BLUE RIVER DROP STRUCTURE: IMPACT ON HISTORICAL SITE BLUE RIVER, KANSAS CITY, MISSOURI

Deborah Cooper

Spillways and Channels Branch, Hydraulics Structures Division, Hydraulics Laboratory, USAE Waterways Experiment Station, Vicksburg, Mississippi

INTRODUCTION

The Blue River -- frequently referred to as the Big Blue River for clarification from its neighboring Little Blue River -- is a right-bank tributary of the Missouri River (Figure 1). The project consists of improving the existing channel from its confluence with the Missouri River upstream for approximately 12 river miles.

The Blue River Basin Projects were authorized by the Flood Control Act of 1970. The existing 14 mile reach of the river in the Blue River Channel Modification Project area meanders through a densely industrialized portion of Kansas City, Jackson County, Missouri. The project entails channel widening and limited realignment, bank stabilization, channel paving, rockshell, and riprap treatments.

The Blue River Channel Modification Project area is divided into three stages. Stage I extends from the mouth of the river to a location north of Independence Avenue; Stage II from the latter to a location between Independence Avenue and Truman Road; and Stage III from the latter to 63rd Street (Figure 1). Construction in Stages I and II is completed. Stage III construction activities are scheduled to start in 1995 and to be completed in 2000. A portion of the Big Blue Battlefield lies within the right-of-way for Stage III of the project. As discussed below, the Kansas City District (CEMRK) redesigned project features to avoid direct effects to Byram's Ford Historic District.

The Big Blue Battlefield is a Civil War battlefield adjacent to the Blue River in Kansas City, Missouri. Two separate battles were fought there on October 22, 1864, and October 23, 1864. The actions at the Big Blue Battlefield on October 23, 1864, influenced the outcome of the Battle of Westport, fought later that day some three miles to the west. The Battle of Westport involved some 25,000-30,000 troops and is known as the largest engagement of land forces west of the Mississippi River.

The limits of the Big Blue Battlefield have never been precisely defined but the battlefield may comprise 100 or more acres. Seventeen (17) acres of the battle field is presently listed on the National Register of Historic Places (NHRP) as Byram's Ford Historic District. This NHRP district consists of two separate sites, Byram's Ford Site (12 acres) and Byram's Ford Road Site (5 acres). The Confederate loss of the control of Byram's Ford during the Battle of the Big Blue on October 23, 1864, helped bring about the defeat of Confederate forces at the Battle of Westport later that day.

The Big Blue Battlefield is located approximately from 58th Street to 63rd Street adjacent to the Blue River in Kansas City, Missouri (Figure 2). The battlefield extends southward from 58th Street to 63rd Street and from the blufftops east of the river to Elmwood Avenue on to the blufftops on the west side of the river.

The battlefield is within the city limits of Kansas City and includes both relatively undeveloped wooded areas and highly developed industrial, commercial, and residential areas. Undeveloped, well-wooded areas border both banks of the historic river crossing known as Byram's Ford and the swale of the historic Byram's Ford wagon road east of the Blue River. Industrial and commercial development is most evident in present day Byram's Ford Industrial Park which occupies a large portion of the battlefield west of the Blue River.

The Civil War Round Table of Kansas City/Monnett Battle of Westport Fund was responsible for getting the Byram's Ford Historic District listed on the NRHP. The Historic District is composed of the Byram's Ford Site which includes Byram's Ford and a remnant swale of Byram's Ford Road. The Byram's Ford Road Site comprises approximately 5 acres and contains a remnant road course of Byram's Ford Road east of Hardesty Avenue.

These two sites were selected for inclusion to the NHRP because the ford and historic wagon road figured prominently in the Battle of the Big Blue. Furthermore, they possess readily identifiable remnants of the Big Blue Battlefield which retain integrity in location, setting, feeling and association reminiscent of the environment found by Union and Confederate forces on October 22-23, 1864.

A grade control structure will be located downstream of Byram's Ford where it will not adversely impact the historic Ford. A three stage weir design was necessary to provide acceptable velocities at all stages of flood flow. The grade control structure was required to minimize the erosion which would result from the high velocities at and upstream of the structure location in the unmodified channel.

An investigation examined the feasibility of providing flood protection to the area. The main purpose of the study was to determine what level of flood protection could be provided in the Byram's Ford Industrial Park area without adversely affecting the cultural values of the historic battle field site.

The need for a model study was considered essential to insure the integrity of the channel design while attempting to minimize the real estate requirements by the city of Kansas City. This report describes model tests and results for a portion of the flood control plan for Stage III of the Blue River Flood Protection Project.

The Prototype

A major portion of the project is in a highly congested industrial area with numerous street, highway, and railroad bridges. The channel improvements were designed to contain a discharge of 35,000 cfs with a coincident 10-year-frequency flood on the Missouri River. This design discharge of 35,000 cfs approximates a 30-year-frequency flood. A grade control structure near sta 99+60 (Figure 3) is the only major concrete structure planned as part of the channel improvements.

The structure will be located downstream of Byram's Ford (Sta 113+50) where it will not adversely impact the historic Ford. The headwater elevations for the grade control structure were originally developed to allow a drawdown in the existing channel corresponding to a five percent differential in velocity upstream. A three stage weir design, shown in Figure 3, was necessary to provide acceptable velocities at all stages of flood flow. The lower stage of the weir had a crest elevation of 732.0 (approach channel elevation) and a weir length of 10 feet. The lower stage of the weir was designed to prevent upstream ponding and sedimentation at normal flows. The middle stage had a weir crest elevation of 750.0 and an additional weir length of 97 feet. The upper stage had a weir crest elevation of 764.0 and a total weir length of 160 feet. Energy dissipation was accomplished with a horizontal apron with baffle blocks terminated by an end sill. The grade control structure was required to minimize the erosion which would result from the high velocities at and upstream of the structure location in the unmodified channel.

