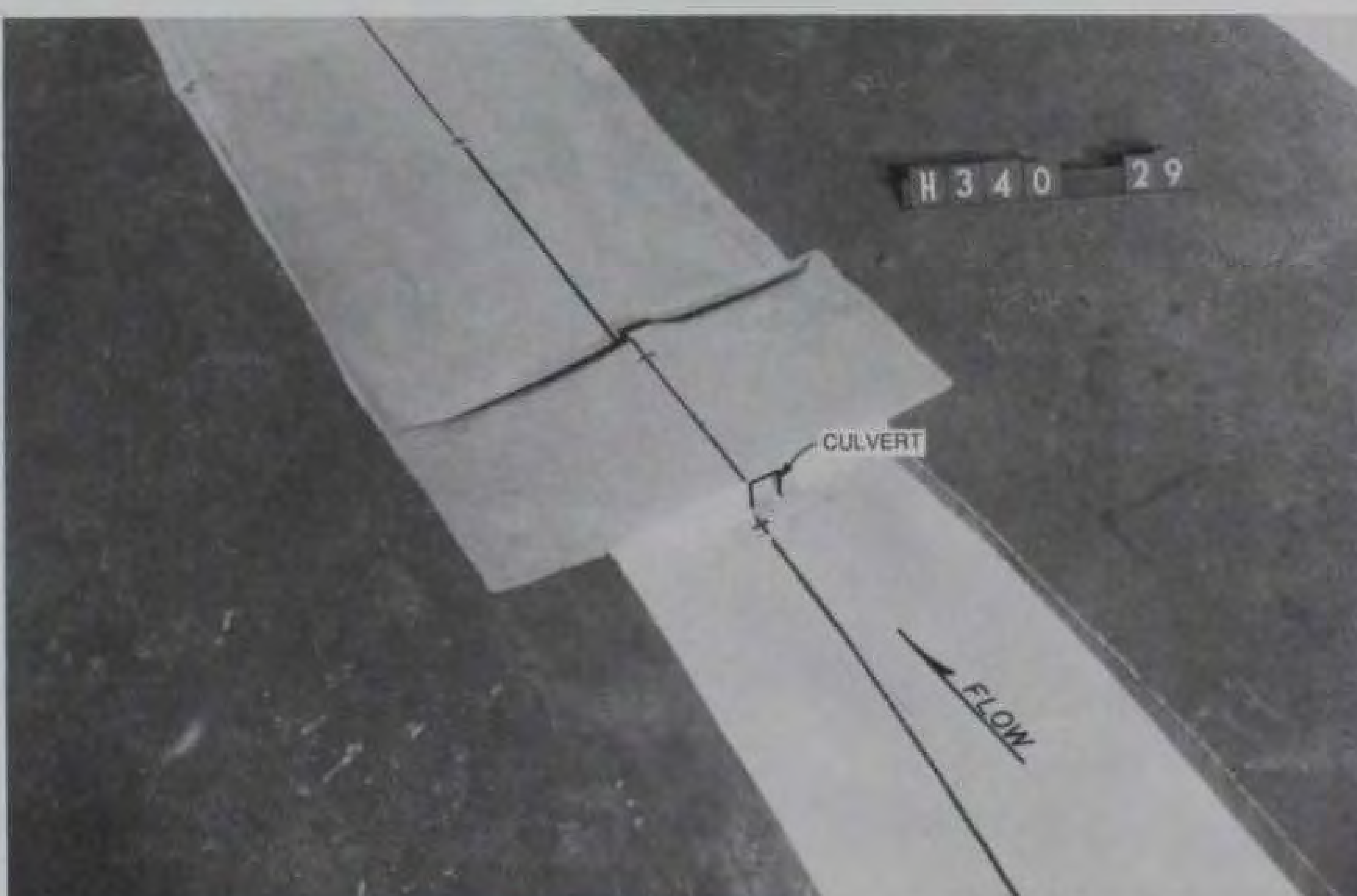


Photo 9. Low-water crossing (51st Street)

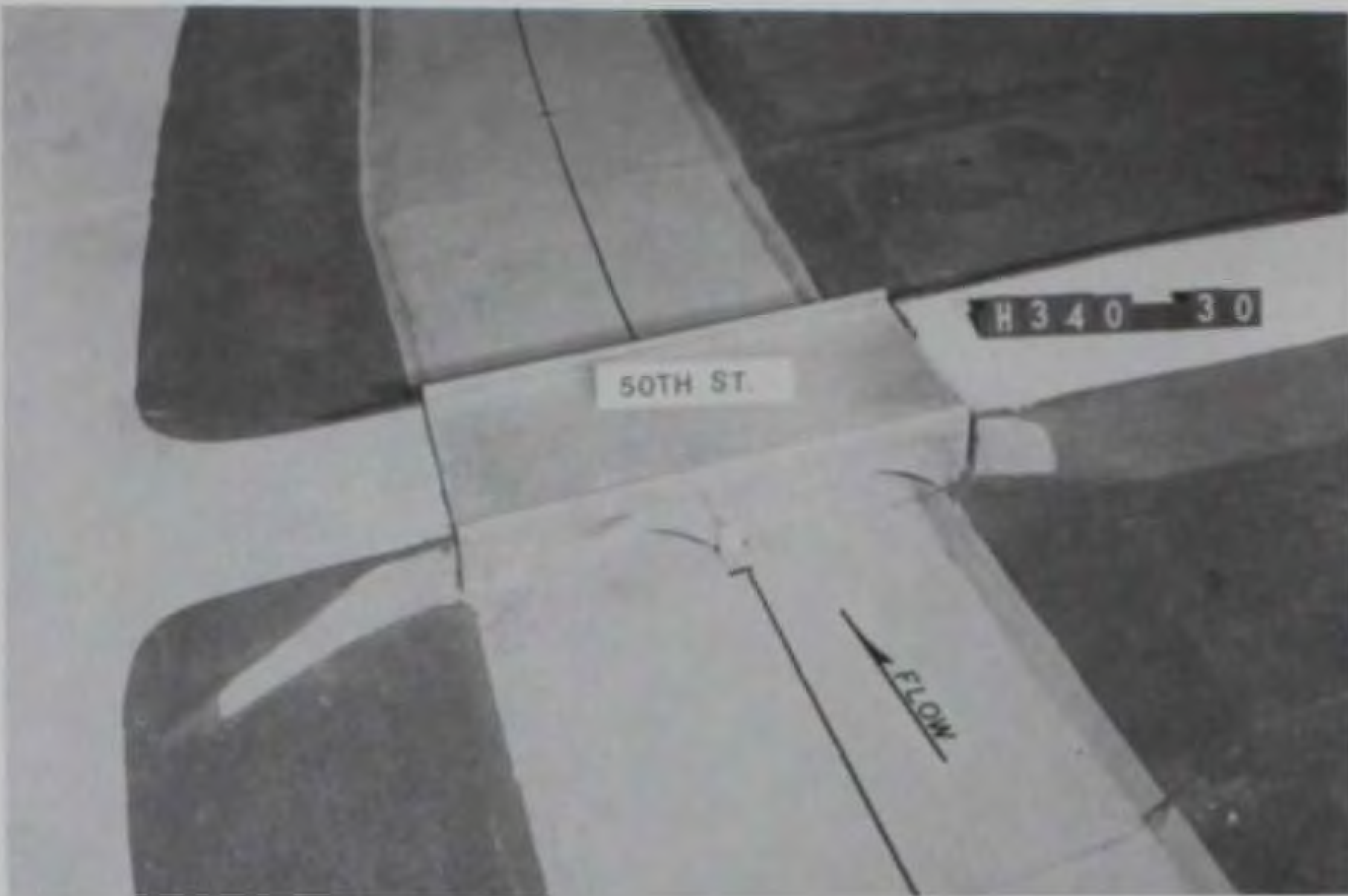


Photo 10. Rockwell Road Bridge (existing) (50th Street)