An investigation was made of the Byram's Ford Industrial Park area to determine the feasibility of providing flood protection to the area. The study addressed both 50-year and 100-year floods on the Blue River. The main purpose of the study was to determine what level of flood protection could be provided in the Byram's Ford Industrial Park area without adversely affecting the cultural values of the historic battle field site. The feasibility of placing a levee to protect the industrial park was coordinated between the Kansas City District, the City of Kansas City, Missouri, the Civil War Roundtable, and the Byram's Ford Industrial Park landowners.

Purpose and Scope of the Model Study

The design for channel improvement of the Blue River was in accordance with sound engineering procedures; however, the need for a model study was considered essential due to significant energy dissipation problems expected downstream of the grade control structure. The model study was necessary to insure the integrity of the channel design while attempting to minimize the real estate requirements by the city of Kansas City. The physical model was also needed to verify the hydraulics of the proposed stilling basin design. With multiple weir elevations, flow conditions across the basin are not uniform. The following information was obtained from the model:

- a. Flow characteristics and stilling basin performance with flow over the drop structure and the left overbank.
- b. Flow characteristics and stilling basin performance with all flow confined to the channel and passing over the structure.
- c. Relative degree of turbulence (as shown by dye) observed visually in the stilling basin and exit channel.
- d. Riprap requirements for protection upstream and downstream of the structure.
- e. Flow conditions at Byram's Ford and Byram's Ford Industrial Park with a breach in the spoil bank levee.

THE MODEL AND TEST PROCEDURE

Description

Originally the 1:36-scale model (Figure 4) reproduced an approach area 2,350 ft wide extending 2,300 ft upstream from the weir and an exit area 2,350 ft wide extending 800 ft downstream from the weir, the 63rd Street and bridge, the spoil bank, Byram's Ford Industrial Park, the three stage weir, the 137-ft-long stilling basin, and basin elements. The weir section, stilling basin, and basin elements were constructed of plastic and wood. The portions of the model representing the approach channel and overbank areas were molded in concrete and the exit channel was molded in sand and gravel. The buildings in Byram's Ford Industrial Park were built of plywood. The original design weir is referred to as the Type 1 (Original) design (Figure 3).

Appurtenances and Instrumentation

Water used in the operation of the model was supplied by pumps, and discharges were measured with venturi meters. The tailwater in the downstream end of the model was controlled by an adjustable tailgate. Water surface elevations were obtained with point gages mounted on tripods. Velocities were measured with a Nixon 402 digital flow meter.

Scale Relations

The accepted equations of similitude, based upon the Froudian relations, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and the prototype. General relations for the transference of model data to prototype equivalents are presented in the following tabulation:

Dimension	Ratio	Scale Relations
Length	$L_r = L$	1:36
Area	$A_r = L_r^2$	1:1296
Velocity	$V_r = L_r^{1/2}$	1:6
Discharge	$Q_r = L_r^{5/2}$	1:7776
Time	$T_r = L_r^{1/2}$	1:6

Because of the nature of the phenomena involved, certain of the 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 the above scale relations. Evidence of scour of the model sand bed, however, is to be considered only as qualitatively reliable since it has not yet been found possible to reproduce quantitatively in a model the relatively greater extent of erosion that occurs in the prototype with fine-grained bed material. Data on scour tendencies provided a basis for determination of the relative effectiveness of the different designs and indicated the areas most subject to attack.

Test Procedure

Tests were conducted in the model to observe the flow patterns, velocities, discharges, and overall hydraulic performance of the drop structure. Various constant discharges were introduced into the model, the tailwater was set, and the river was allowed to stabilize. Sufficient time was allowed for stabilization of the river upstream of the structure. Water-surface elevations were measured at various stations along the river as shown on Figure 4. Tailwater elevations were measured at a point 81 ft downstream from the end sill (sta 97+02.5). A tailwater rating curve used in these tests was provided by CEMRK. Water-surface profile elevations and velocities were measured in the river as well as in the left overbank.

TESTS AND RESULTS

Discharge Characteristics

Calibration Data. CEMRK provided computed water-surface elevations without levees and the drop structure in place throughout the study area for discharges up to 80,000 cfs. These computed water-surface elevations were the best representation of "existing conditions." All modelling efforts were concentrated on matching these "existing conditions" thereby not impacting on the Byram's Ford Crossing. Initial tests were conducted to document water-surface elevations without the drop structure and without roughness materials (trees, brush, etc.) in the model to determine the extent of roughness materials that would be needed to reproduce the computed water-surface elevations. The water-surface elevation at sta 102+00 was set with the tailgate and measurements were then obtained for stations upstream of sta 102+00. The discharges ranged from 1,000 to 80,000 cfs and results indicated that significant roughness was required in the model for discharges greater than 10,000 cfs.

The tests also showed that for discharges greater than 20,000 cfs, overbank flow began to enter the river near sta 120+15. The entire flow was routed down the river for the computed water-surface elevations and did not account for flow entering the river at this location. This caused the computed water-surface elevations to be higher for the large overbank flows (>30,000 cfs) than would actually exist. CEMRK indicated that the roughness material should be added to the model to match the computed water-surface elevations for discharges up to 35,000 cfs and that the computed values greater than 35,000 cfs should be disregarded.