Photo 11. Belleview Avenue Bridge

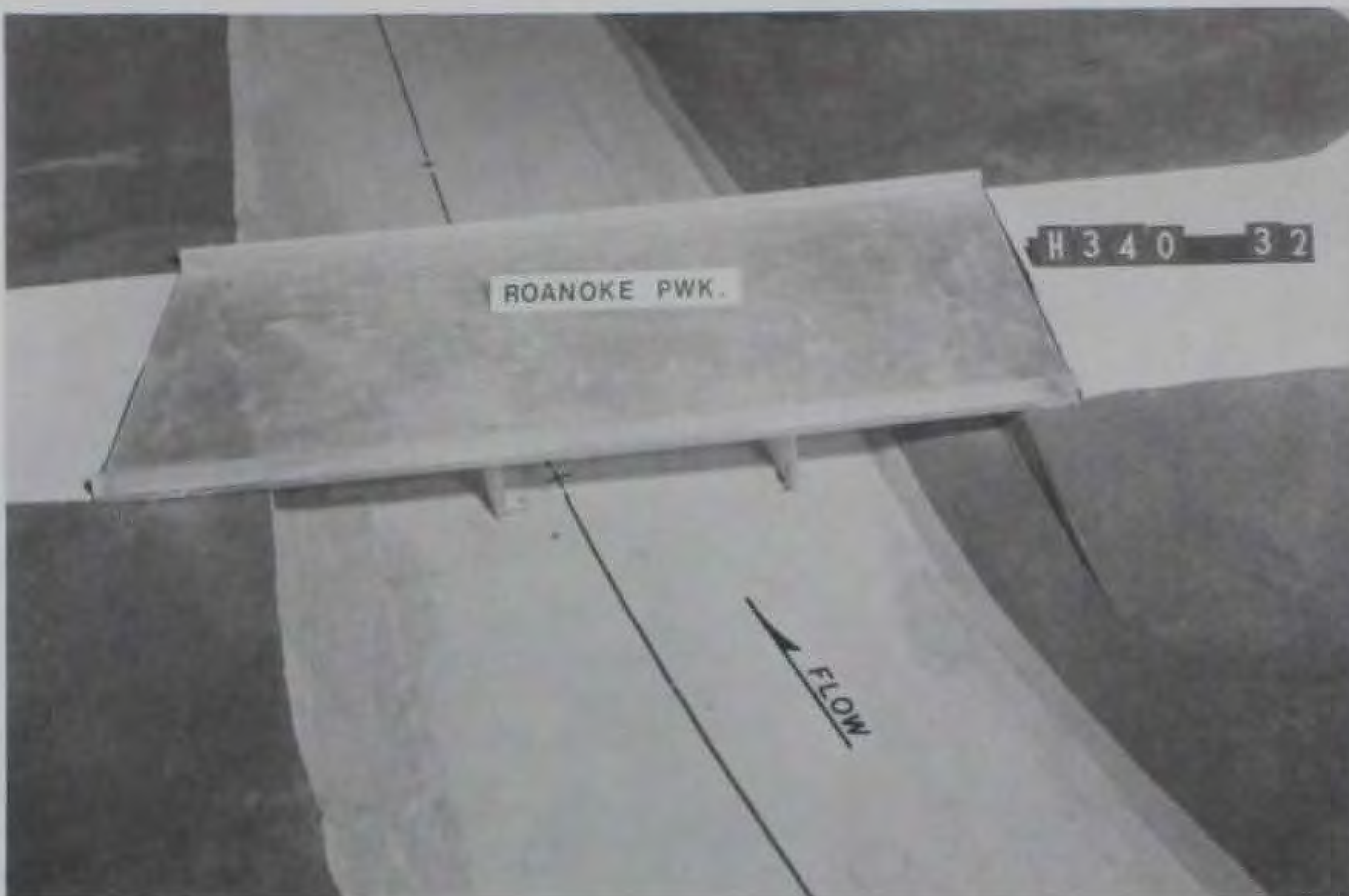


Photo 12. Roanoke Parkway Bridge

Photo 13. Plaza footbridge

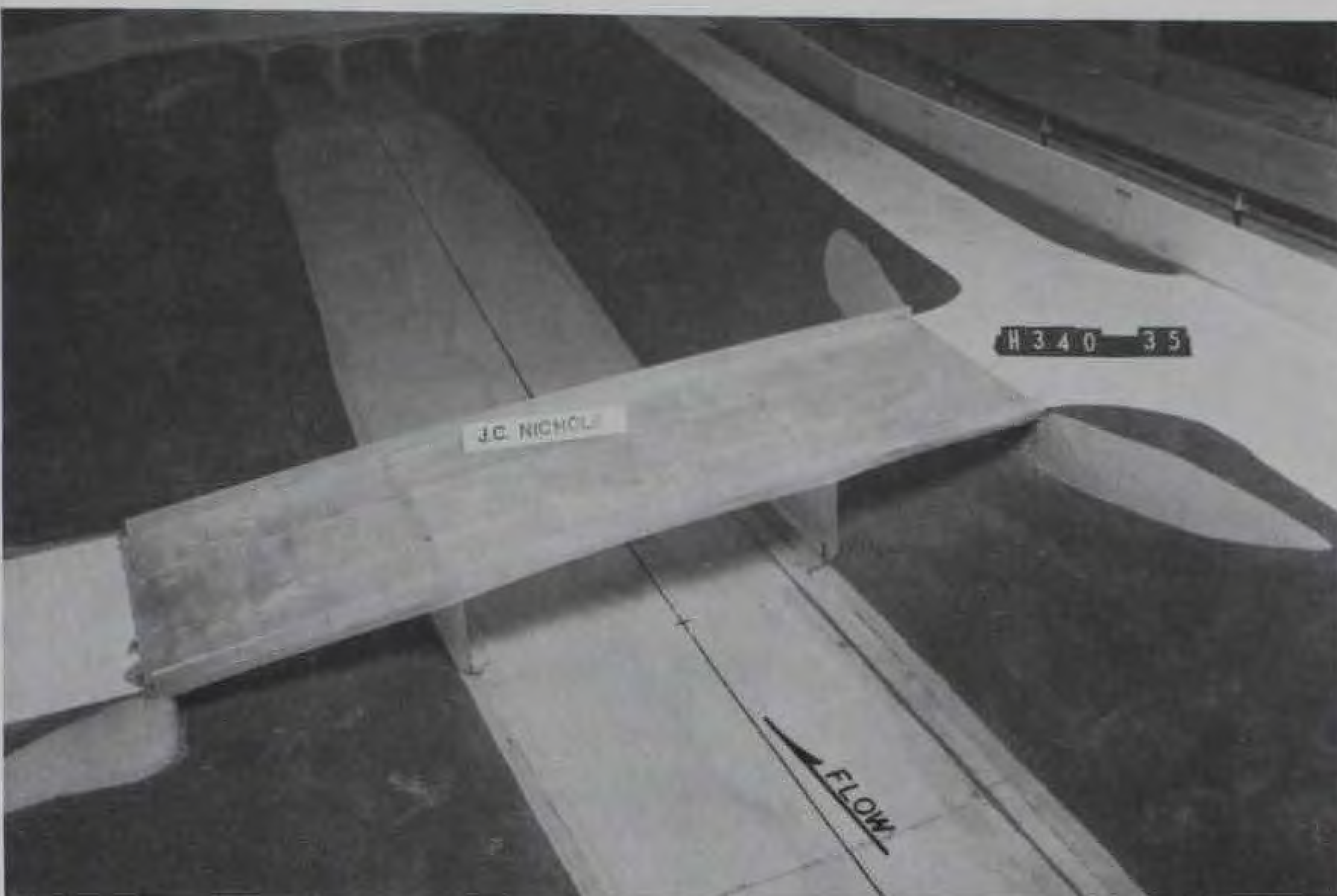


Photo 14. J. C. Nichols Parkway Bridge

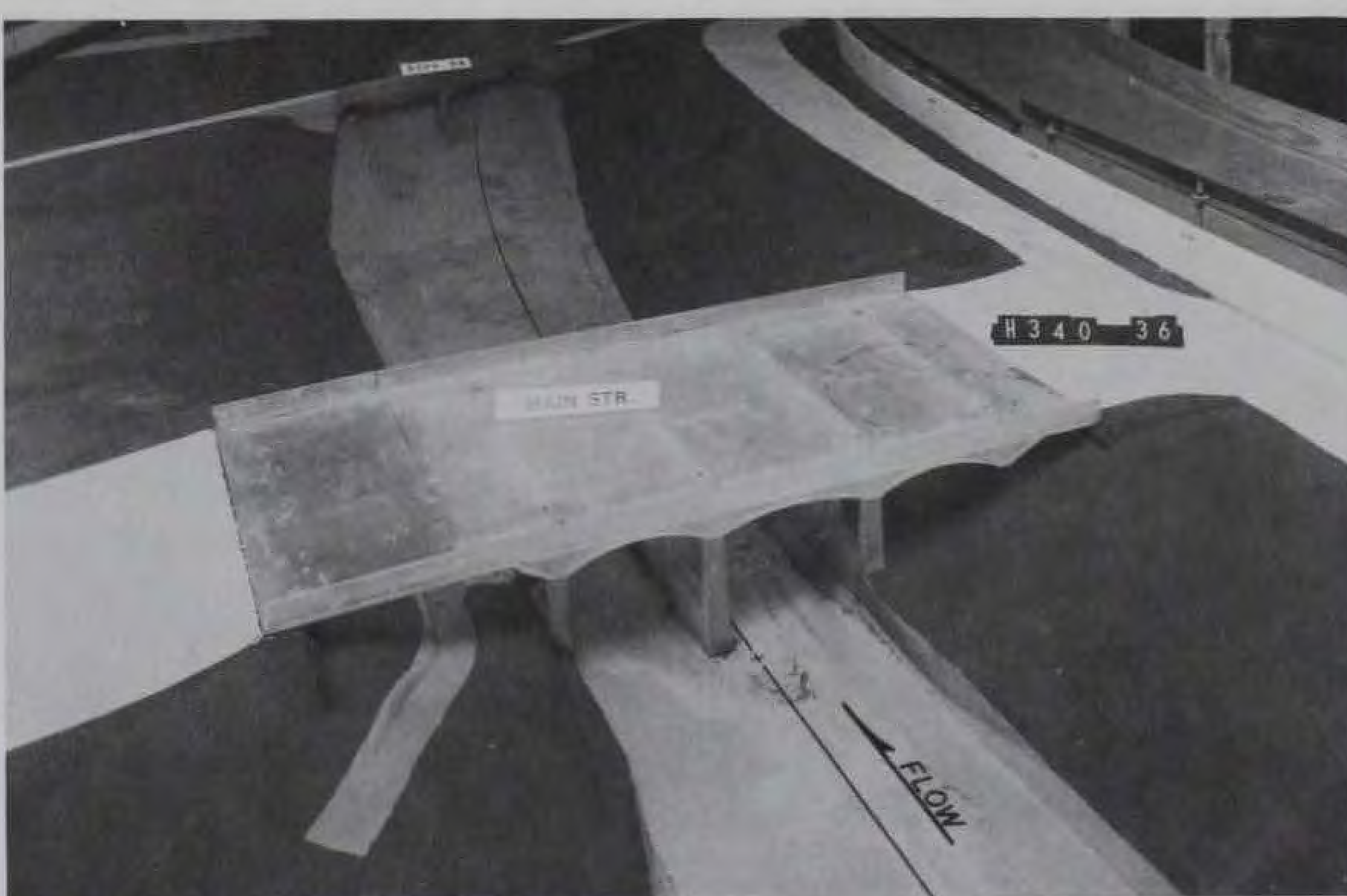


Photo 15. Main Street Bridge

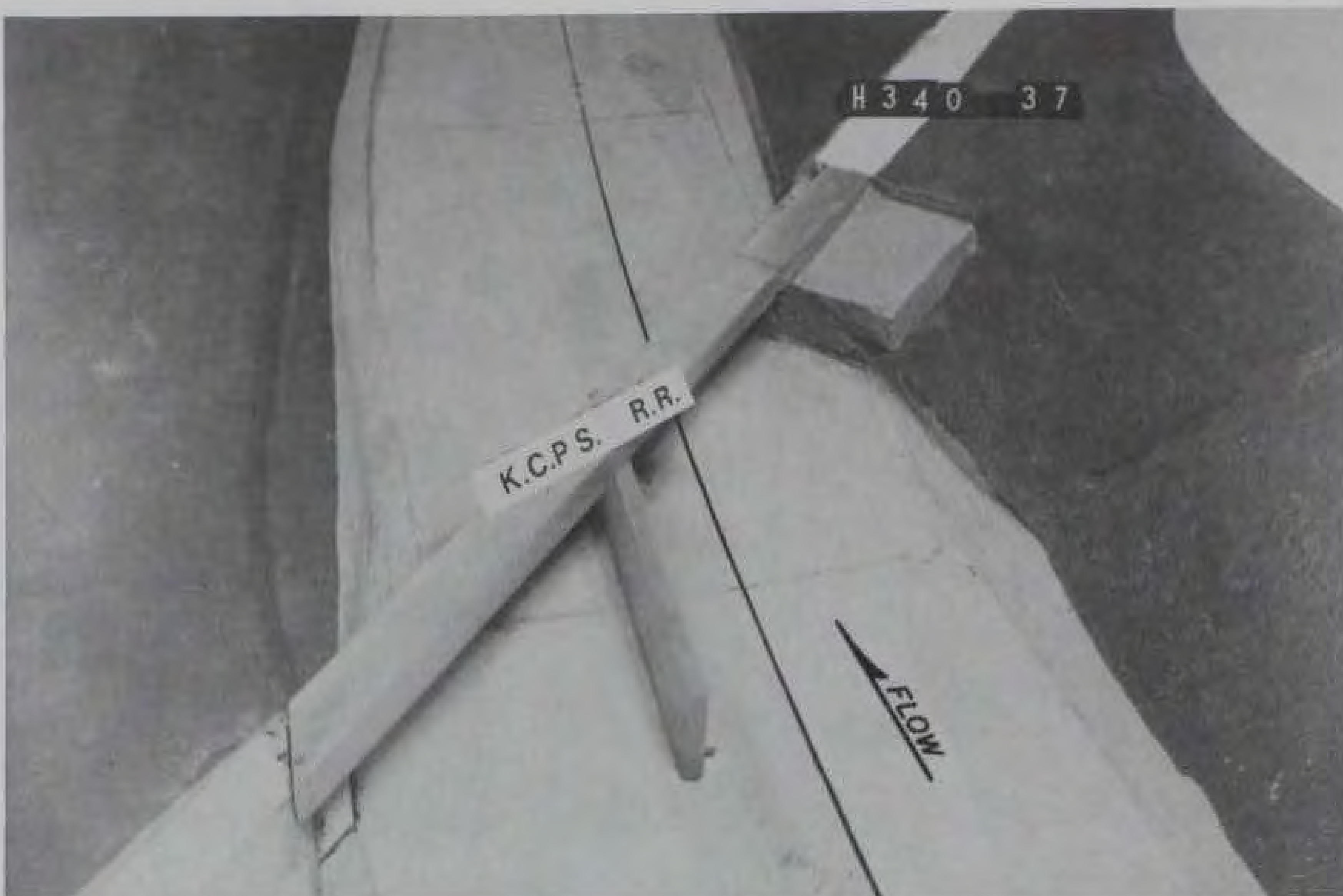


Photo 16. KCPS Railroad bridge

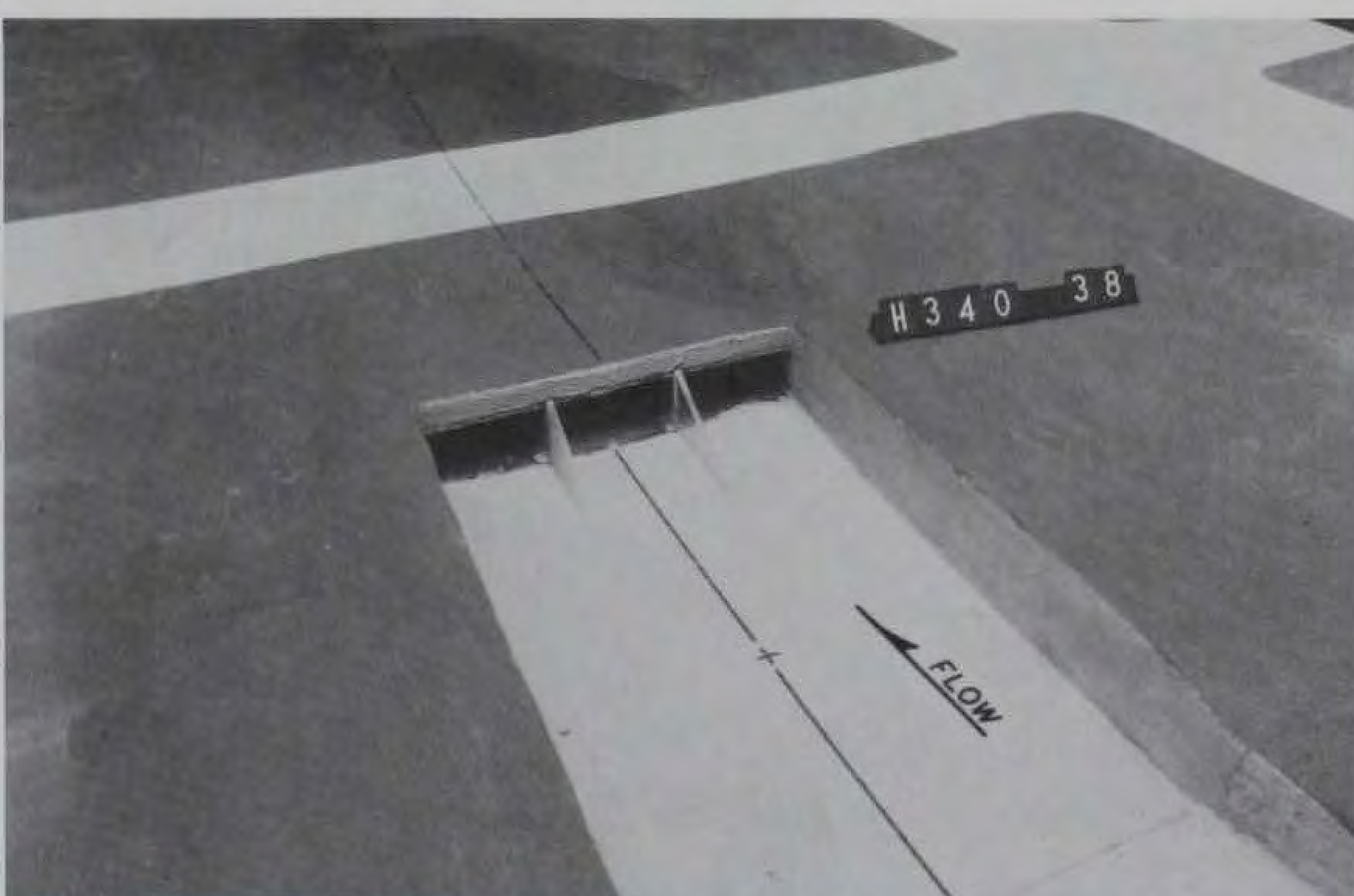


Photo 17. Entrance to Volker Park conduit

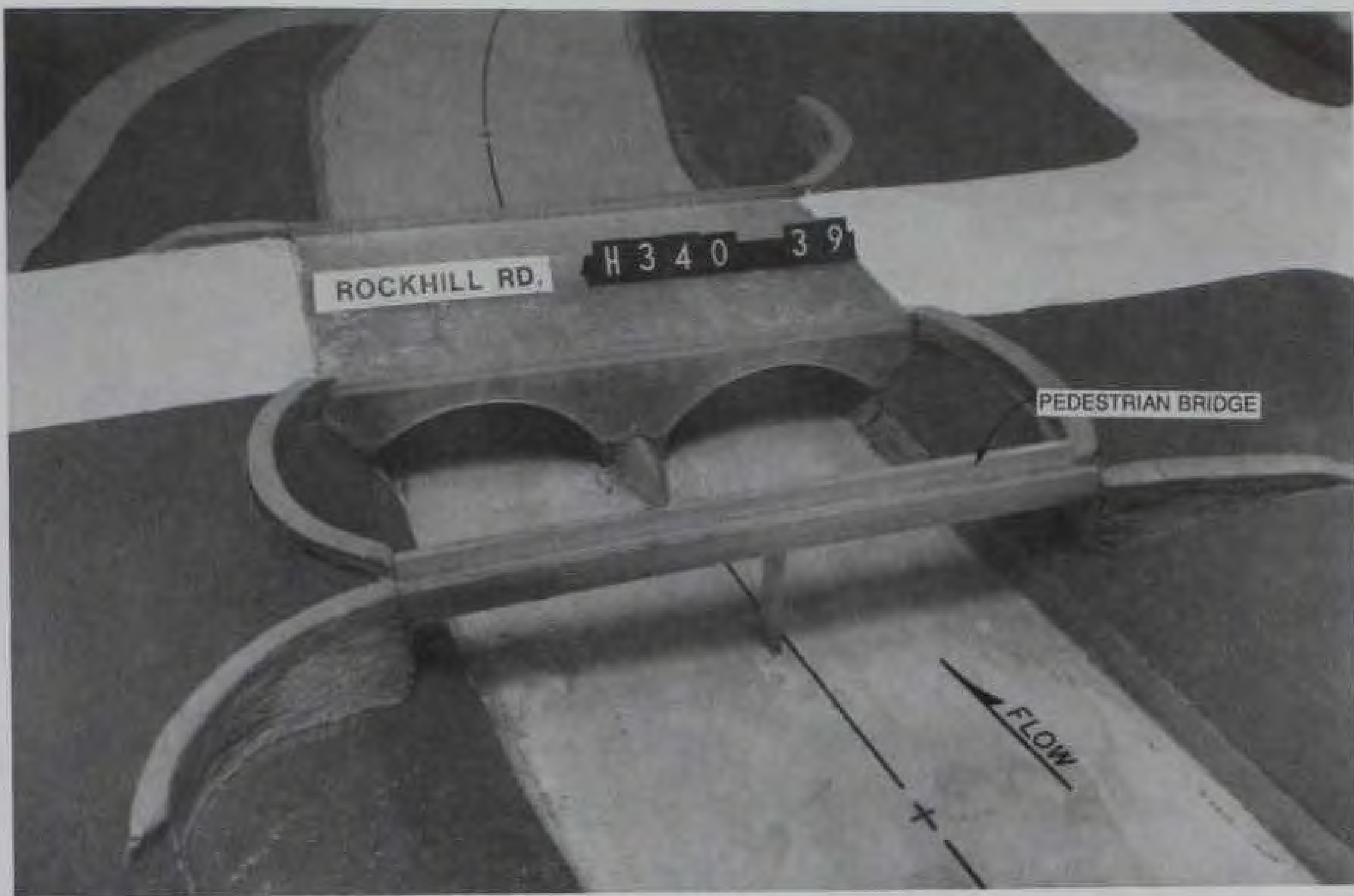


Photo 18. Rockhill Road and pedestrian bridges

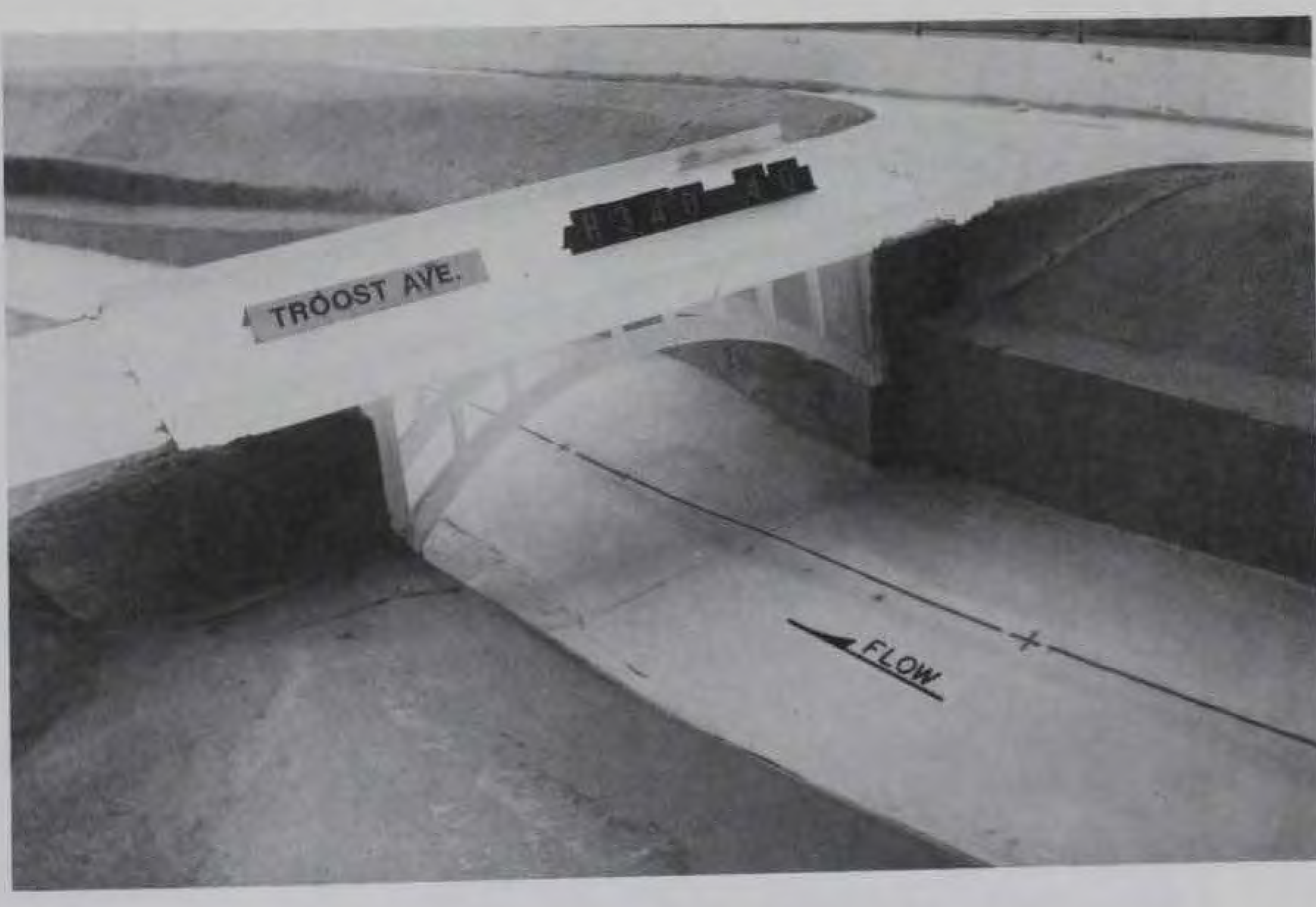


Photo 19. Troost Avenue Bridge

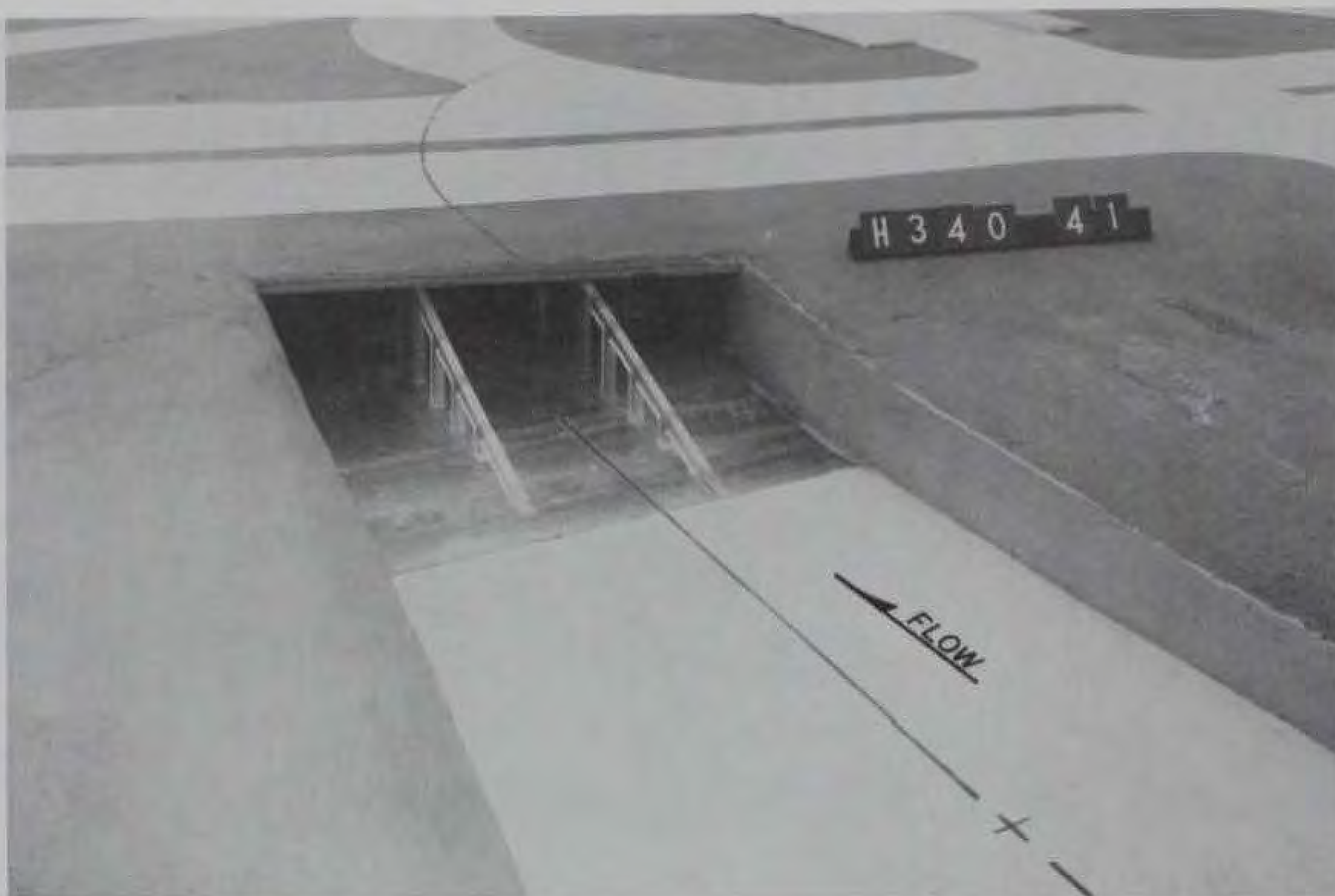


Photo 20. Paseo conduit entrance

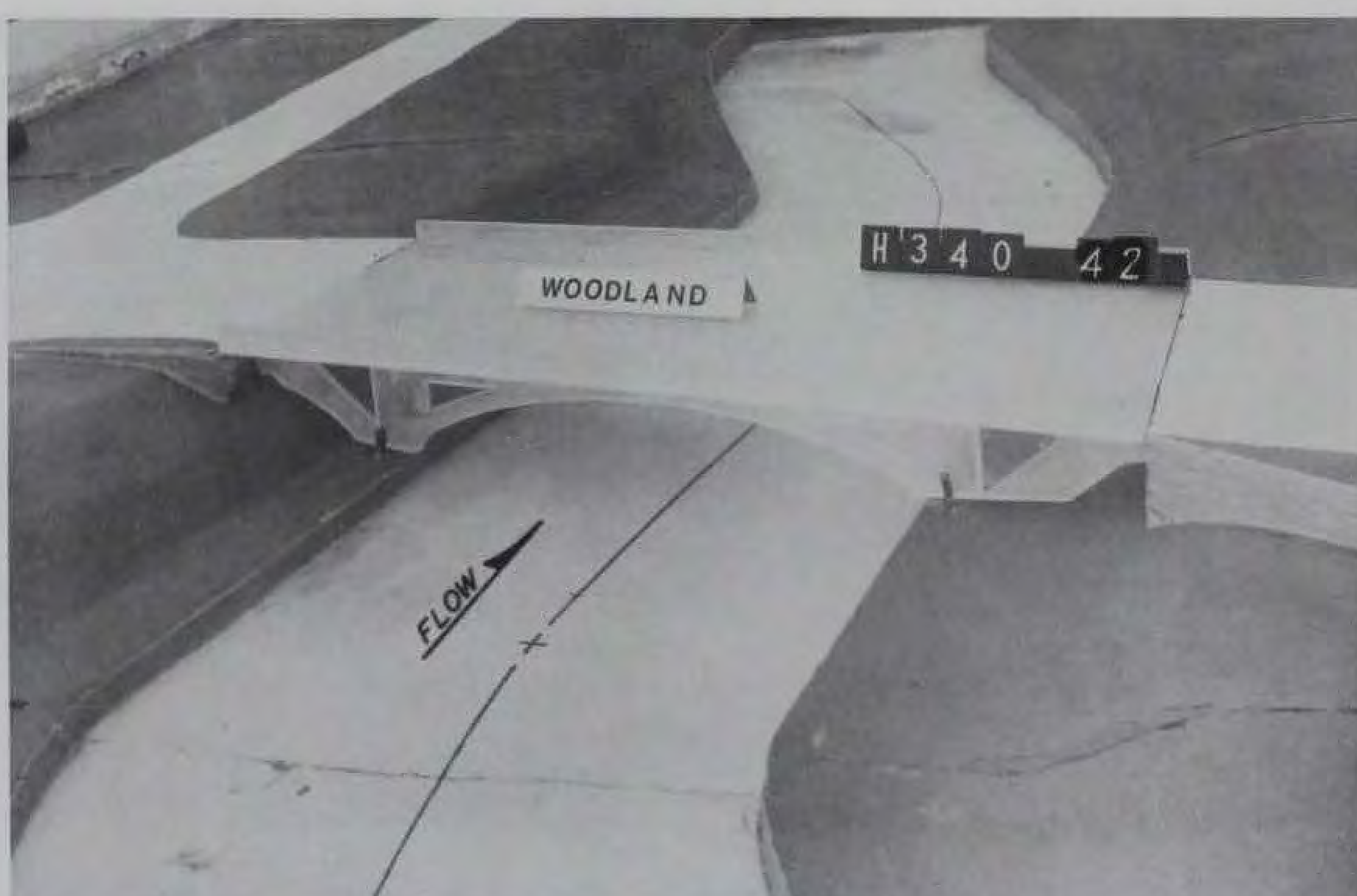
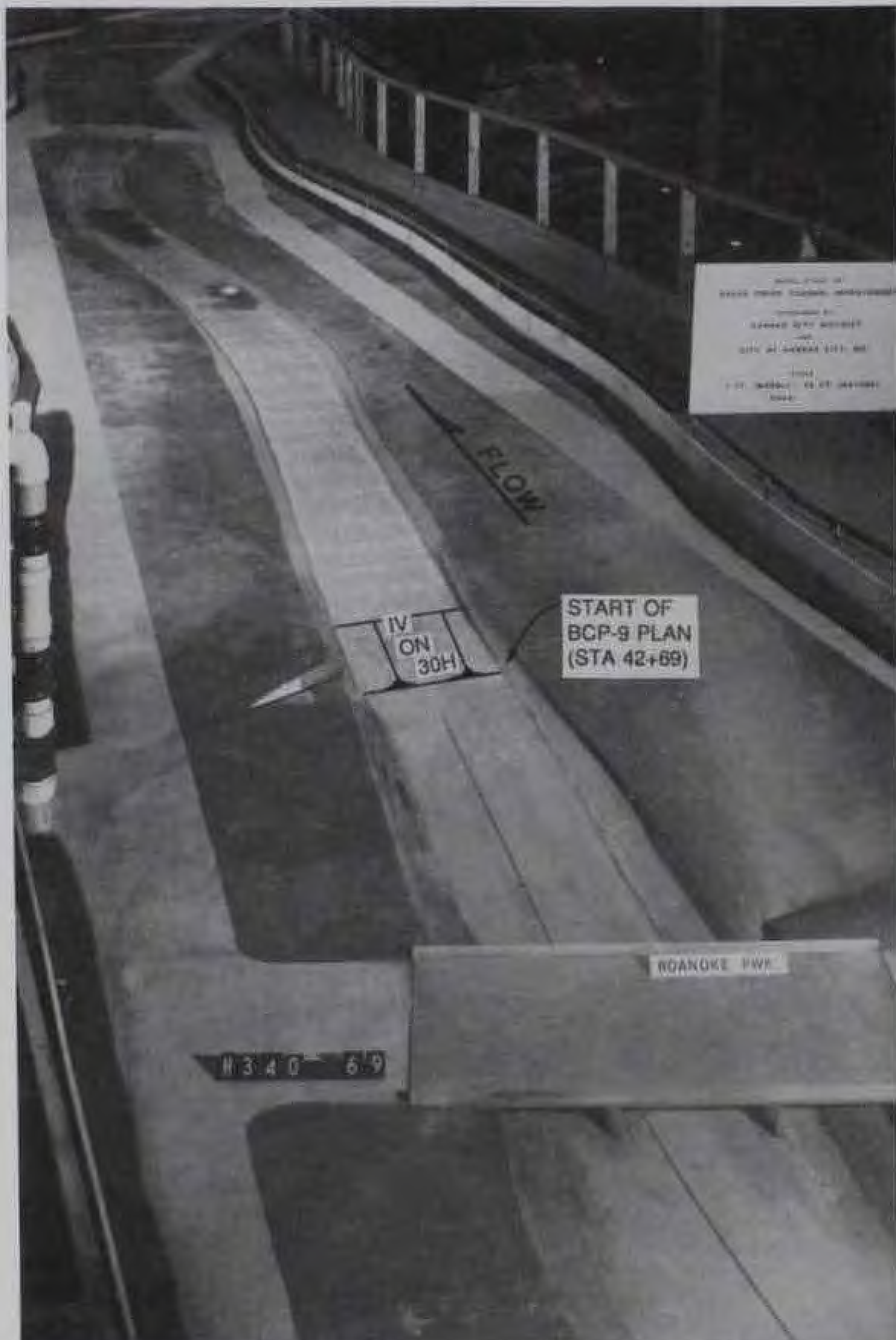
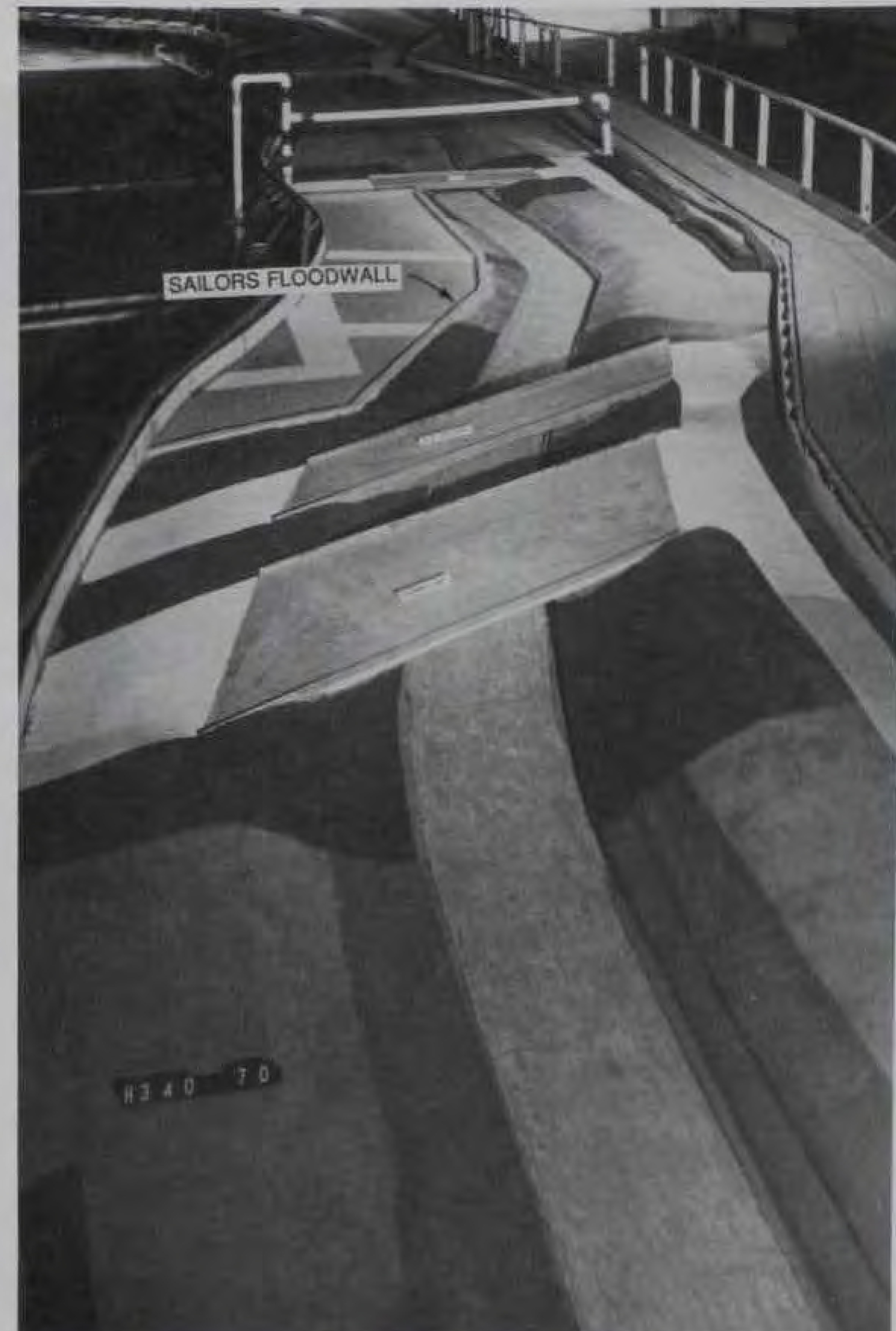