Tests were conducted next with roughness material added in the model in an attempt to match the computed water-surface elevations. A screen wire material was placed on the channel bottom to produce the appropriate roughness for flows contained in the channel (flows up to 10,000 cfs). A porous rubberized material (commonly referred to as horsehair) was used to produce the desired roughness on the overbanks. Masonry bricks were used to hold this material in place. An aerial photograph furnished by the Missouri River Division (CEMRD) showed locations of heavy tree growth. The roughness material was placed in the model in the locations to match the heavy tree growth shown on the aerial photograph.

The measured water-surface elevations with roughness compared well with the computed water-surface elevations up to 35,000 cfs. Plots comparing the computed water-surface profile with the water-surface profile measured in the model for 10,000, 30,000, 35,000 and 80,000 cfs were produced for graphical comparison. These measured values were then considered the baseline water-surface elevations for the weir design.

Weir Tests

Tests were conducted to design a weir that will provide a stage-discharge relationship upstream from sta 102+00 similar to the one determined from the calibration tests with existing conditions.

Type 1 Weir. The type 1 weir (Figure 3) was designed for CEMRK by a consulting firm to pass 68,000 cfs. This design assumed all flow went through the weir and did not consider overtopping of the 35,000 cfs spoil bank levee. Rating curves for the type 1 weir at sta 102+00 (the first station upstream of the structure out of the drawdown zone) and sta 113+50 (the approximate location of Byram's Ford) were plotted along with the stage-discharge curve for the baseline conditions for graphical comparison. The type 1 weir performed well up to 10,000 cfs, but was much too efficient for discharges greater than 10,000 cfs.

Types 2-13 Weirs. The original design three stage weir was modified in an attempt to match computed water-surface elevations provided by CEMRK. The types 2-13 weirs were modifications of the type 1 weir concept of keeping the entire weir overflow at sta 99+60. The stepped type weir designs did not perform satisfactorily for the higher discharges and matching the stage-discharge relationship with this type design was not possible.

Type 14 Weir. The type 14 weir design shown in Figure 5 provided stages that were very close to the baseline conditions for the nonovertopping discharges up to 35,000 cfs. For discharges greater than 35,000 cfs, the stages with the type 14 weir were lower than the baseline water-surface elevations. The type 14 weir was not desirable due to poor energy dissipation in the stilling basin, so additional designs were tested.

Type 15-21 Weirs. The type 15-21 weirs consisted of modified drop inlet type designs. The type 21 weir design provided stages that were very close to the baseline conditions for the nonovertopping discharges up to 35,000 cfs. Energy dissipation with the type 21 weir was much better than with the type 14 weir. Since the type 21 weir appeared feasible, changes to the approach channel and the original design stilling basin were made so that the riprap stability tests could be conducted.

Type 22 and 23 Weirs. The type 22 and 23 weirs consisted of modified drop inlet type designs with upstream debris deflectors and low flow training walls in the stilling basin. The details of the type 23 design is shown in Figure 5. The type 23 weir design provided stages that were very close to the baseline conditions for the nonovertopping discharges up to 35,000 cfs. Rating curves for the type 1 (original), type 14, and type 23 weir at sta 13+50 are shown in Figure 6.

CEMRD engineers requested comparative water-surface elevations and rating curves for weirs with crest elevations 2 and 4 ft lower than the Type 23 weir to determine if additional protection could be provided to the Byram's Ford Industrial Park without adversely impacting the Byram's Ford Crossing. These weirs, designated the Types 24 and 25 weirs, respectively, were tested. The water-surface elevations were lower with the type 24 weir than with the type 23 weir and lower still with the type 256 weir than with the type 24 weir.

Velocities at Byram's Ford

Velocities were measured at sta 112+00 and 113+50, the location of Byram's Ford, with existing conditions as well as with the types 23-25 weir designs. The bottom velocities for several discharges were compared to determine what impact, if any, channel improvements have on the Byram's Ford crossing. The velocities along the centerline at Byram's Ford increased up to 48% (35,000 cfs) with the Type 23 design, 54% (35,000 cfs) with the Type 24 design and 74% (35,000 cfs) with the Type 25 design. This indicated that decreasing the top elevation of the weir increased velocities at Byram's Ford. With the decrease in water-surface elevation due to the lower weir crest, more flow is confined to the channel, increasing the velocities along the channel centerline.

Debris Deflector Tests

The original (Type 1) design debris deflector (Figure 3) consisted of two 54-ft-long parallel walls sloping at 1V on 3H. This debris deflector increased water surface elevations throughout the river above the baseline water surface elevations. The type 2 design debris deflector consisting of two walls flared at 30 degrees to flow and sloping at 1V on 2H was tested. The type 2 debris deflector provided stages that were very close to the baseline conditions for the nonovertopping discharges up to 35,000 cfs. Twigs simulating 20 to 30-ft-long logs were diverted through the structure. Visual observations of debris passage with the type 2 design debris deflector indicated satisfactory debris passage through the low flow notch with the type 2 design.

Stilling Basin Tests

The original (Type 1) design stilling basin (Figure 4) consisted of an apron at el 725.6, parallel low flow training walls, baffle blocks, and an endsill. Visual observations and velocity measurements over the endsill and 100 ft downstream of the endsill with the types 23-25 weir designs indicated 35,000 cfs over the type 25 weir produced the worst flow conditions and highest bottom velocities. Therefore, stilling basin tests and riprap stability tests were conducted with the type 25 weir. Velocities were measured downstream of the original (type 1) design stilling basin and Type 25 weir. The stilling basin apron was elevated 4 ft to el 729.6 from the weir to the upstream face of the first row of baffles to reduce the amount of excavation for construction of the project (Type 2 stilling basin). Velocities and visual observations indicated no improvement in flow conditions over the original basin. The stilling basin apron was elevated 4 ft to el 729.6 from the weir to the endsill (Type 3 stilling basin). This increased velocities downstream of the basin and caused damage to riprap on the sideslopes.