Photo 21. Woodland Bridge

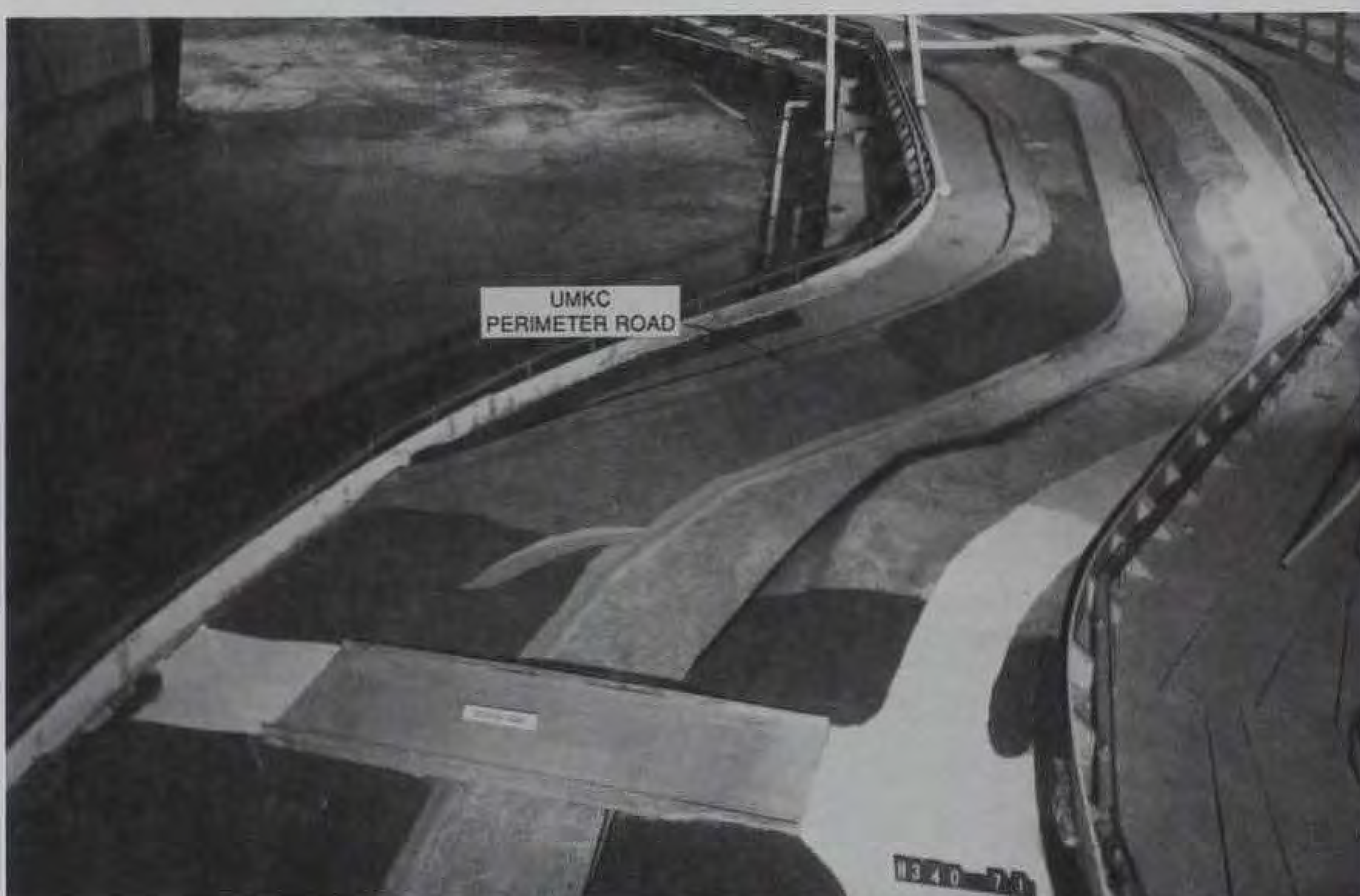


a. Sta 39+00 to sta 70+00



b. Sta 70+00 to sta 94+00

Photo 22. Corps BCP-9 Plan (Continued)



c. Sta 94+00 to sta 114+00

Photo 22. (Concluded)

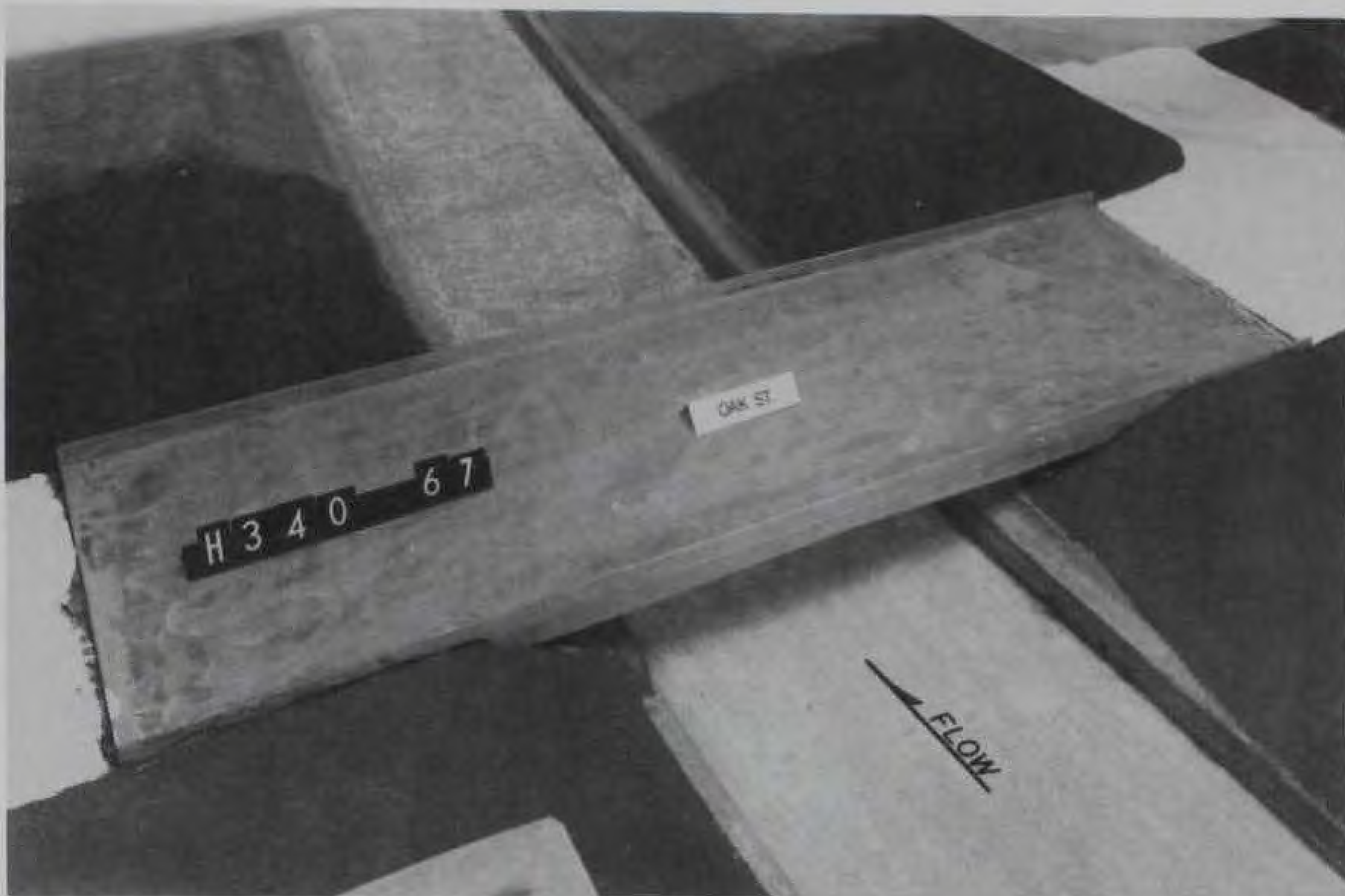


Photo 23. Oak Street Bridge (new)

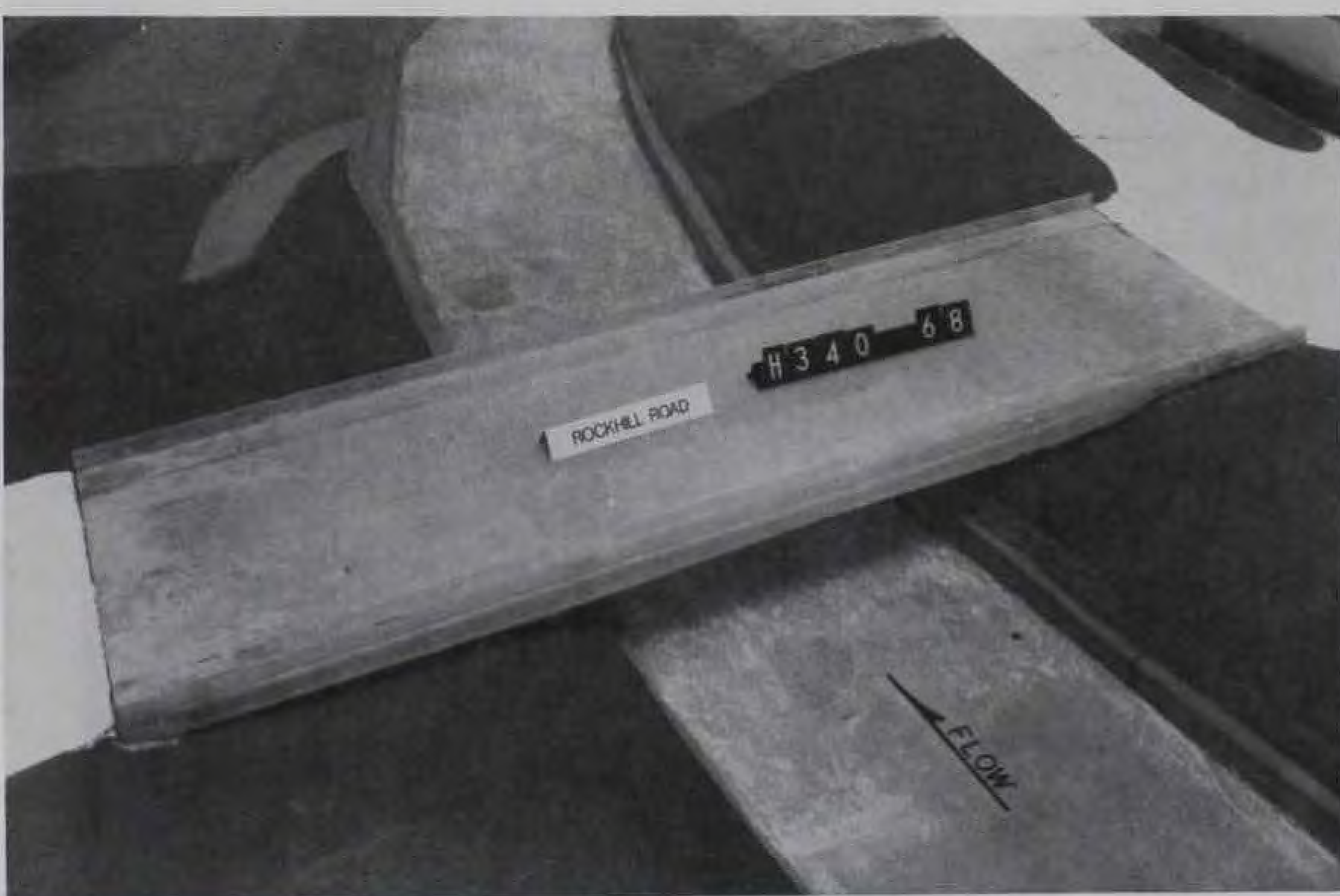


Photo 24. Rockhill Road Bridge (new)

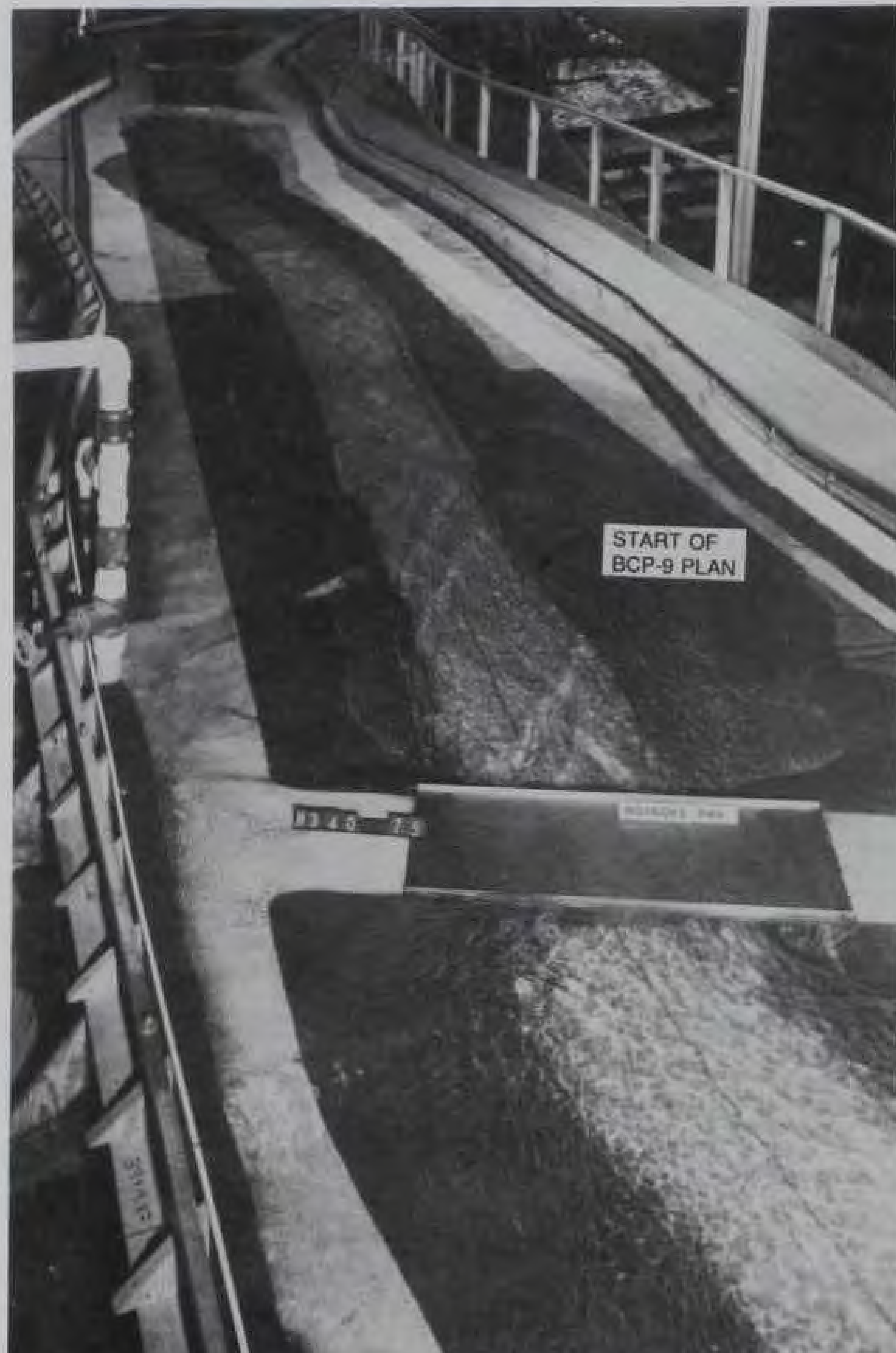
a. Sta 39+00 to sta 70+00

b. Sta 70+00 to sta 94+00

Photo 25. BCP-9 Plan, 10-year flood (Continued)

c. Sta 94+00 to sta 114+00

Photo 25. (Concluded)



a. Sta 39+00 to sta 70+00

b. Sta 70+00 to sta 94+00

Photo 26. BCP-9 Plan, 500-year flood (Continued)

c. Sta 94+00 to sta 114+00

Photo 26. (Concluded)

Photo 27. Transition into BCP-9 Plan (1V on 3H slope)

a. 10-year flood

b. 500-year flood

Photo 28. Flow conditions at transition into BCP-9 Plan (1V on 3H slope)