Riprap Requirements

Riprap protection was installed in the model upstream of the Type 25 weir and immediately downstream of the Type 1 stilling basin endsill. The upstream riprap protection gradation was based on the gradation for an 18-inch minimum layer thickness given in the Blue River Channel Modification Design Memorandum No. 4, Volume 1. The Type 1 riprap design consisted of an 18-in.-thick blanket (Class "A") simulating protective stone with a D_{50min} of 11.5 in. placed 100 ft upstream of the weir and 466 ft downstream of the endsill. Initially, discharges of 35,000, 55,000 and 80,000 cfs were run for 6 hours (prototype). The riprap remained stable upstream and downstream of the structure. The maximum discharge from the May 1990 flood, 35,000 cfs, was then run for 36 hours (the duration of the peak flow as provided by CEMRK). The riprap immediately downstream of the endsill failed after 36 hours (prototype) of operation.

The riprap blanket thickness 100 ft downstream of the endsill was increased to a 24-in.-thick blanket (Class "B") simulating protective stone with a D_{50min} of 15 in. This was designated the Type 2 riprap design. The model was again operated with a discharge of 35,000 cfs for 36 hours (prototype). The Type 2 riprap design remained stable for these conditions.

In an effort to reduce excavation during construction in the prototype, the elevation of the stilling basin apron from the weir to the endsill was raised four feet. This was designated the Type 3 stilling basin. The riprap blanket thickness 100 ft downstream of the endsill remained 24-in.-thick. The model was again operated with a discharge of 35,000 cfs for 36 hours (prototype). The riprap scoured downstream of the endsill and along the side slopes just downstream of the flared training walls. Measurements at several depths indicated that raising the basin apron floor four feet increased velocities especially closer to the water surface.

CONCLUSIONS

The model study initially addressed the hydraulic impact of the drop structure on the Byram's Ford Civil War Crossing. Additional tests were conducted to determine if additional flood protection could be given the Byram's Ford Industrial Park by changing the drop structure design while minimizing impact on the Ford. The three-stage (Type 1, original) weir design matched (baseline) water-surface elevations calculated by CEMRK for existing conditions for discharges up to about 10,000 cfs. The three-sided (type 23) weir design shown in Figure 5 provided stages that were very close to the baseline conditions for the nonovertopping discharges up to 35,000 cfs. During the course of testing, some emphasis was placed on finding a trade-off point where the weir design did not adversely impact on the Byram's Ford Crossing but would provide additional flood protection to the Byram's Ford Industrial Park area. The types 24 and 25 designs, consisting of lower crests, increased protection of the Park with lower stage elevations while increasing velocities at the Ford. CEMRK and CEMRD will recommend a drop structure design based on model results and the modified scope.

The bottom velocities at Byram's Ford for several discharges were compared to determine what impact, if any, channel improvements will have on the Byram's Ford crossing. Comparing the bottom velocities measured with simulated existing conditions to bottom velocities measured with the types 23, 24, and 25 weirs, the velocity along the center line of the channel increased from 3.5 and 3.7 fps (existing conditions at sta 112+00 and 113+50) to 4.4 and 5.2 (at sta 112+00 and 113+50), 4.7 and 5.4 (sta 112+00 and 113+50), and 5.1 and 6.1 fps (sta 112+00 and 113+50) for the types 23, 24, and 25 weirs, respectively, and a discharge of 35,000 cfs.

The original parallel sloped deflectors increase water-surface elevations throughout the river and caused debris to jam in the low flow slot. Tests indicated that a 30 degree flare of the debris deflector was necessary to improve the "draw" of debris through the low flow slot.

The original (Type 1) design stilling basin consisted of an apron at el 725.6, parallel low flow training walls, baffle blocks, and an endsill. Visual observations and velocity measurements over the endsill and 100 ft downstream of the endsill with the types 23-25 weir designs indicated 35,000 cfs over the type 25 weir produced the worst flow conditions and highest bottom velocities. Therefore, stilling basin tests and riprap stability tests were conducted with the type 25 weir. Flaring the low flow training walls increased velocities at the corners of the flared walls. Elevating the stilling basin apron 4 ft also increased velocities and caused damage to the riprap blanket downstream of the structure. It is recommended that the stilling basin with low flow training walls be built as originally designed with the apron el the same.

The upstream riprap protection gradation was based on the gradation for an 18-inch (minimum layer thickness) given in the <u>Blue River Channel Modification Design Memorandum No. 4, Volume 1</u>. The downstream riprap protection gradation was based on Hydraulic Design Criteria (HDC) 712-1. An 18-in.-thick blanket (Class "A") simulating protective stone with a D_{50min} of 11.5 in. was placed for 100 ft upstream of the weir. The riprap remained stable after 35,000 cfs was discharged for 36 hours (prototype).

The riprap blanket thickness 100 ft downstream of the endsill was increased to a 24-in.-thick blanket (Class "B") simulating protective stone with a D_{50min} of 15 in followed by 366 ft of the 18-in.-thick blanket. The riprap remained stable after 35,000 cfs was discharged for 36 hours (prototype).

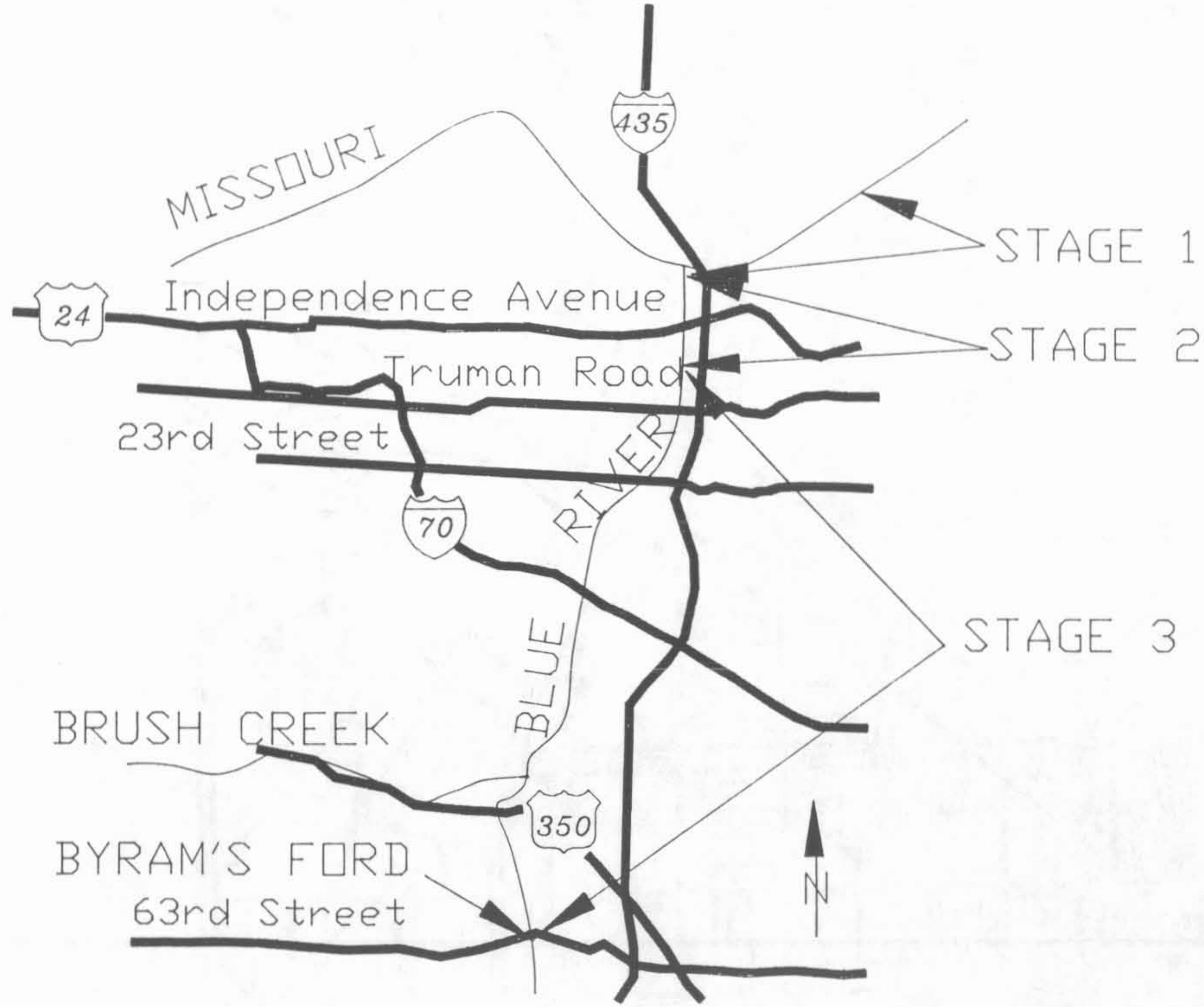

Figure 1. Location Map

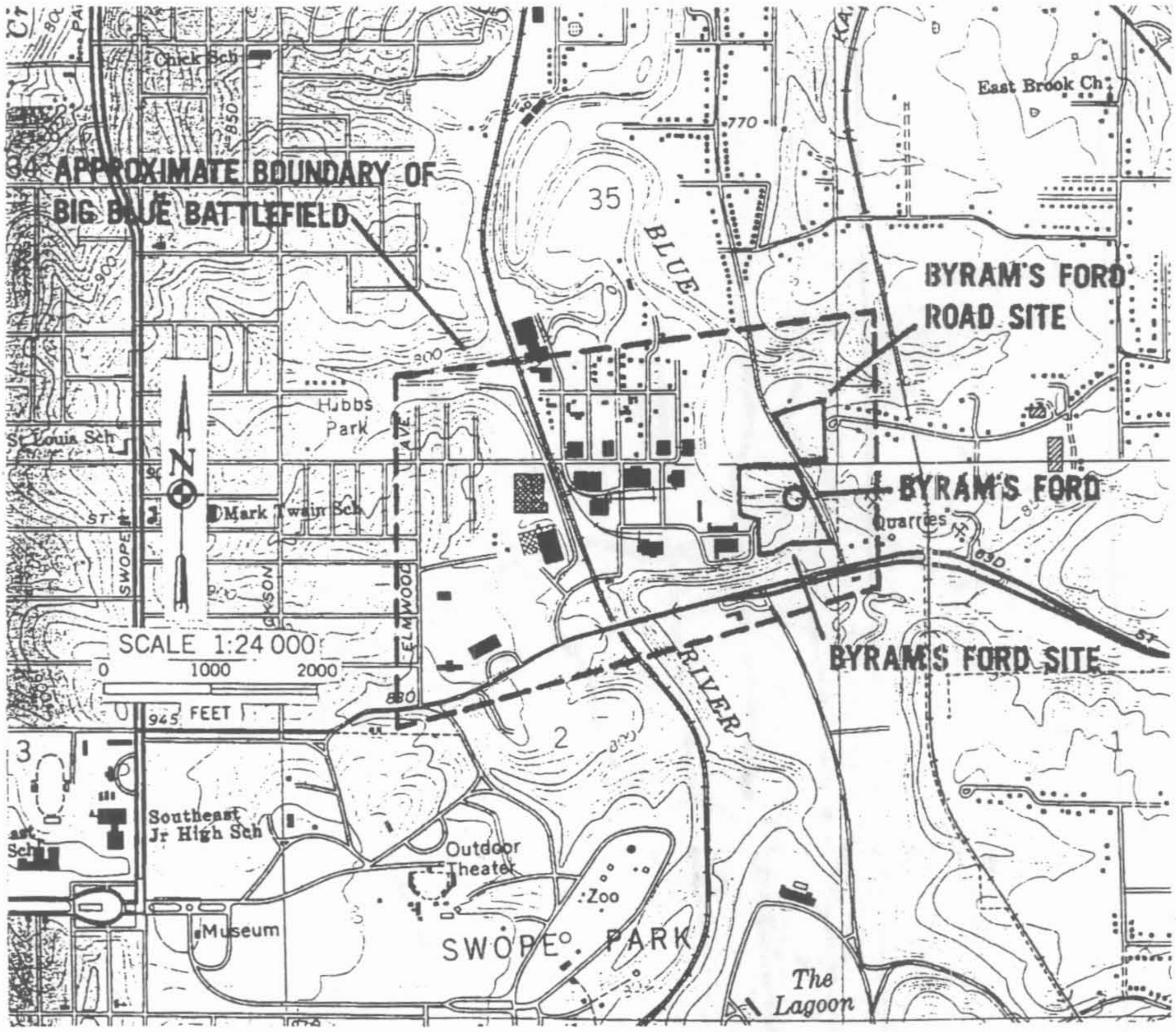

Figure 2. Location