Photo 29. Transition into BCP-9 Plan (vertical drop)

a. 10-year flood

b. 500-year flood

Photo 30. Flow conditions at vertical drop transition into BCP-9 Plan

Photo 31. Transition just downstream of start of BCP-9 Plan (1V on 11H, 50-ft-long slope)

a. 10-year flood

b. 500-year flood

Photo 32. Flow conditions at 50-ft-long slope transition

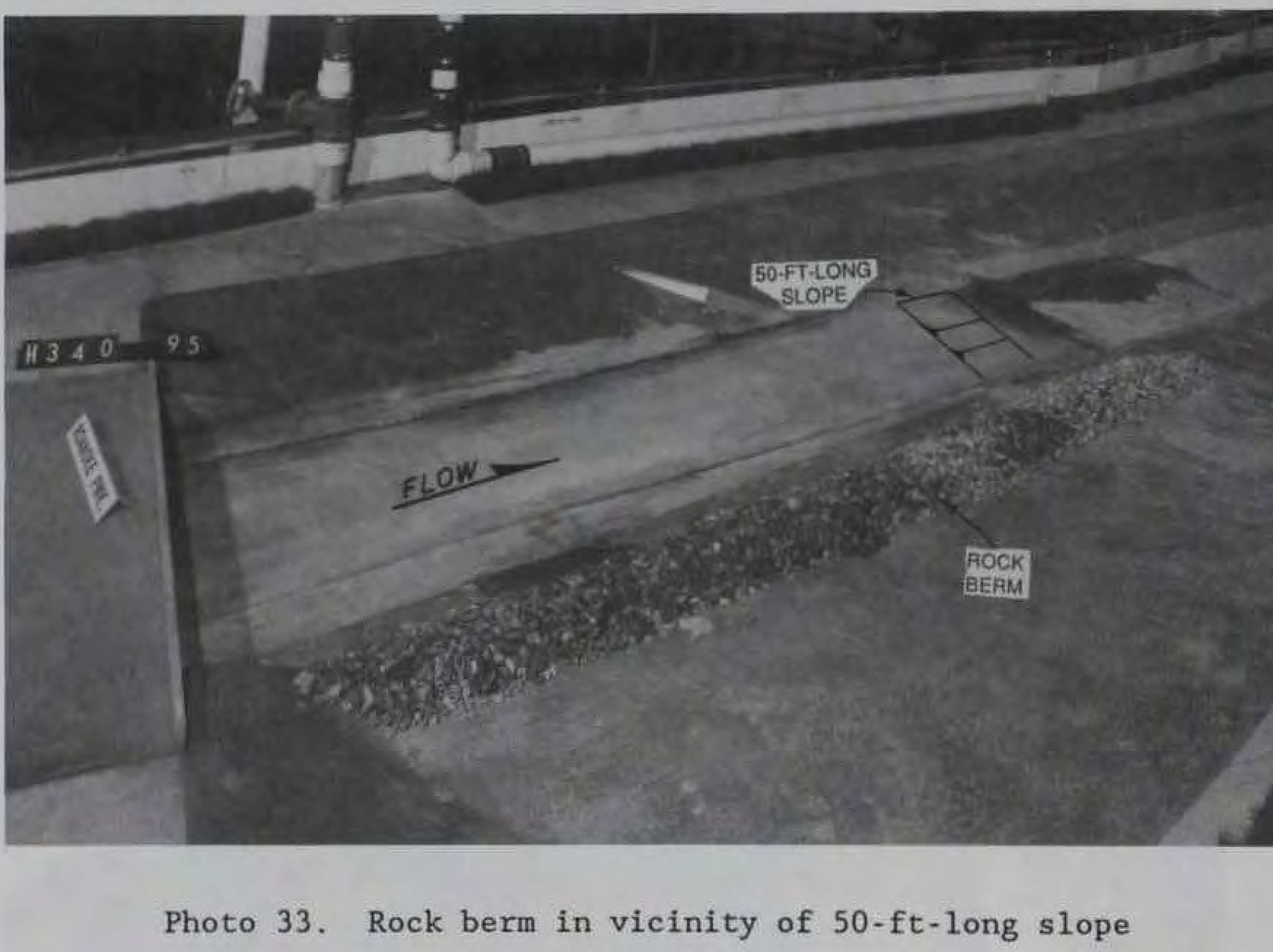


Photo 33. Rock berm in vicinity of 50-ft-long slope

a. 10-year flood

b. 500-year flood

Photo 34. Flow conditions at 50-ft-long slope transition with rock berm

a. Sta 20+00 to sta 31+00

b. Sta 34+00 to sta 40+00

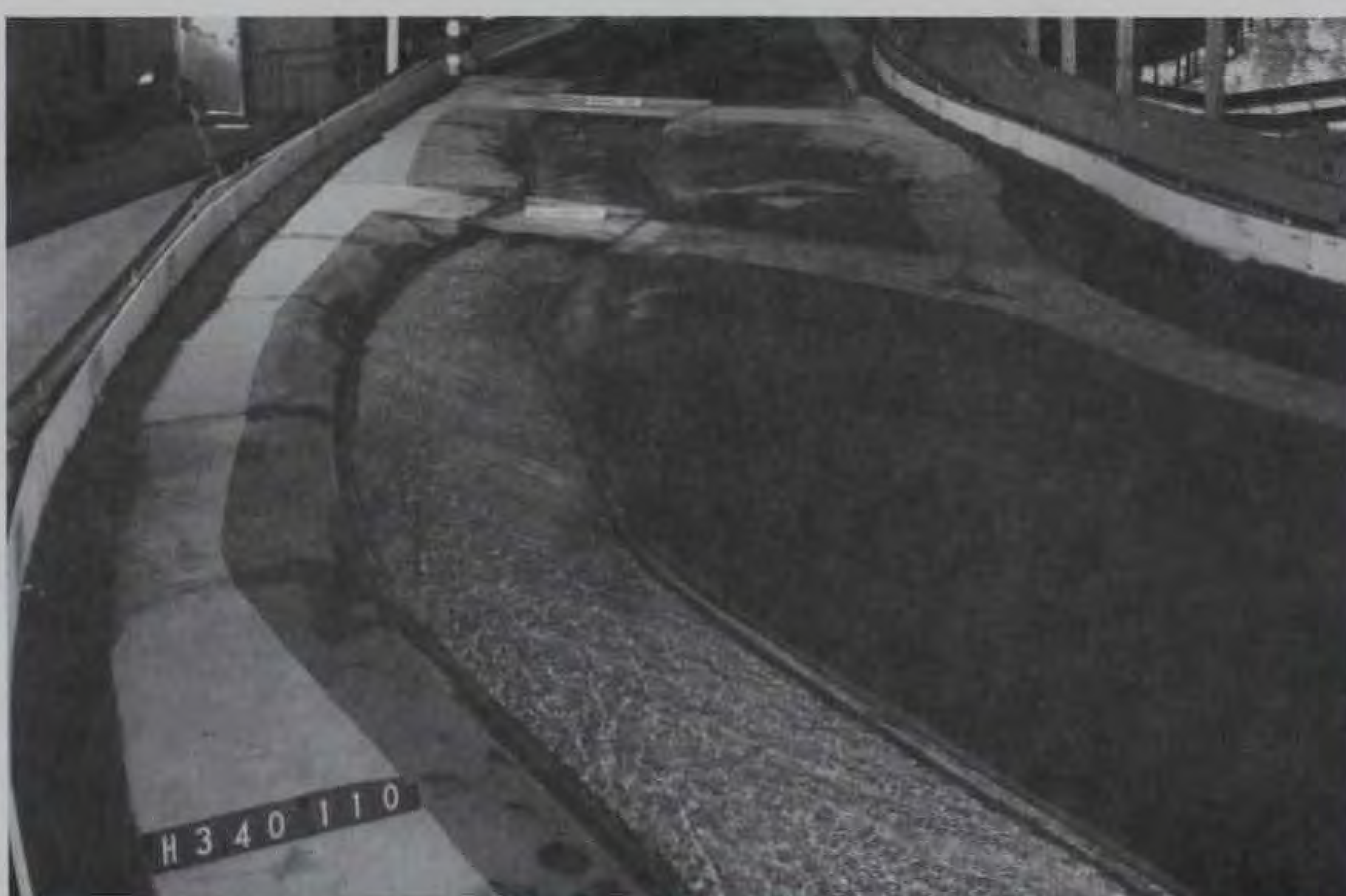
Photo 35. City upstream plan

a. Belleview Avenue Bridge

b. Roanoke Parkway Bridge

Photo 36. City upstream deepening modification

a. Sta 18+00 to sta 36+00



b. Sta 31+00 to sta 40+00

Photo 37. City upstream deepening plan, 10-year flood

a. Sta 18+00 to sta 36+00

b. Sta 31+00 to sta 40+00

Photo 38. City upstream deepening plan, 500-year flood

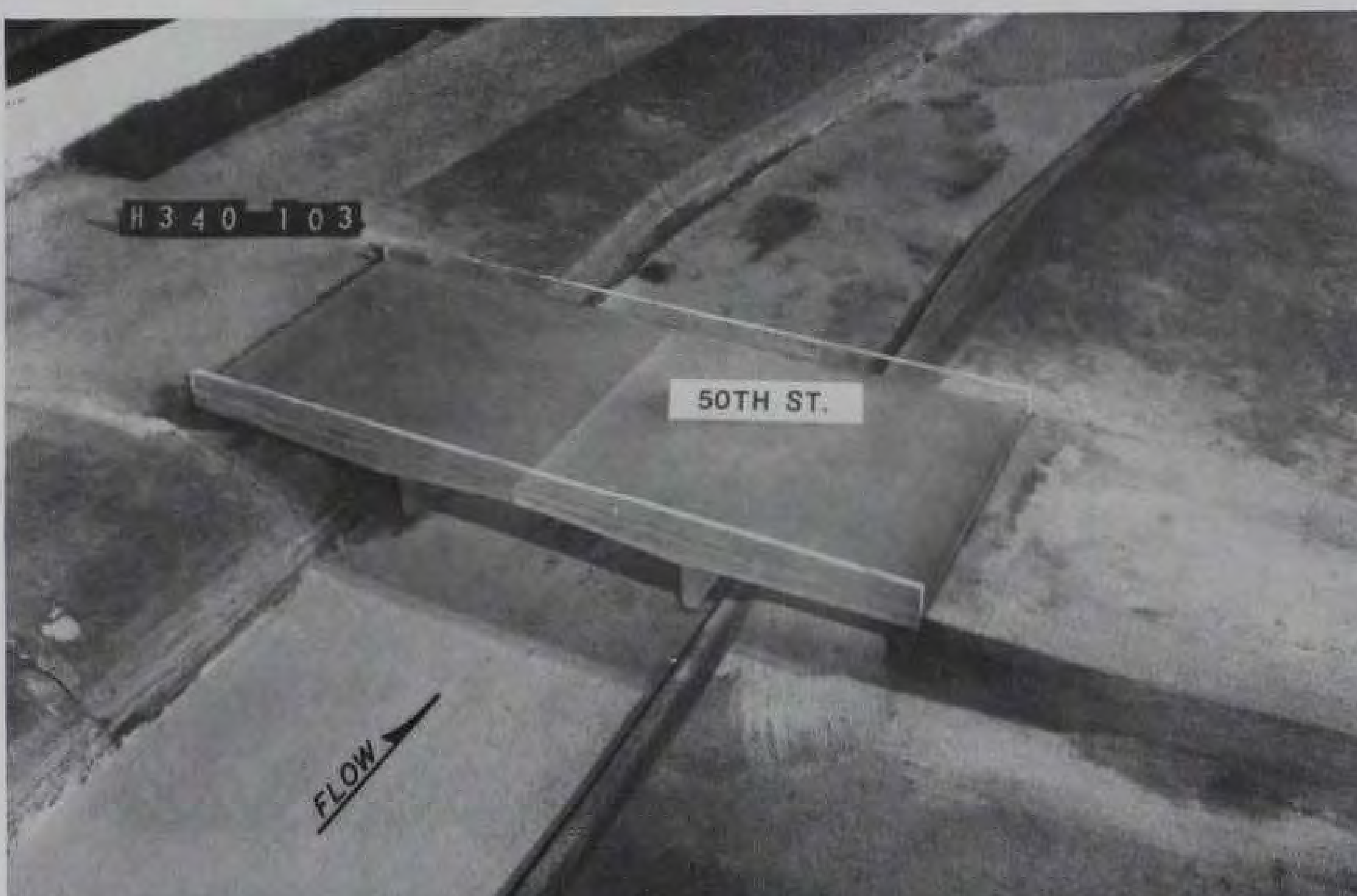


Photo 39. New 50th Street Bridge

a. Sta 34+00 to sta 65+00

b. Sta 60+00 to sta 84+00

Photo 40. Park Plan (Continued)

c. Sta 81+00 to sta 112+00

d. Sta 112+00 to sta 147+00

Photo 40. (Concluded)

Photo 41. Modification at low-water crossing (51st Street)

Photo 42. Irregular dam 1, sta 68+65

a. 10-year flood

b. 100-year flood

Photo 43. Flow conditions at irregular dam 1 (sta 68+65) (Continued)

c. 500-year flood

Photo 43. (Concluded)

Photo 44. Irregular dam 1, sta 79+00

a. 10-year flood

b. 100-year flood

Photo 45. Flow conditions at irregular dam 1 (sta 79+00) (Continued)

c. 500-year flood

Photo 45. (Concluded)

Photo 46. Drop 1, type 1 design stilling basin

a. 10-year flood

b. 100-year flood

Photo 47. Flow conditions at drop 1, type 1 design stilling basin

Photo 48. Drop 1, type 2 design stilling basin

a. 10-year flood

b. 100-year flood

Photo 49. Flow conditions at drop 1, type 2 design stilling basin

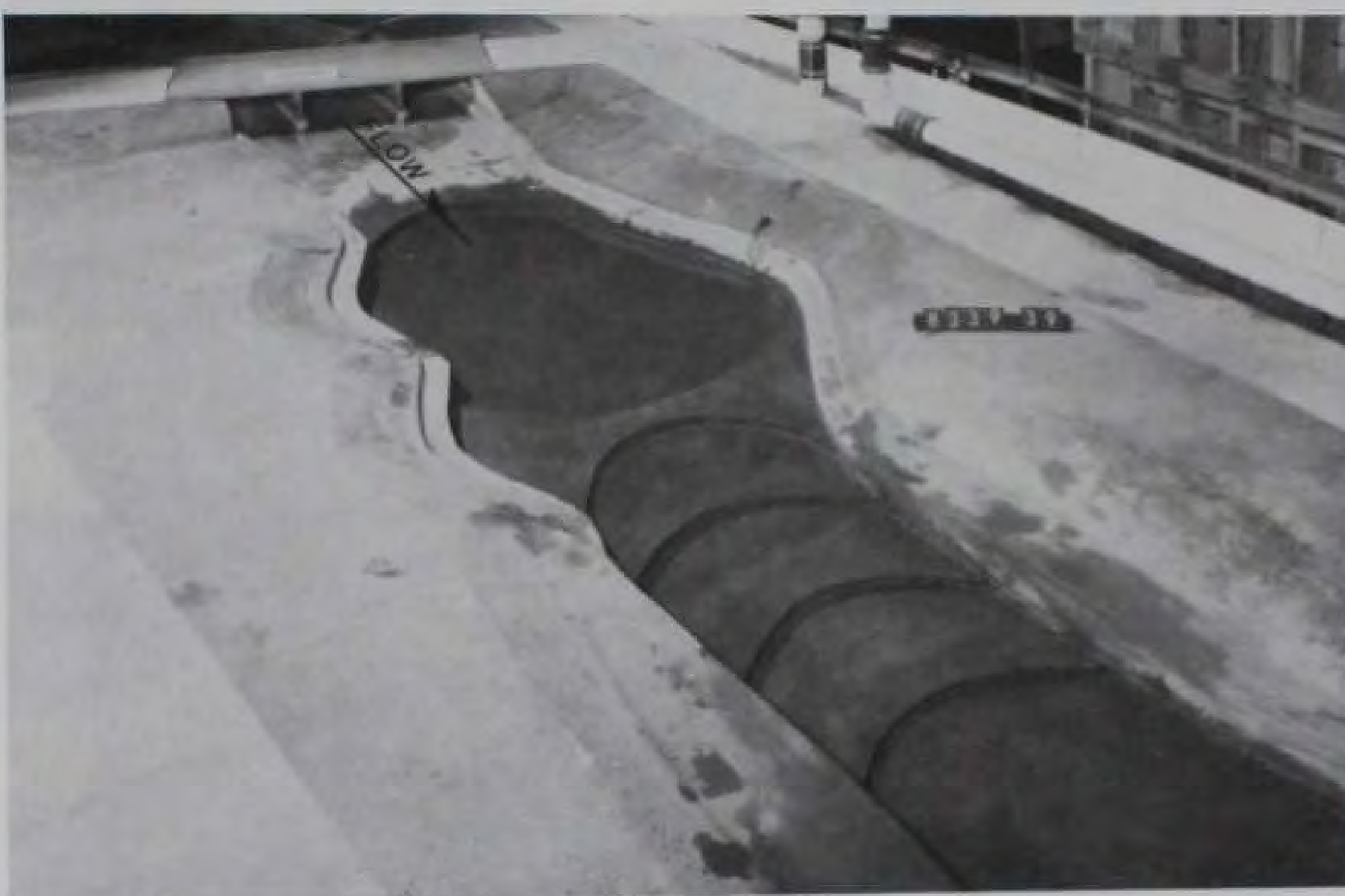


Photo 50. Drop 1, type 4 design stilling basin

a. 10-year flood

b. 100-year flood

Photo 51. Flow conditions at drop 1, type 4 design stilling basin (Continued)

c. 500-year flood

Photo 51. (Concluded)