of Big Blue Battlefield and Byram's Ford Historic District

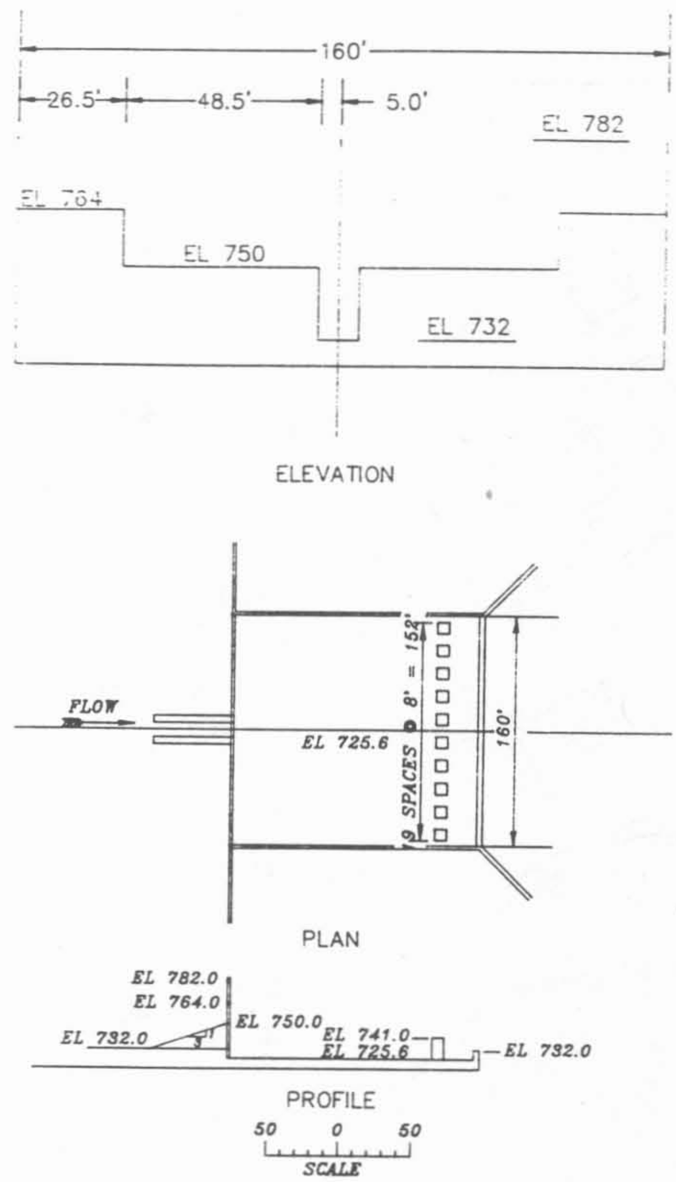

Figure 3. Type 1 (Original) Design