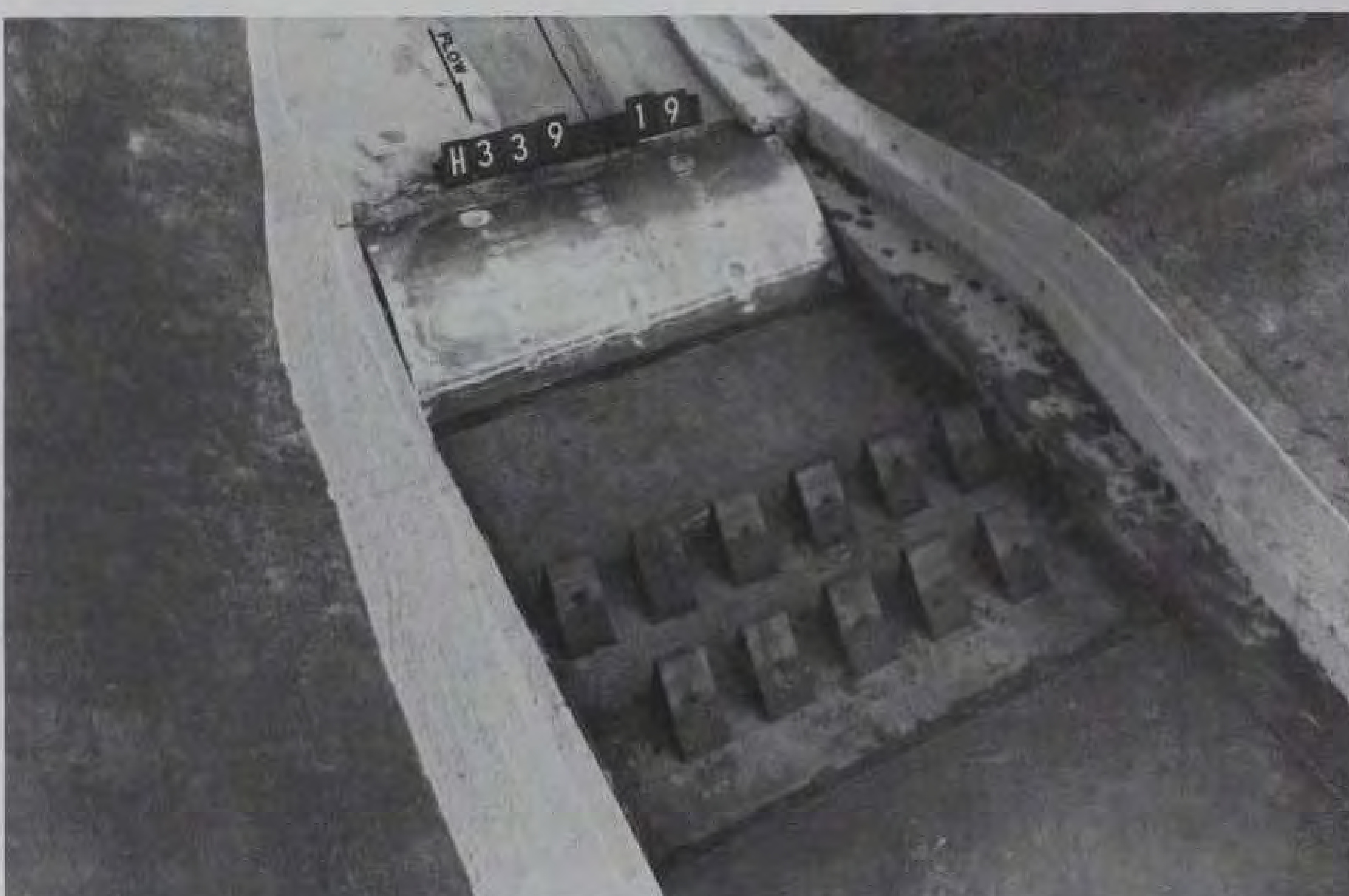


Photo 52. Drop 2, type 1 design stilling basin

a. 10-year flood

b. 100-year flood

Photo 53. Flow conditions at drop 2, type 1 design stilling basin

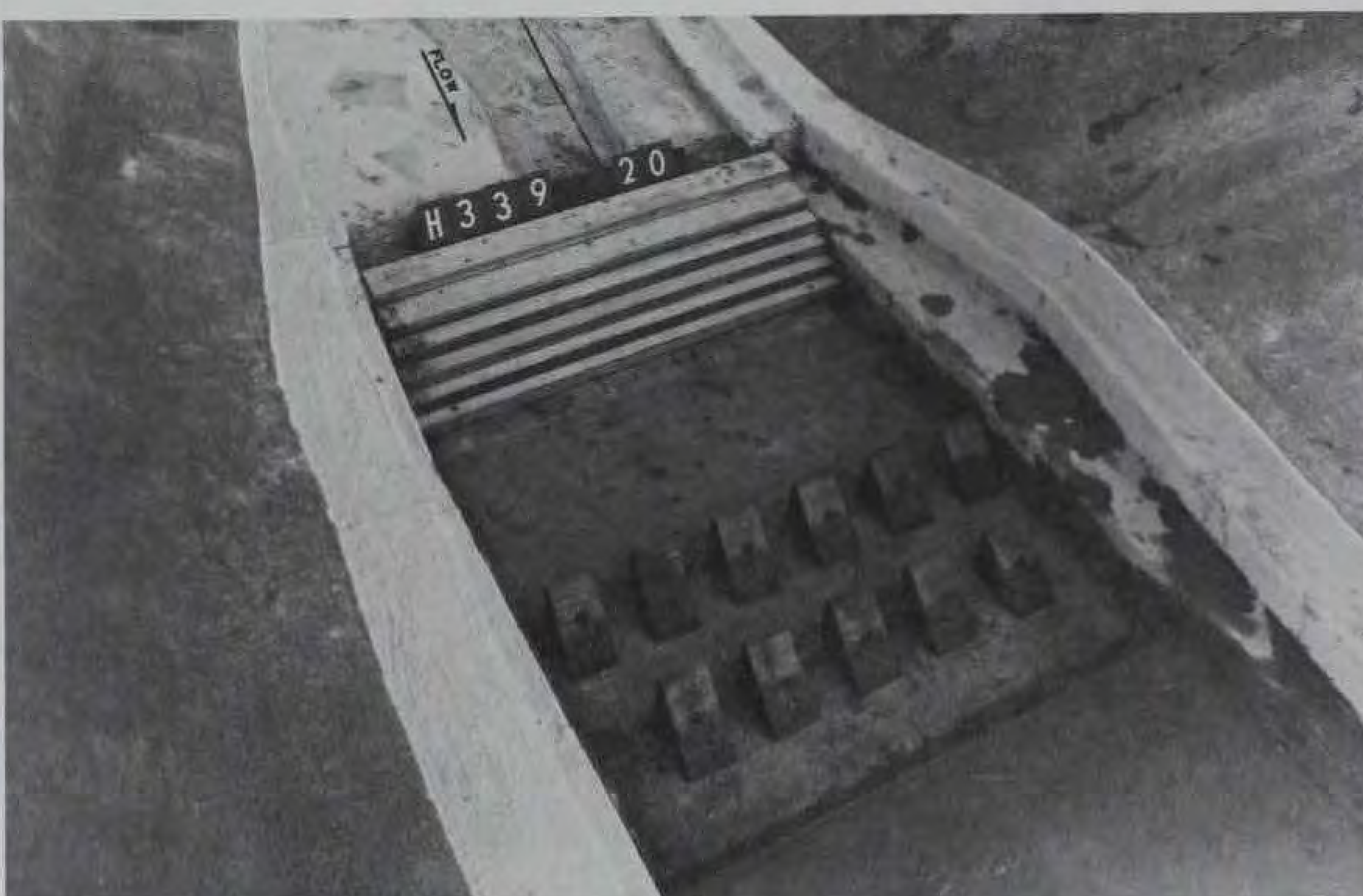


Photo 54. Drop 2, type 2 design stilling basin

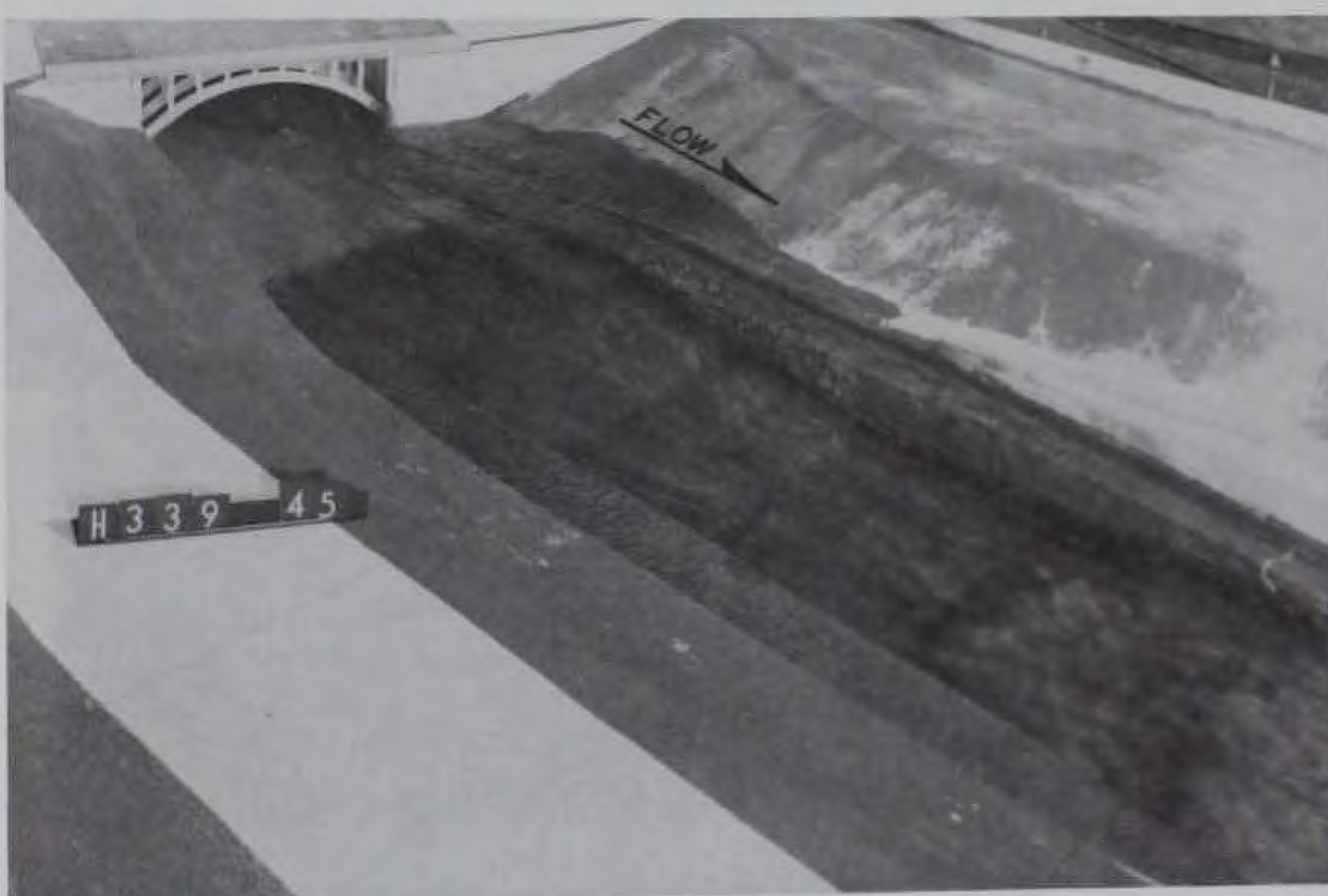
a. 10-year flood

b. 100-year flood

Photo 55. Flow conditions at drop 2, type 2 design stilling basin

Photo 56. Drop 2, type 3 design stilling basin

a. 10-year flood



b. 100-year flood

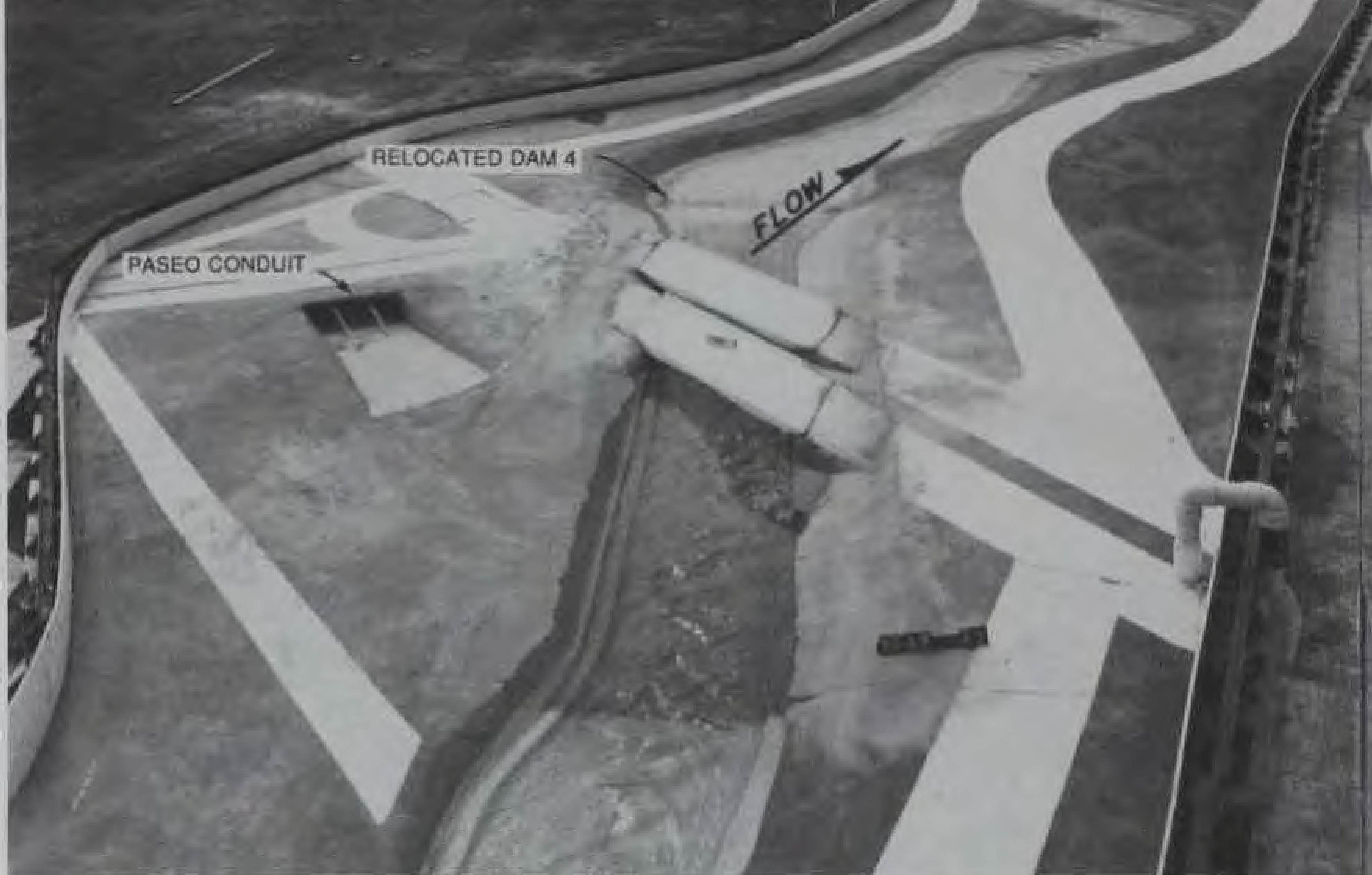
Photo 57. Flow conditions at drop 2, type 3 design stilling basin (Continued)

c. 500-year flood

Photo 57. (Concluded)

Photo 58. New Paseo bridges

Photo 59. Paseo realignment, sta 123+00 to sta 147+00



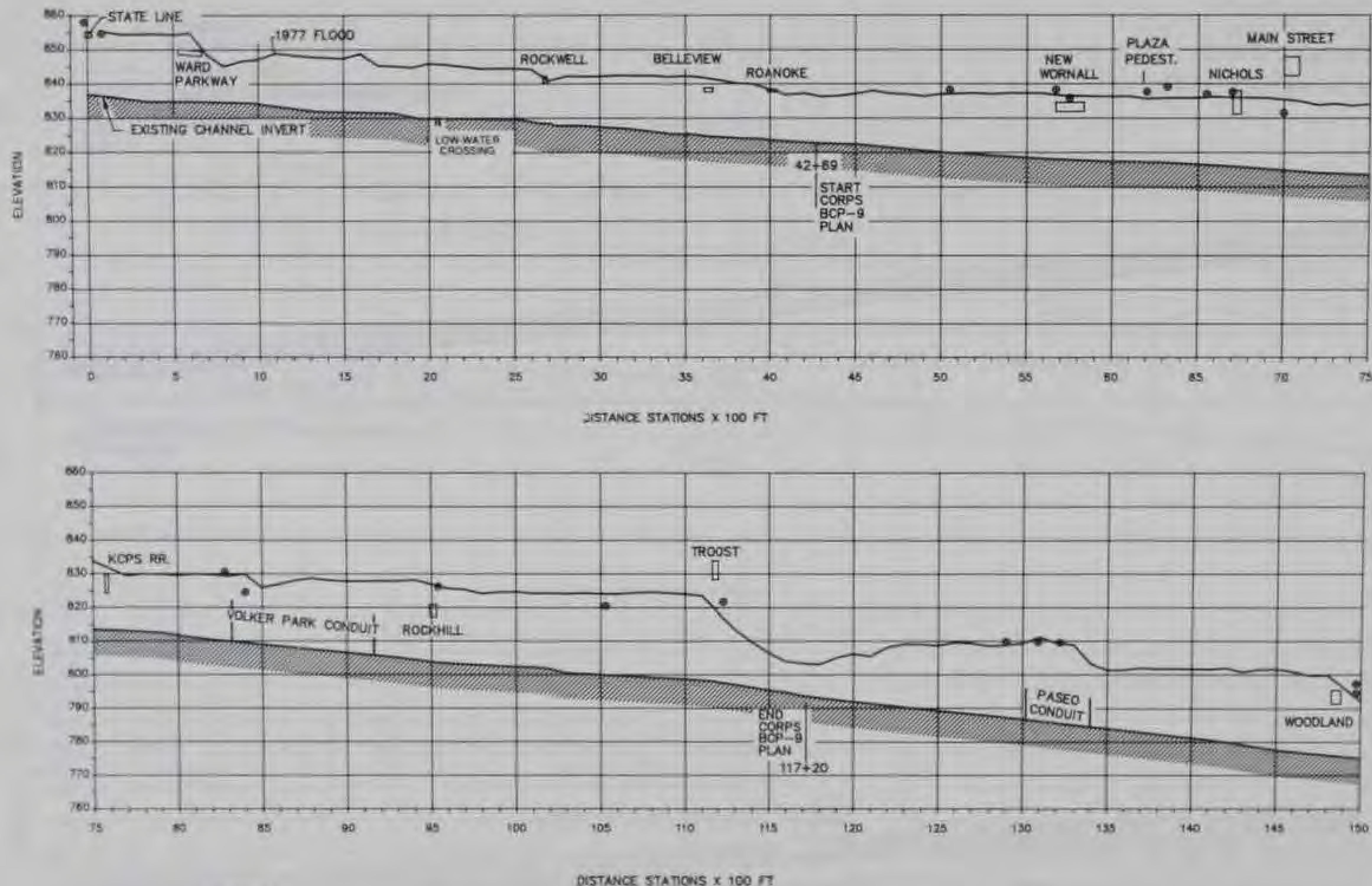
a. 10-year flood

b. 100-year flood

Photo 60. Flow conditions at Paseo realignment with new Paseo bridges, sta 123+00 to sta 147+00 (Continued)

c. 500-year flood

Photo 60. (Concluded)



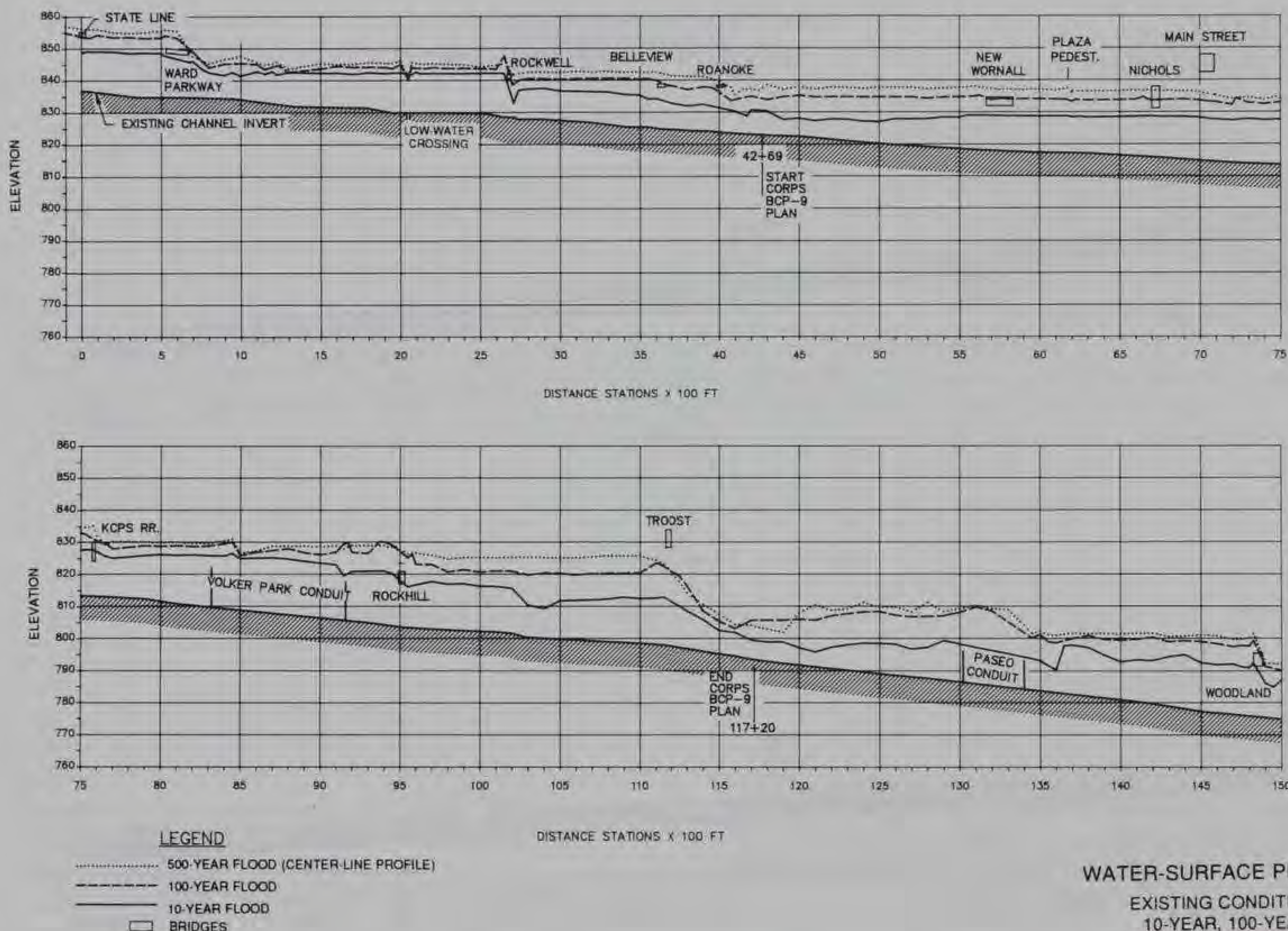
LEGEND

- 1977 FLOOD HIGH-WATER MARKS
- 1977 FLOOD
- BRIDGES

NOTE: ELEVATIONS IN PLATES ARE GIVEN IN FEET REFERRED TO THE NATIONAL GEODETIC VERTICAL DATUM.

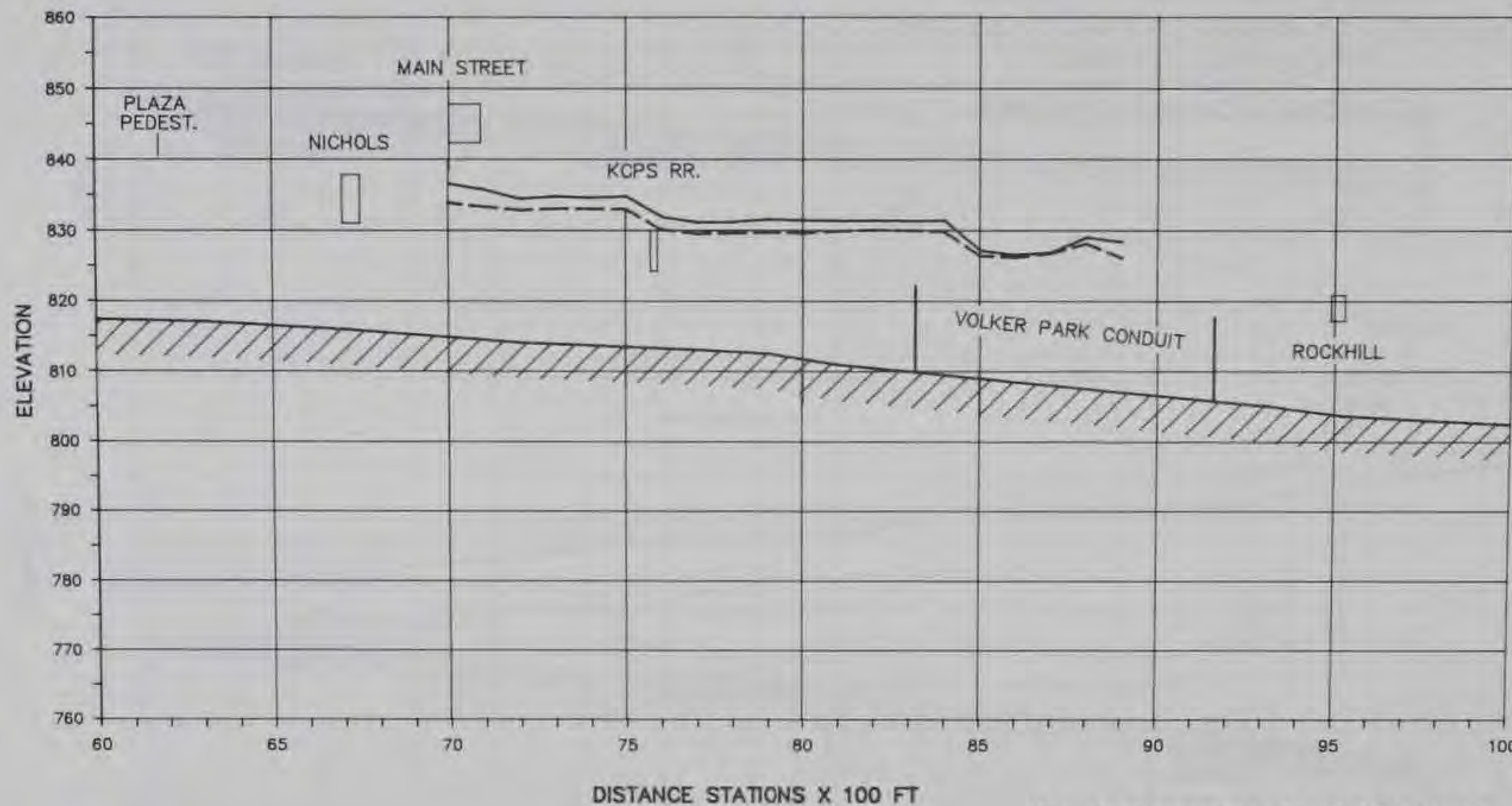
WATER-SURFACE PROFILES
EXISTING CONDITIONS
1977 FLOOD

PLATE 2



WATER-SURFACE PROFILES

EXISTING CONDITIONS
10-YEAR, 100-YEAR,
AND 500-YEAR FLOODS



LEGEND

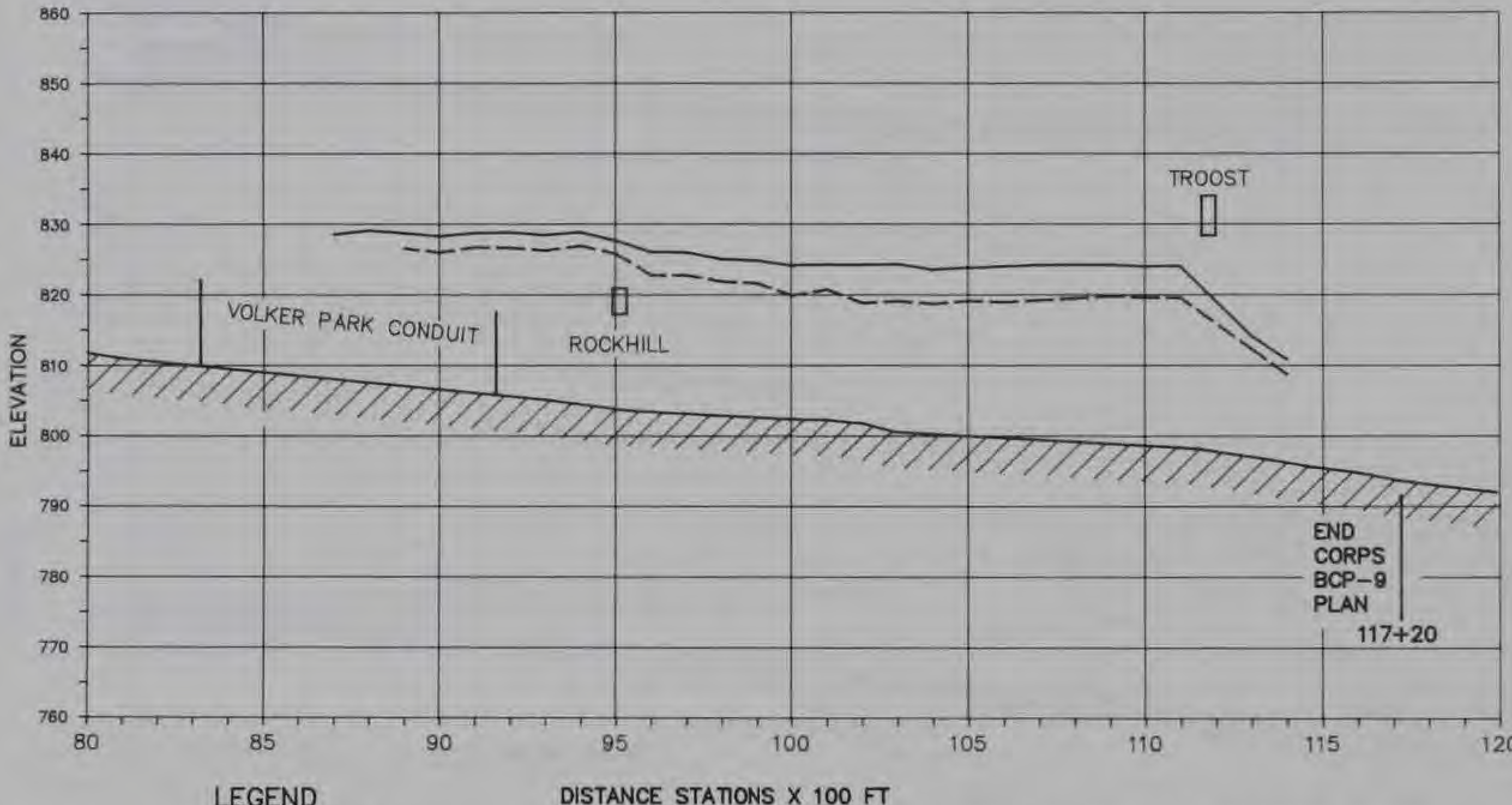
- - - 100-YEAR FLOOD
—— 500-YEAR FLOOD
▭ BRIDGES