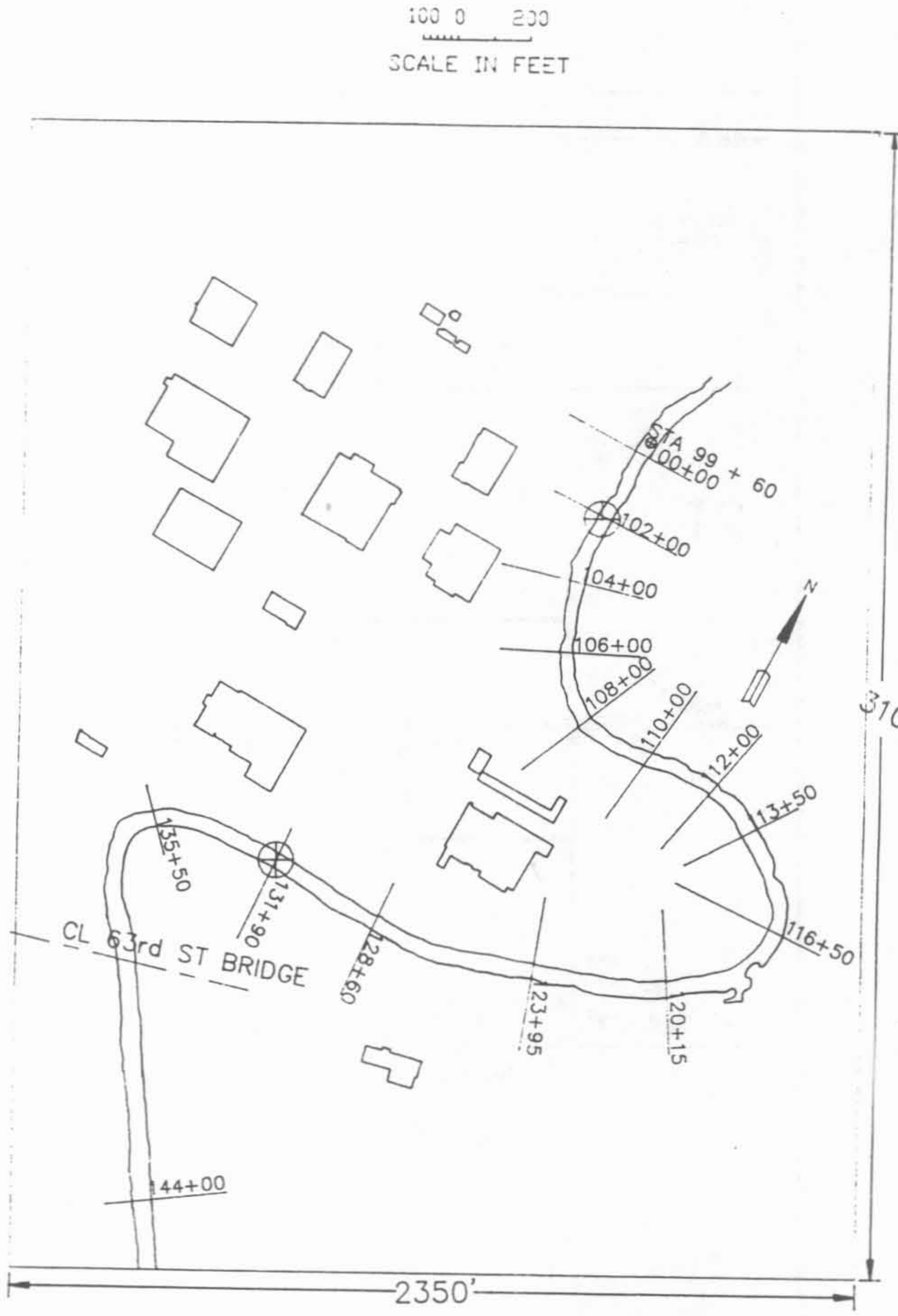

Figure 4. 1:36-scale Physical Model

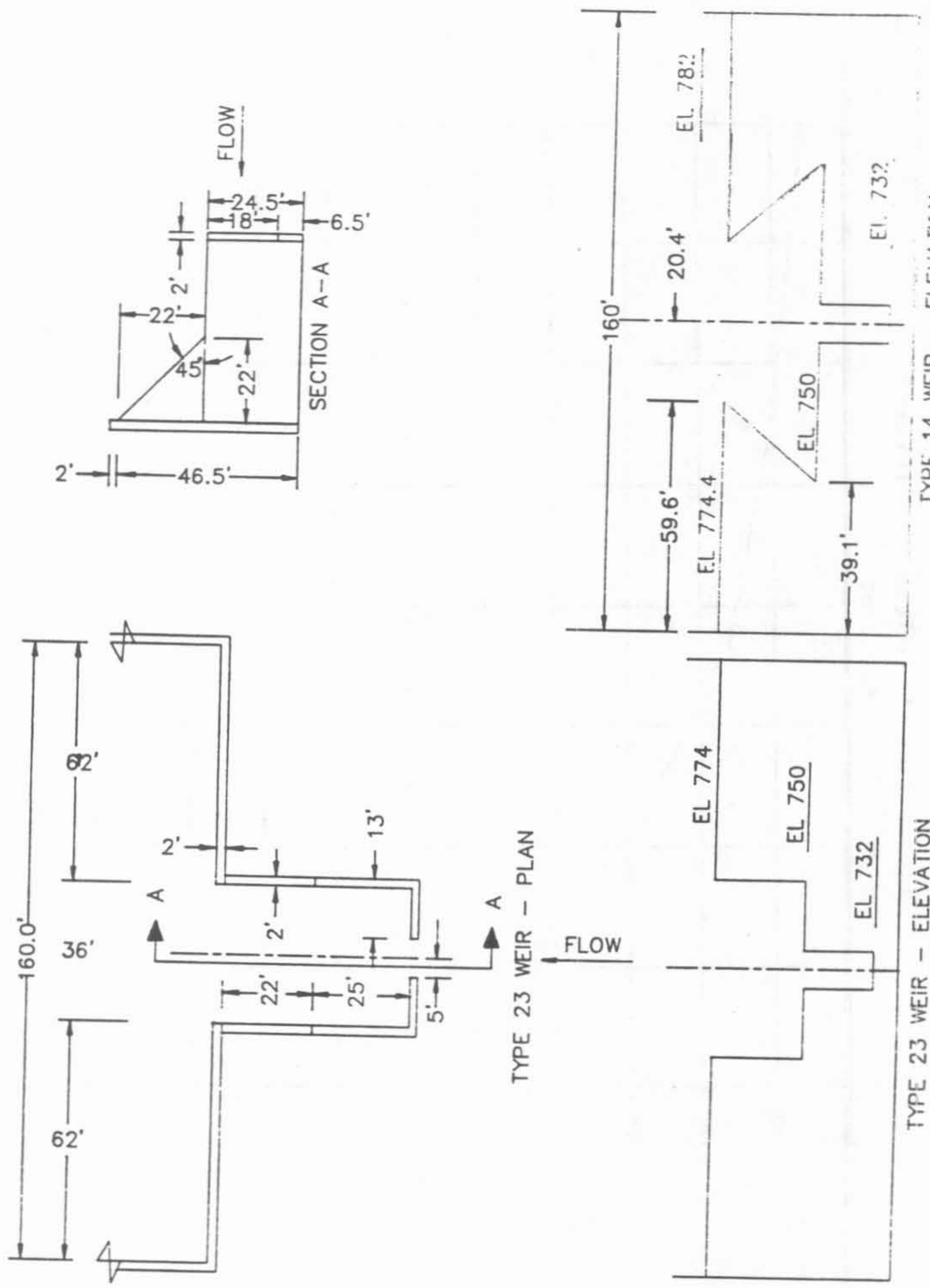