WATER-SURFACE PROFILES

EXISTING CONDITIONS
SAILORS DEVELOPMENT WITH FLOODWALL
100-YEAR AND 500-YEAR FLOODS

PLATE 3

PLATE 4

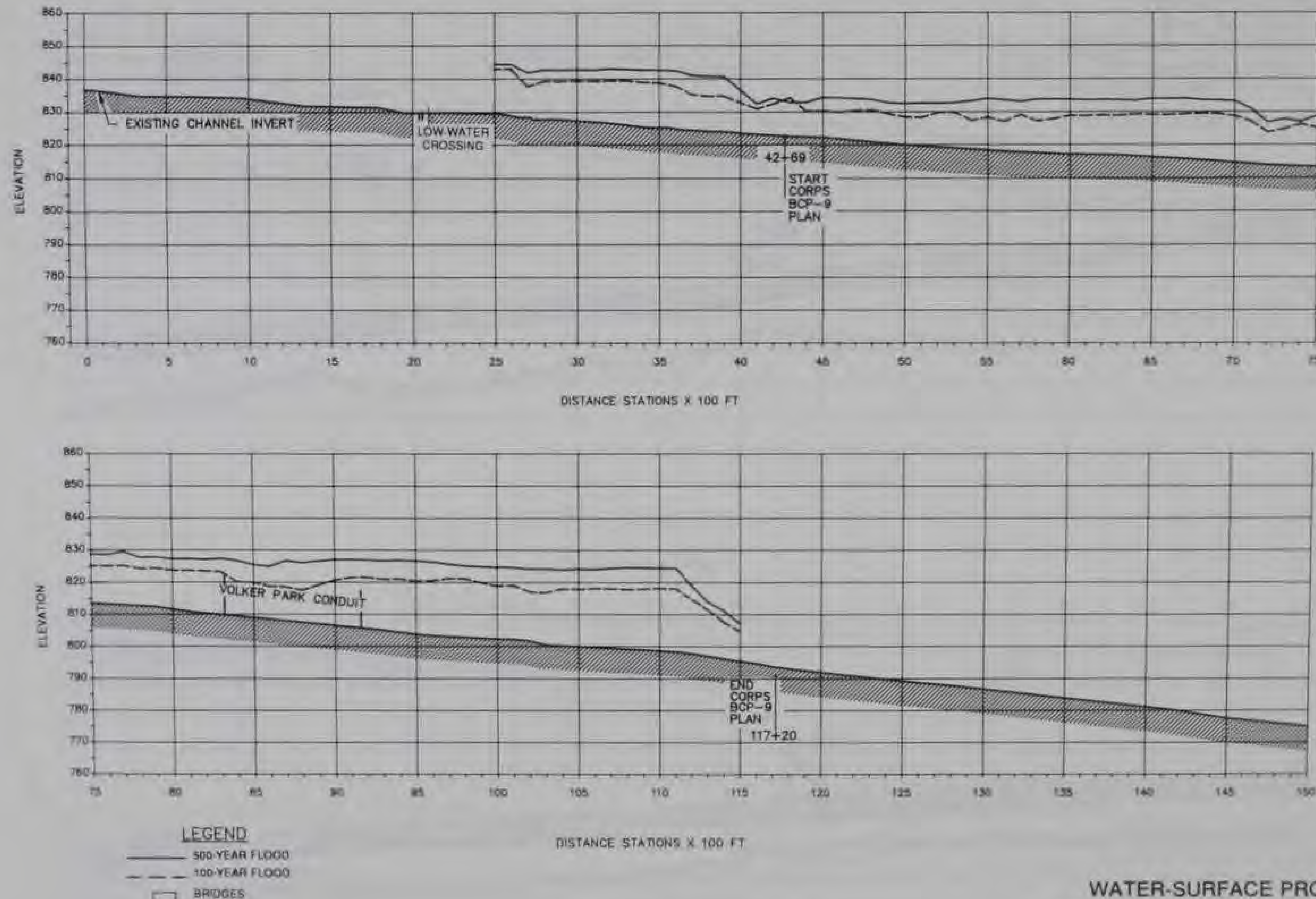


LEGEND

- - - 100-YEAR FLOOD
—— 500-YEAR FLOOD
▭ BRIDGES

WATER-SURFACE PROFILES

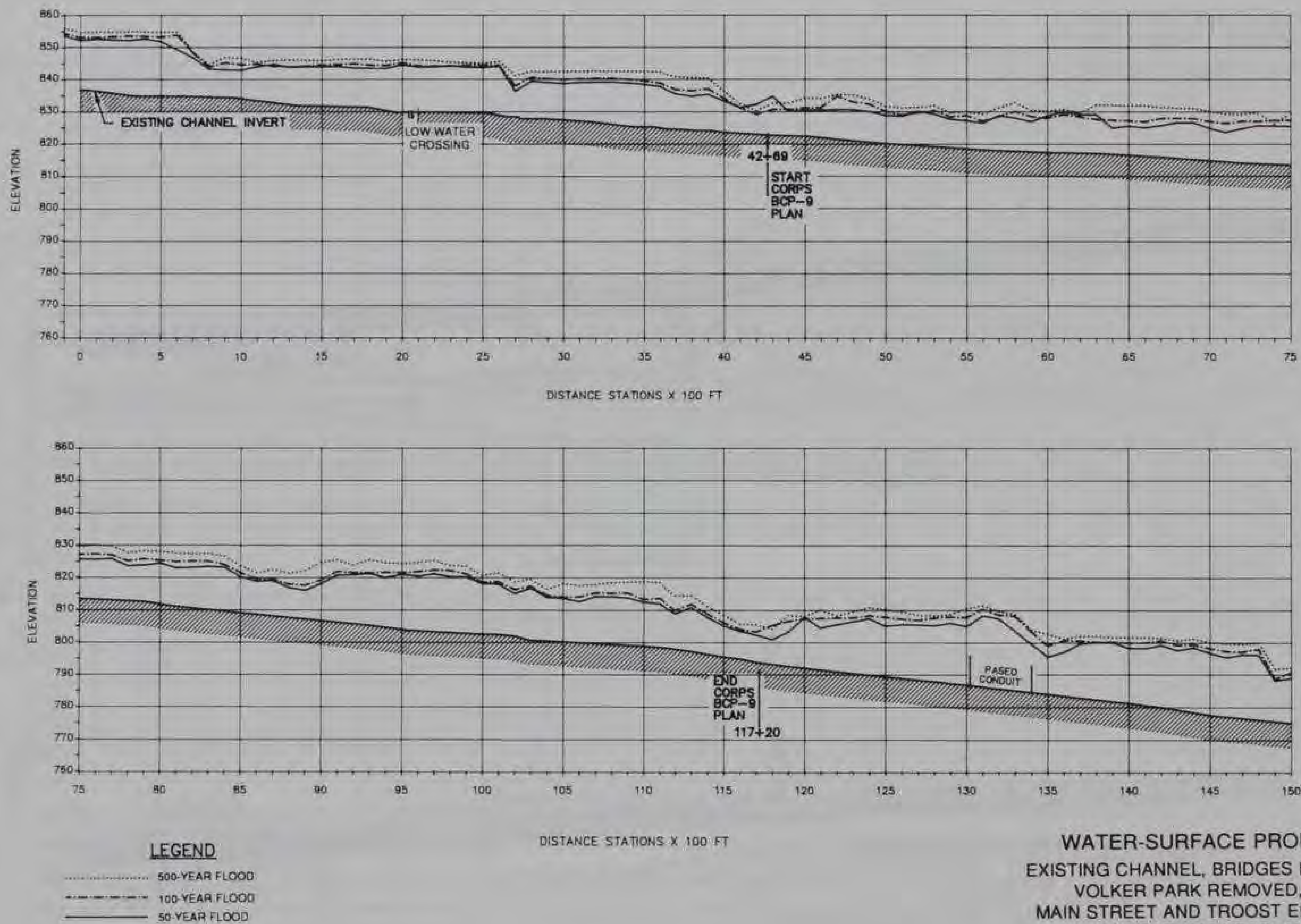
EXISTING CONDITIONS
UMKC DEVELOPMENT WITH PERIMETER ROAD
100-YEAR AND 500-YEAR FLOODS



WATER-SURFACE PROFILES

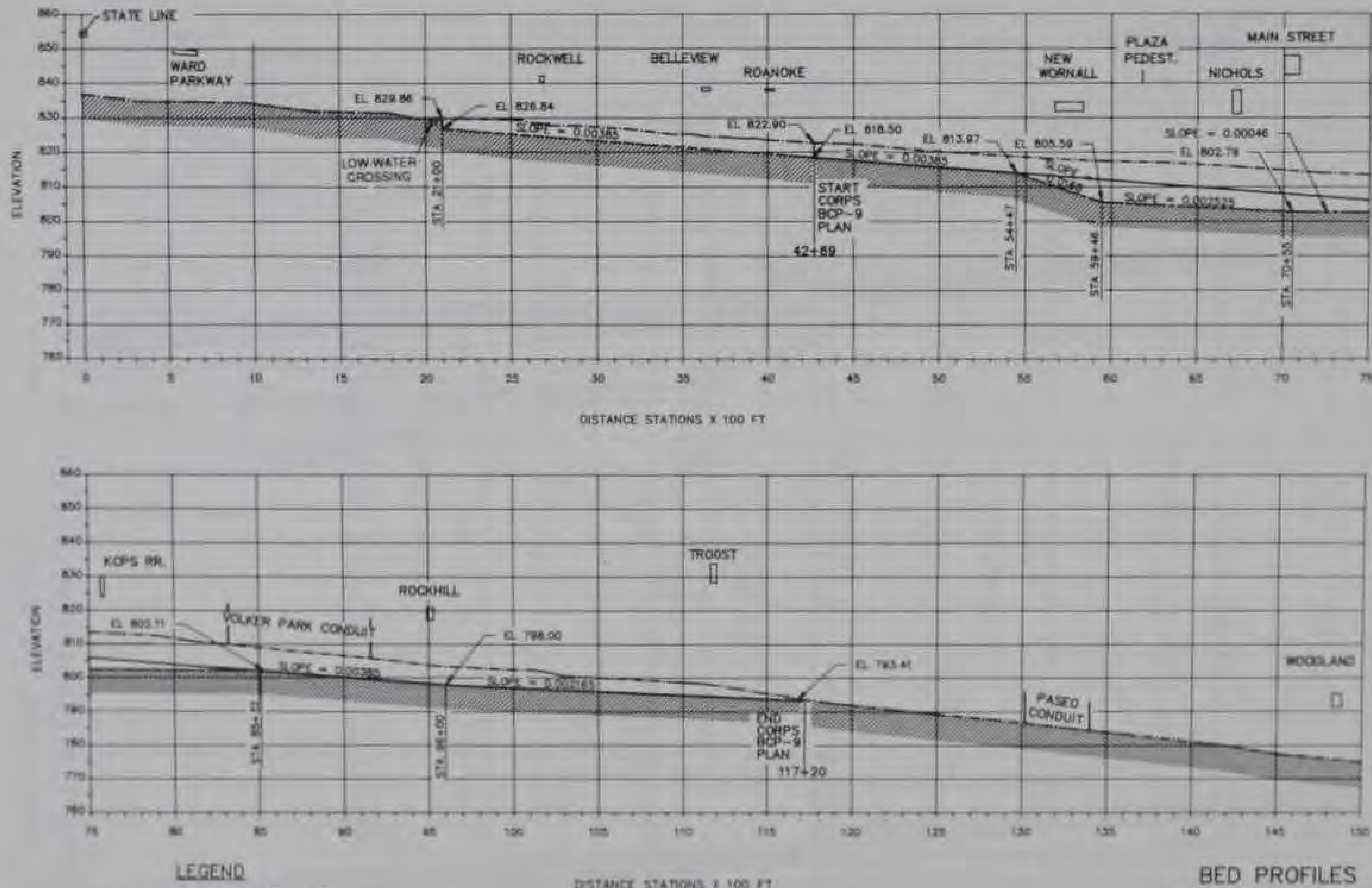
EXISTING CHANNEL, BRIDGES REMOVED
100-YEAR AND 500-YEAR FLOODS

PLATE 6



WATER-SURFACE PROFILES

EXISTING CHANNEL, BRIDGES REMOVED, VOLKER PARK REMOVED, AND MAIN STREET AND TROOST ENLARGED 50-YEAR, 100-YEAR, AND 500-YEAR FLOODS



LEGEND

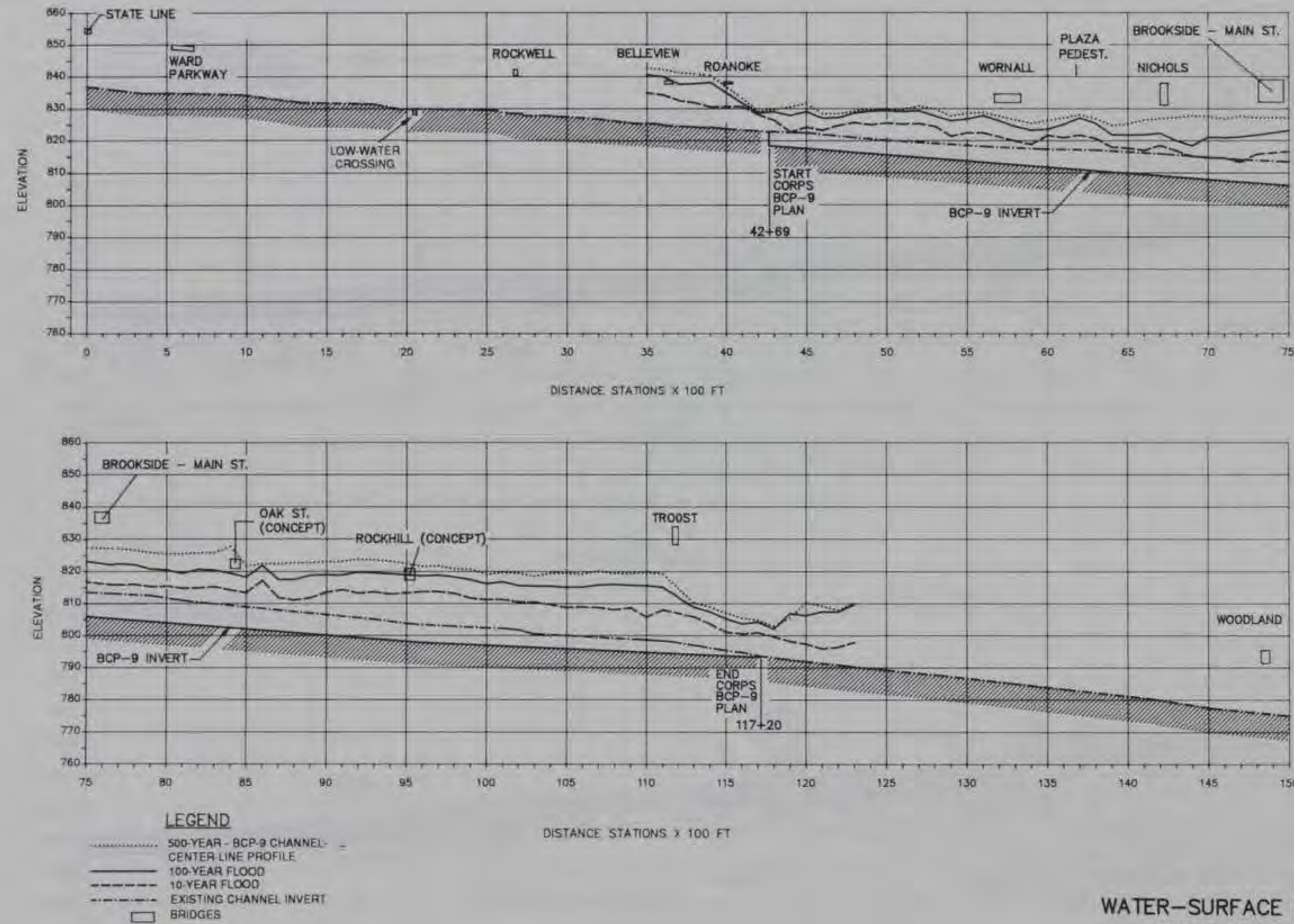
- EXISTING CHANNEL INVERT
- UPSTREAM CITY DEEPENING
- OVERDEEPENED BOTTOM
- BCP-9 CHANNEL INVERT
- BRIDGES

BED PROFILES

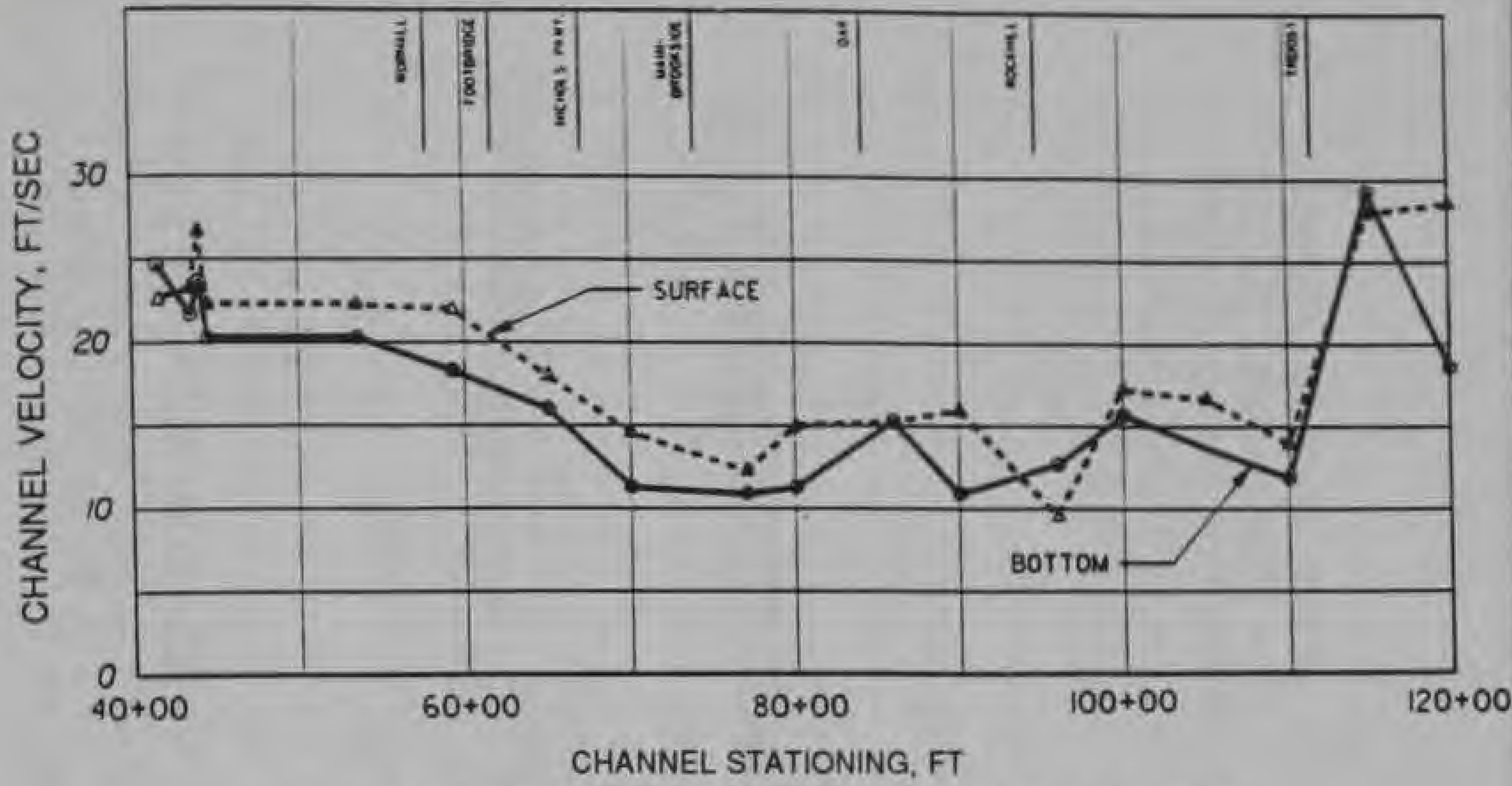
EXISTING CHANNEL INVERT,
BCP-9 INVERT,
AND DEEPENED INVERTS

PLATE 7

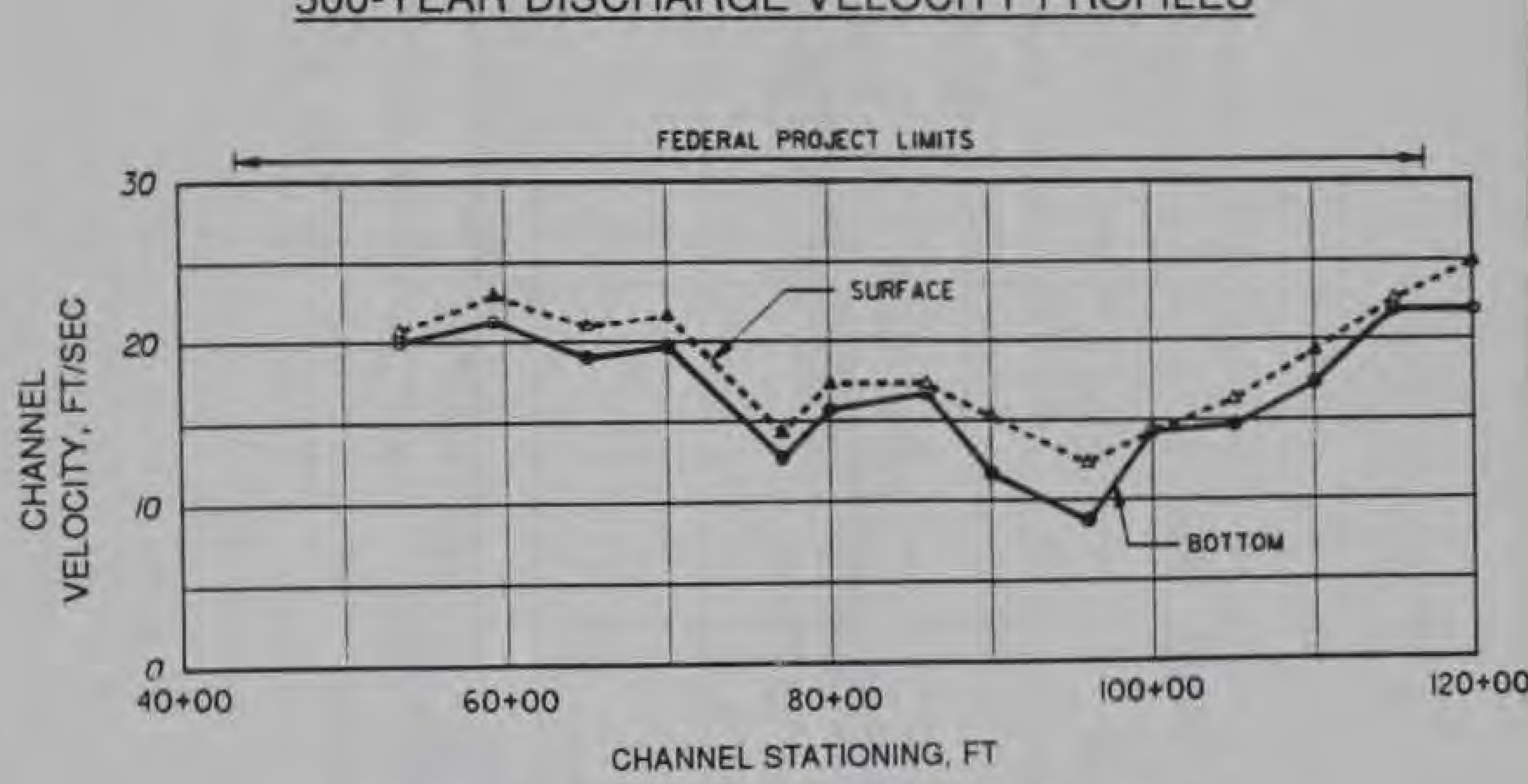
PLATE 8



WATER–SURFACE PROFILES
BCP–9 CORPS PLAN



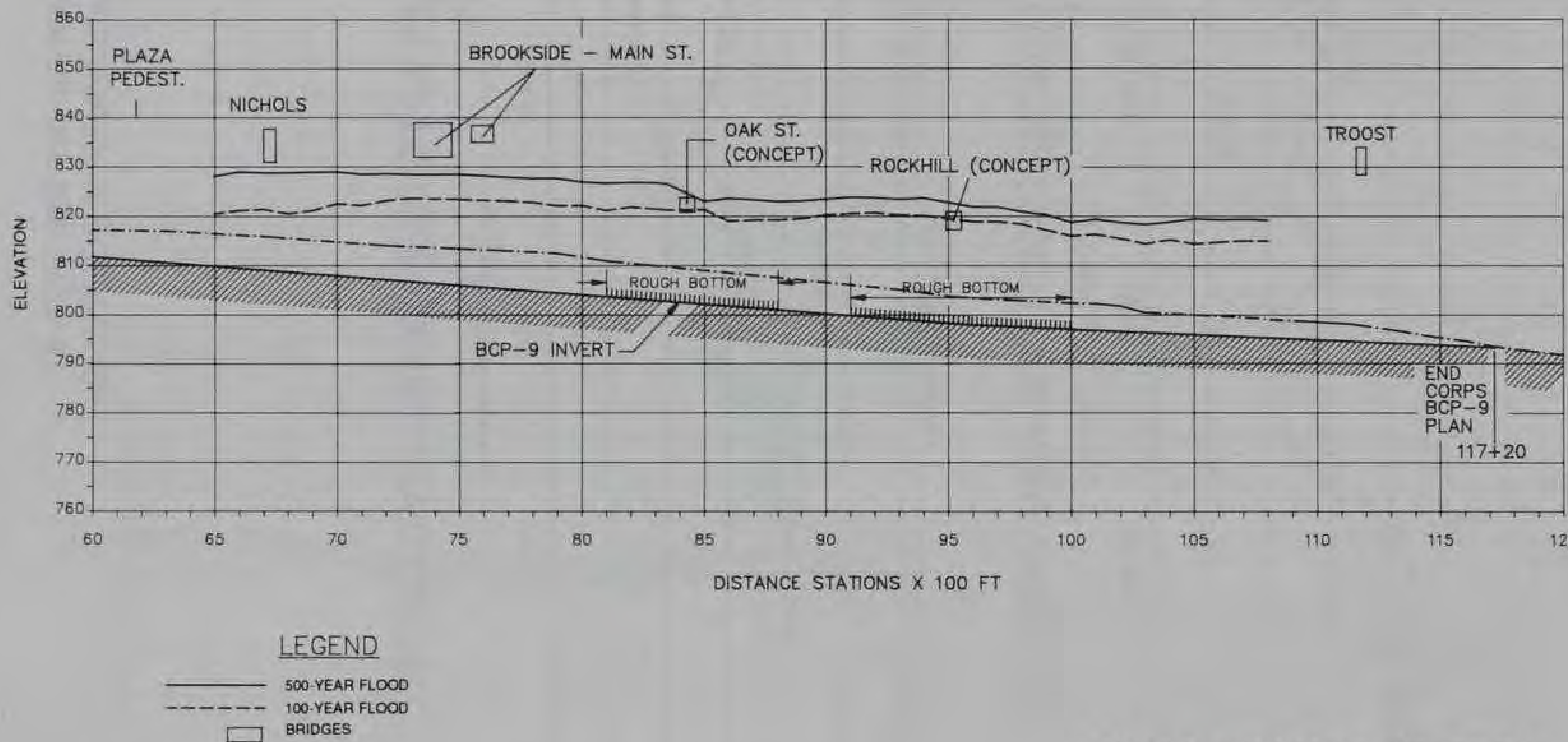
500-YEAR DISCHARGE VELOCITY PROFILES



10-YEAR DISCHARGE VELOCITY PROFILES

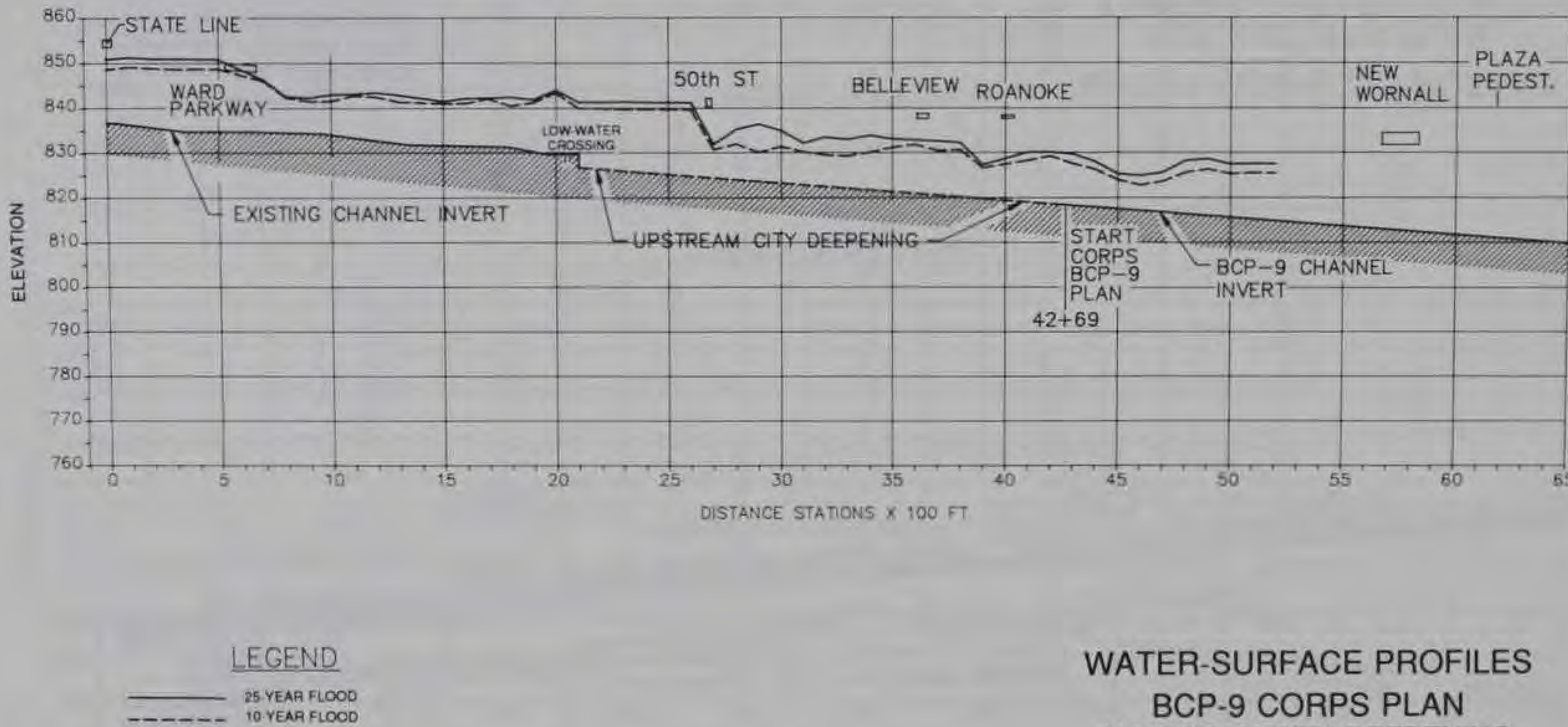
DISCHARGE VELOCITY PROFILES
10-YEAR AND 500-YEAR FLOODS

PLATE 10



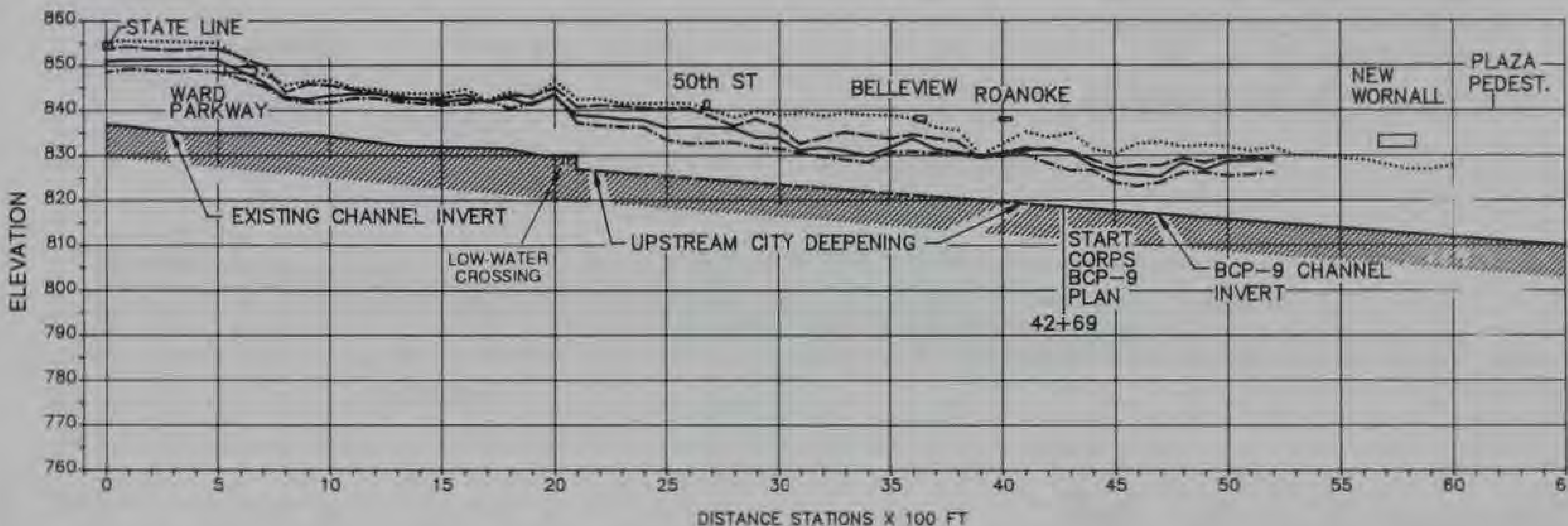
WATER–SURFACE PROFILES

BCP–9 CHANNEL WITH ROUGH BOTTOM
AT STA 81+00 TO STA 87+00
AND AT STA 91+00 TO STA 100+00



WATER-SURFACE PROFILES
BCP-9 CORPS PLAN
UPSTREAM CITY DEEPENING
NEW 50TH STREET BRIDGE
25-AND 10-YEAR FLOODS

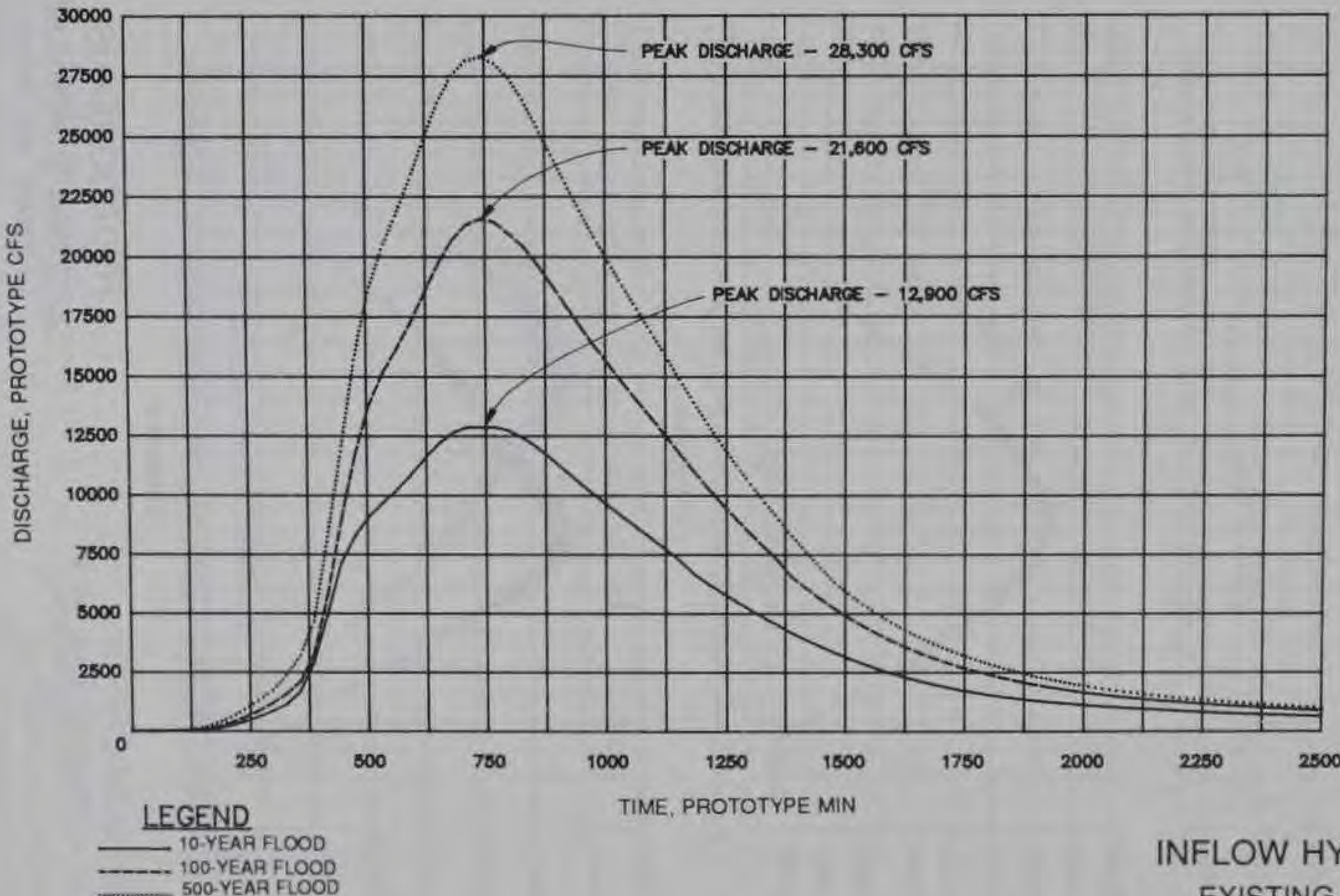
PLATE 12



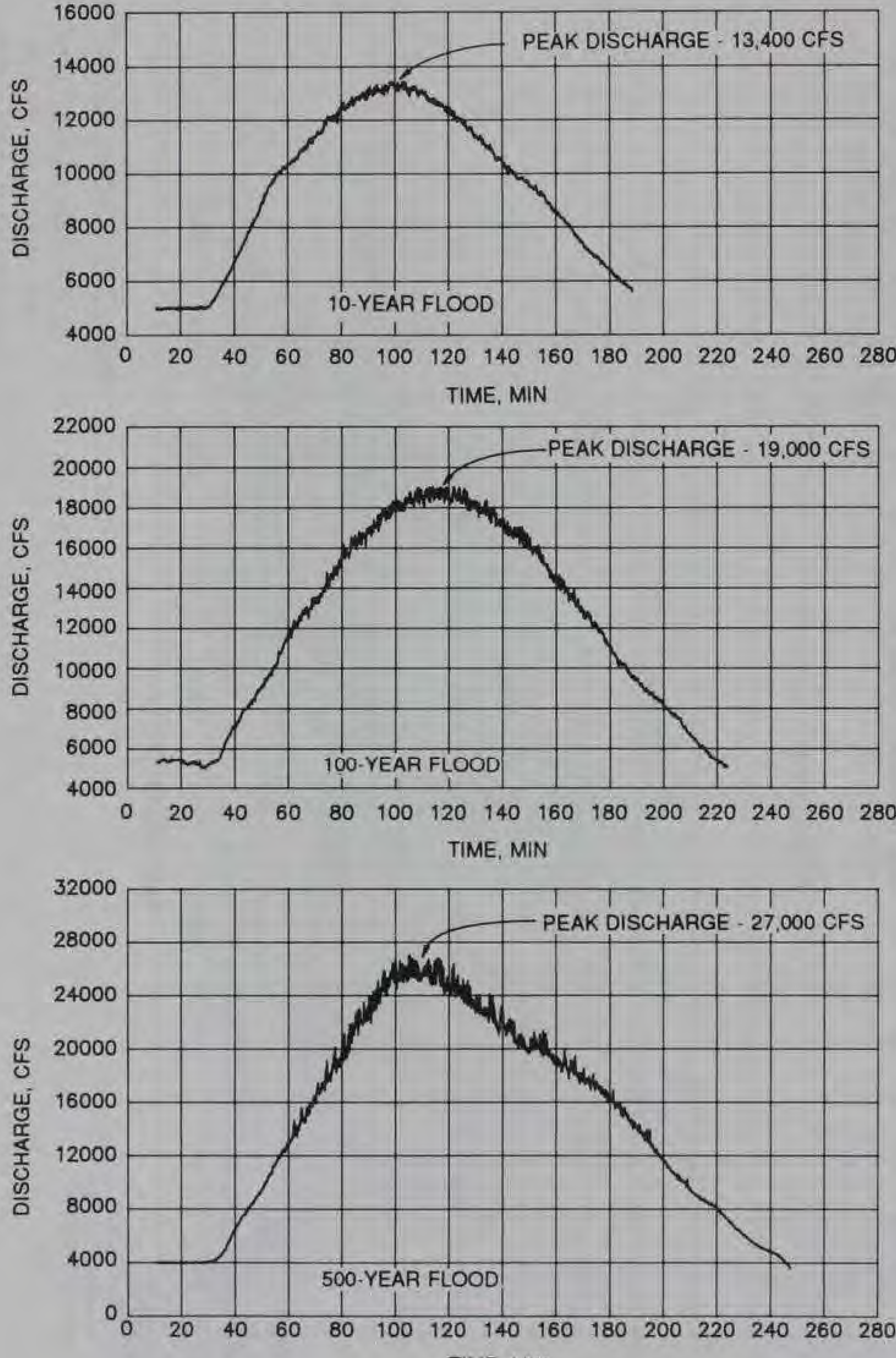
LEGEND

- ··············· 500-YEAR FLOOD
- — — — — — 100-YEAR FLOOD
- ———————— 25-YEAR FLOOD
- -·-·-·-·-·- 10-YEAR FLOOD

WATER-SURFACE PROFILES
BCP-9 CORPS PLAN
UPSTREAM CITY DEEPENING
NEW 50TH STREET BRIDGE
500-, 100-, 25-, AND
10-YEAR FLOODS



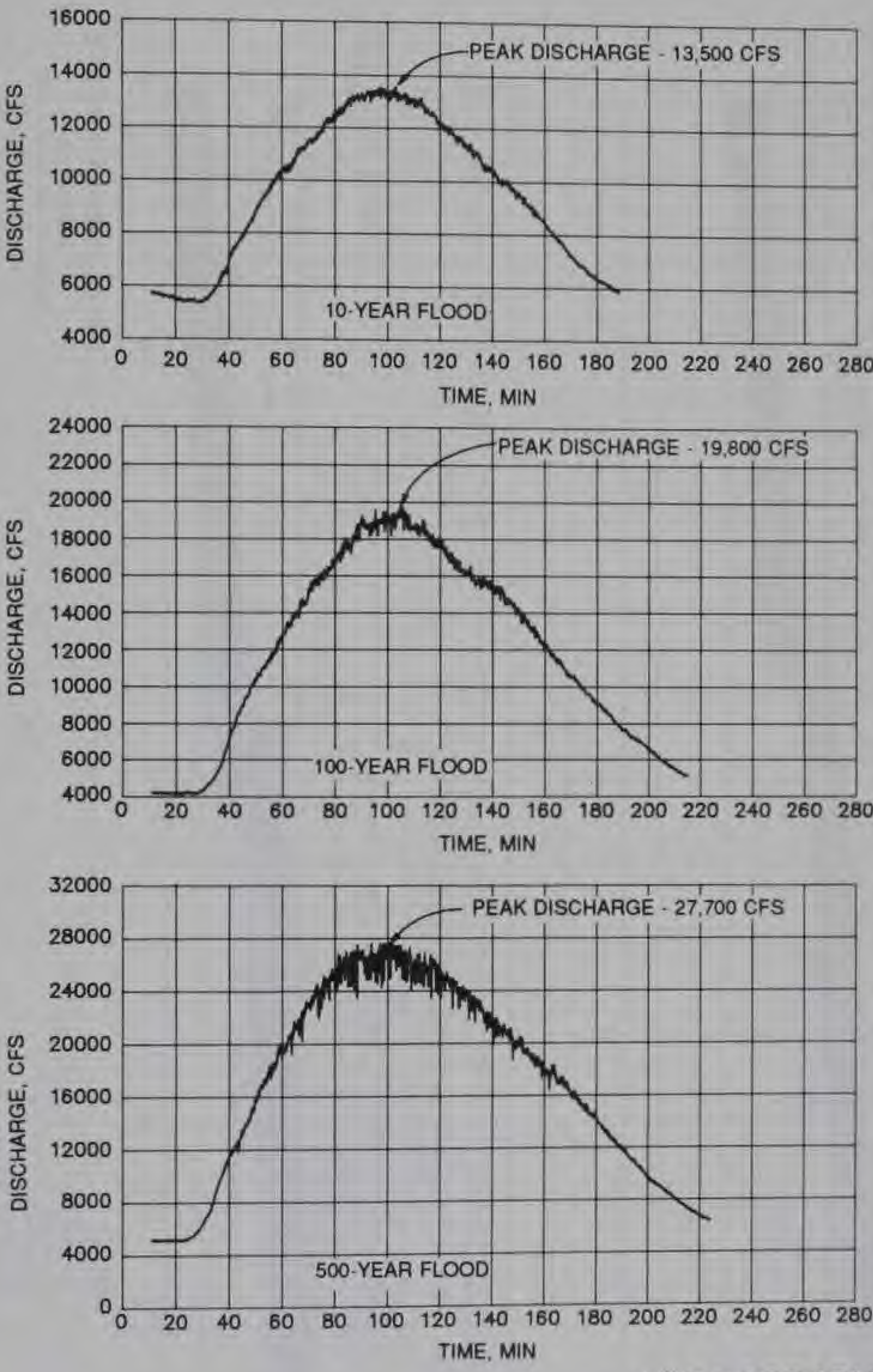
INFLOW HYDROGRAPHS
EXISTING CONDITIONS
10-YEAR, 100-YEAR
AND 500-YEAR FLOODS



NOTE: DISCHARGE AND TIME ARE IN PROTOTYPE UNITS.