Figure 5. Type 14 and Type 23 Weir Designs

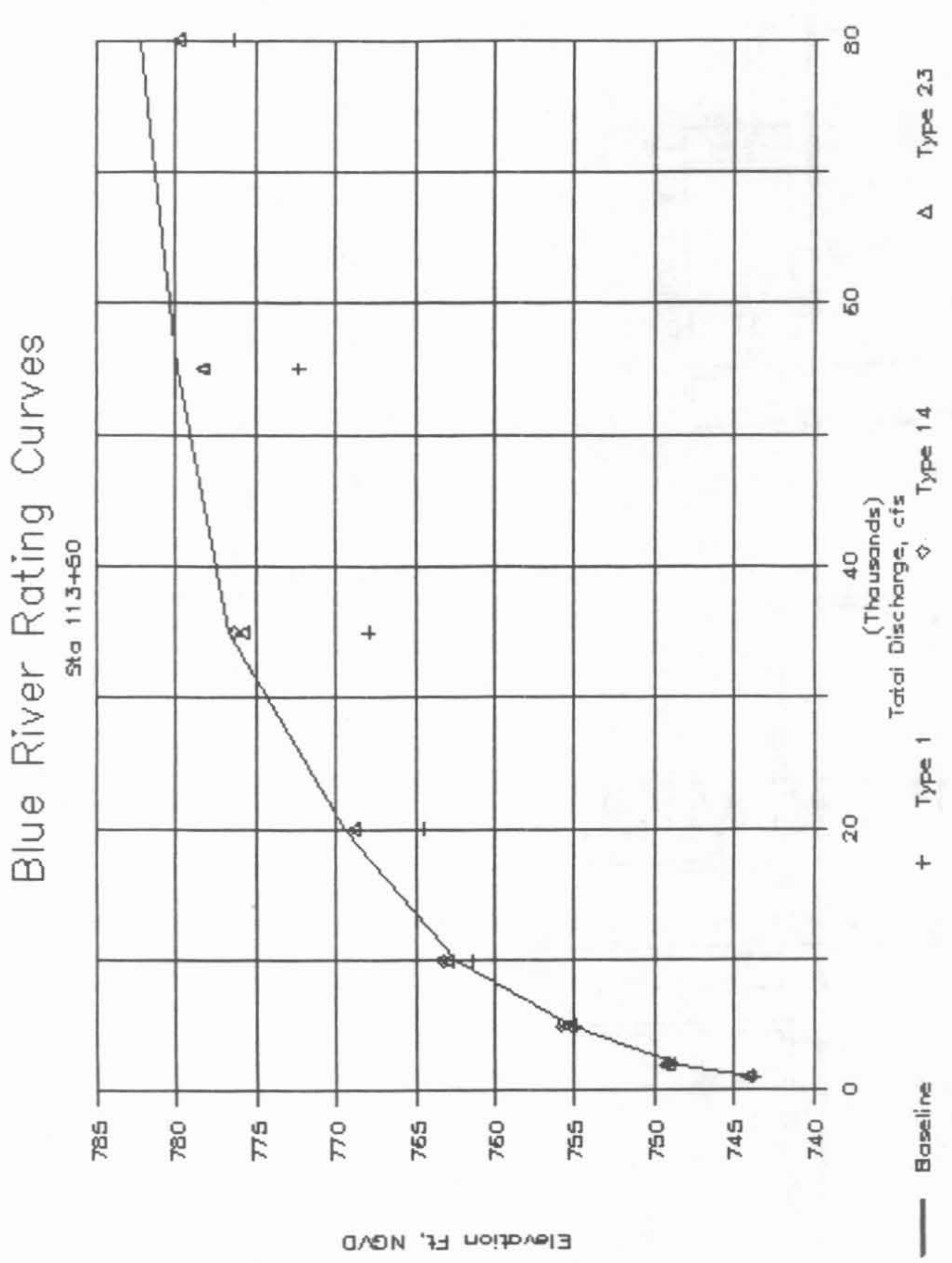

Figure 6. Rating Curve at Byram's Ford