HYDROGRAPHS

EXISTING CONDITIONS
10-YEAR, 100-YEAR
AND 500-YEAR FLOODS

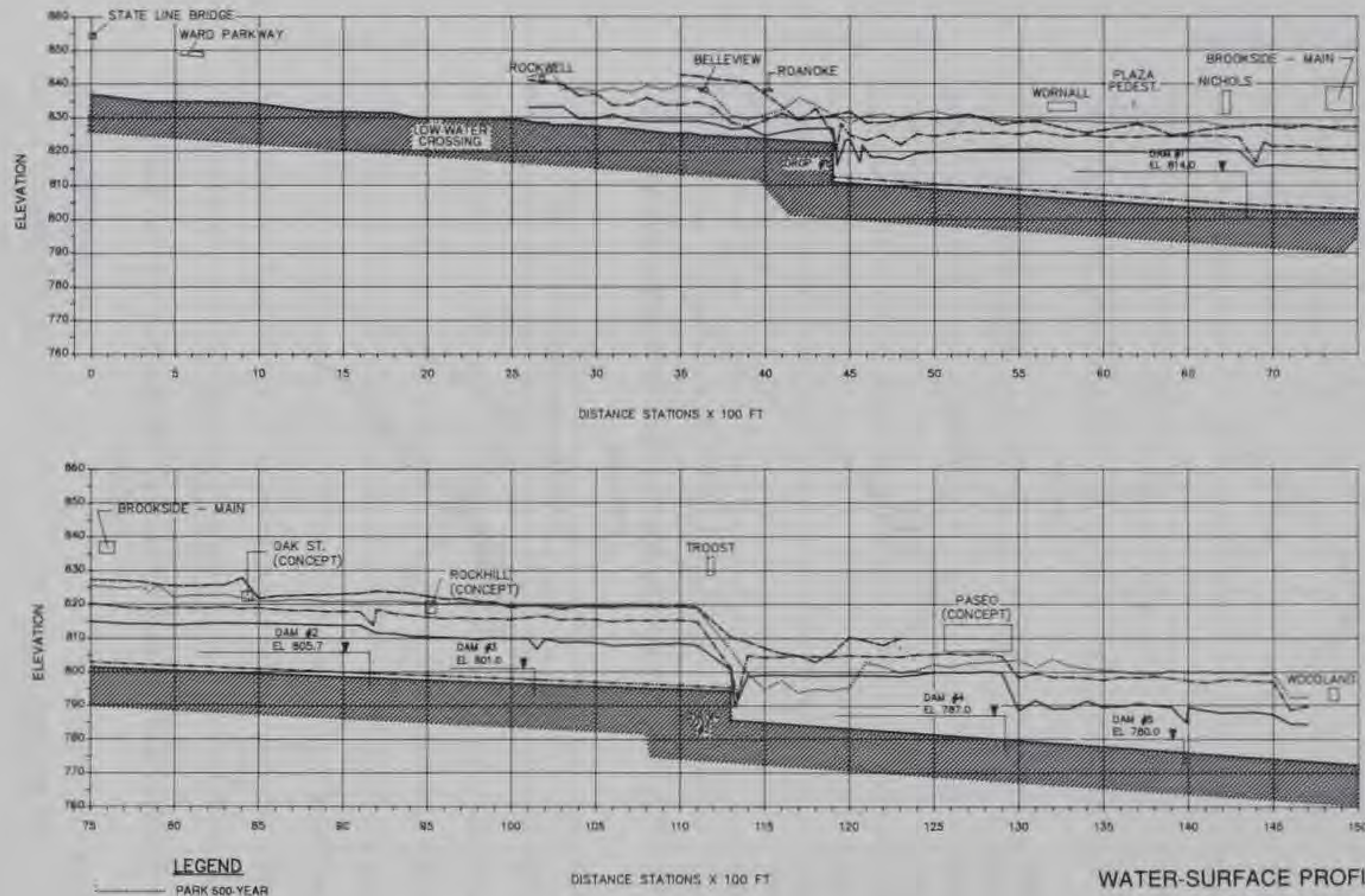


NOTE: DISCHARGE AND TIME ARE IN PROTOTYPE UNITS.

HYDROGRAPHS

BCP-9 CORPS PLAN
10-YEAR, 100-YEAR
AND 500-YEAR FLOODS

PLATE 16

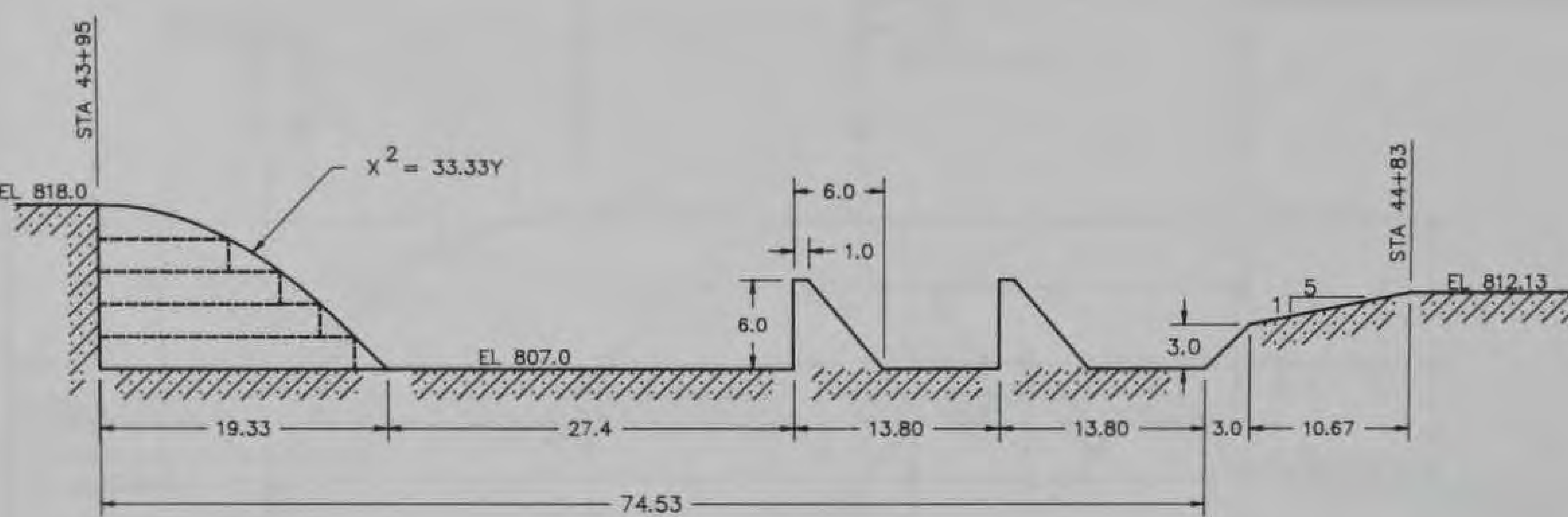


LEGEND

- PARK 500-YEAR
- PARK 100-YEAR
- PARK 10-YEAR
- BCP-9 500-YEAR
- RAISED PARK INVERT
- BRIDGES

WATER-SURFACE PROFILES

PARK PLAN
500-YEAR, 100-YEAR, AND
10-YEAR FLOODS



LEGEND

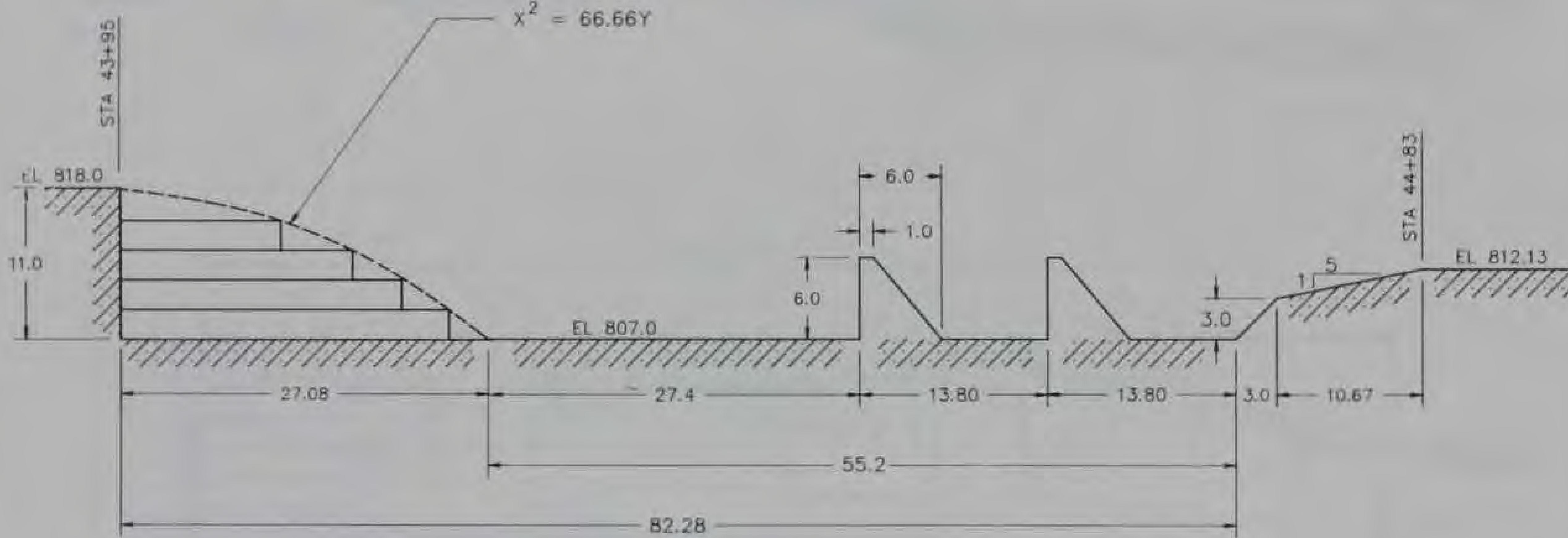
——— TYPE 1 – PARABOLIC TRAJECTORY

- - - - TYPE 2 – STEPPED TRAJECTORY

NOTE: DIMENSIONS ARE IN PROTOTYPE FEET.

$q=210$ CFS/FT
$F=2.51$
$D1=6.0$
$D2=18.4$
$Y_c=11.11$
$H=1.5\ Y_c=16.67$

DROP STRUCTURE
STA 43+95
TYPES 1 AND 2 DESIGNS



LEGEND

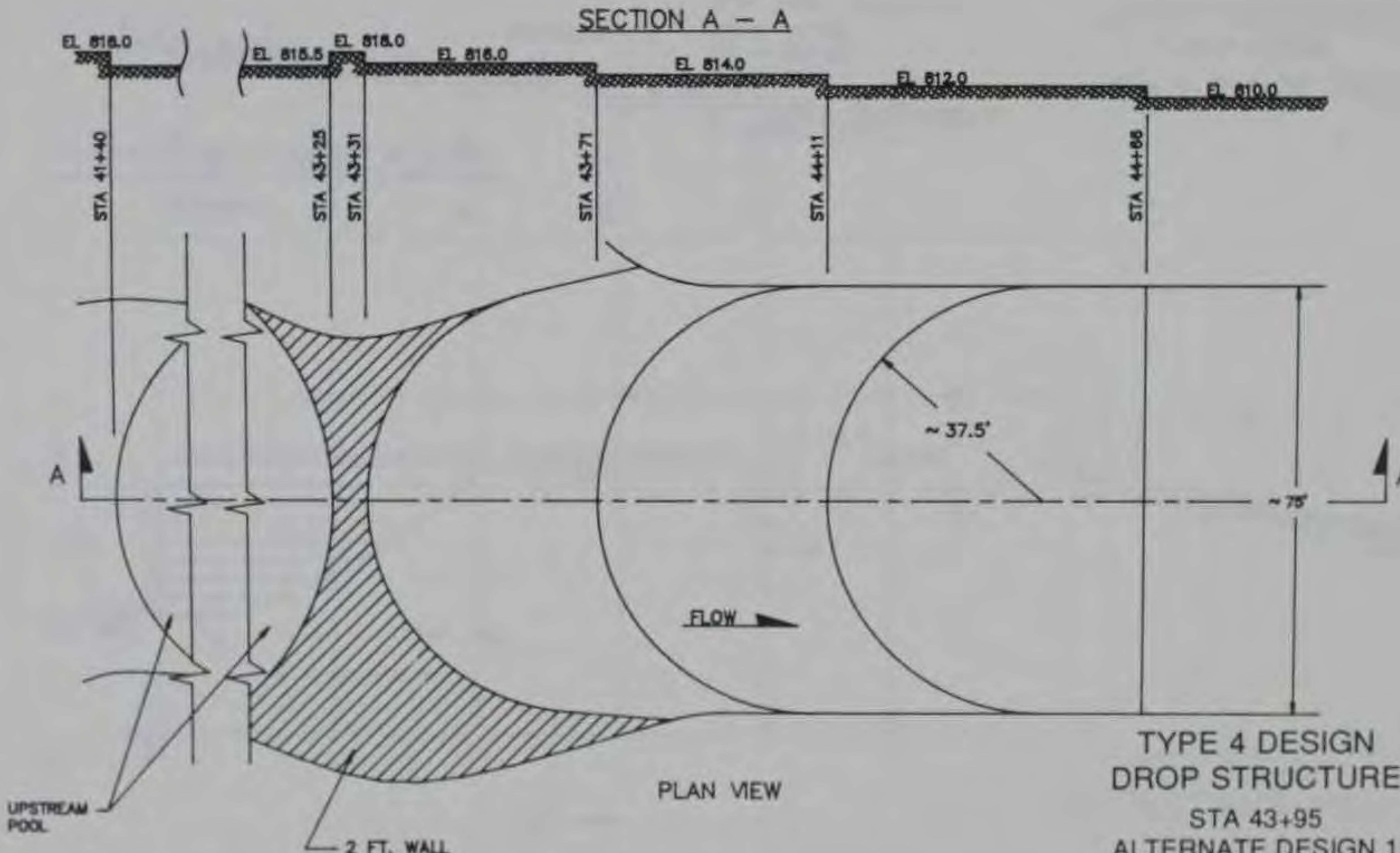
———— TYPE 3 - STEPPED TRAJECTORY

NOTE: DIMENSIONS ARE IN PROTOTYPE FEET.

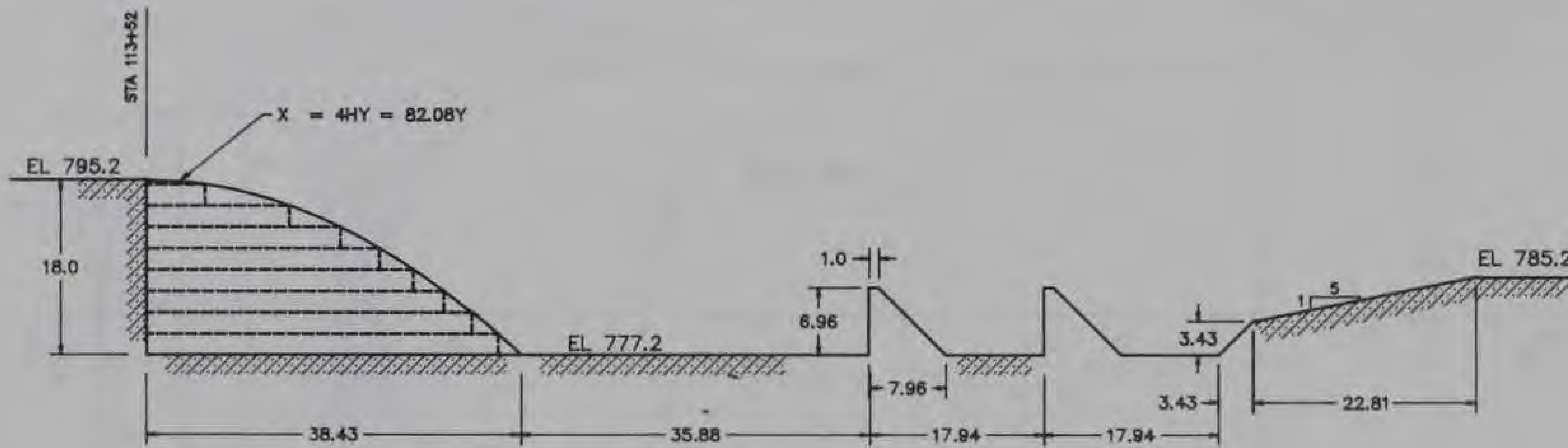
q=210 CFS/FT
F=2.51
D1=6.0
D2=18.4
Y_c =11.11
H=1.5 Y_c =16.67

DROP STRUCTURE

STA 43+95
TYPE 3 DESIGN



TYPE 4 DESIGN
DROP STRUCTURE
STA 43+95
ALTERNATE DESIGN 1
WITH UPSTREAM POOL
TYPICAL CONFIGURATION



LEGEND

———— TYPE 1 – PARABOLIC TRAJECTORY

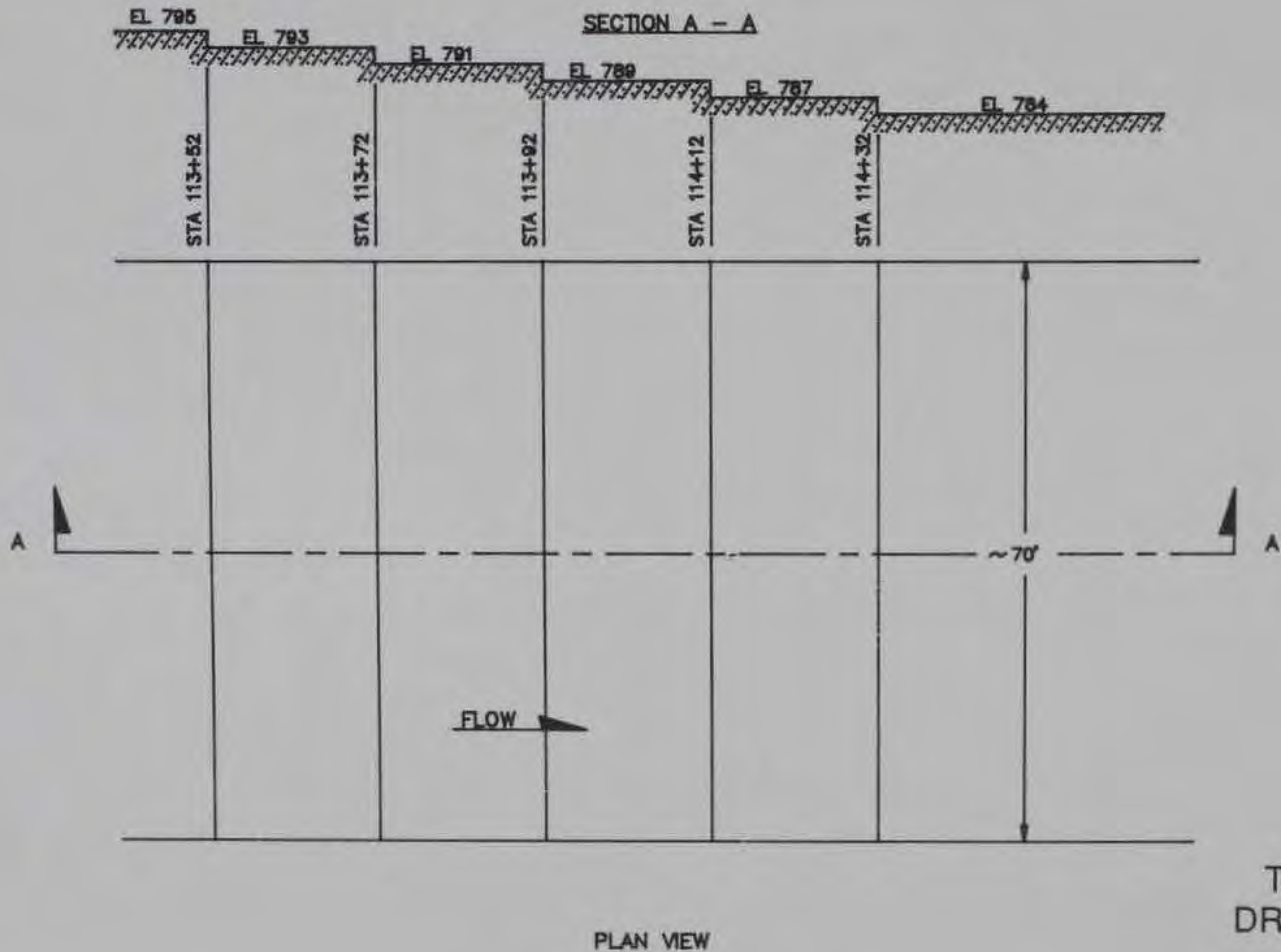
- - - - - TYPE 2 – STEPPED TRAJECTORY

q = 287 CFS/FT
F = 2.82
D1 = 6.85
D2 = 23.92
Y_c = 13.86
H = 1.5Y_c =20.52

DROP STRUCTURE

STA 113+52

TYPES 1 AND 2 DESIGNS



TYPE 3 DESIGN
DROP STRUCTURE
STA 113+52
ALTERNATE DESIGN 2
TYPICAL CONFIGURATION