University of Minnesota
St. Anthony Falls Hydraulic Laboratory

Project Report No. 206

ROCHESTER DROPSHAFTS

MODEL STUDIES

by

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and

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Conducted for

LOZIER-SEELYE-TONIAS, A JOINT VENTURE
Rochester, New York

and

HARZA ENGINEERING COMPANY
Chicago, Illinois

Sponsored by

ROCHESTER PURE WATERS DISTRICT
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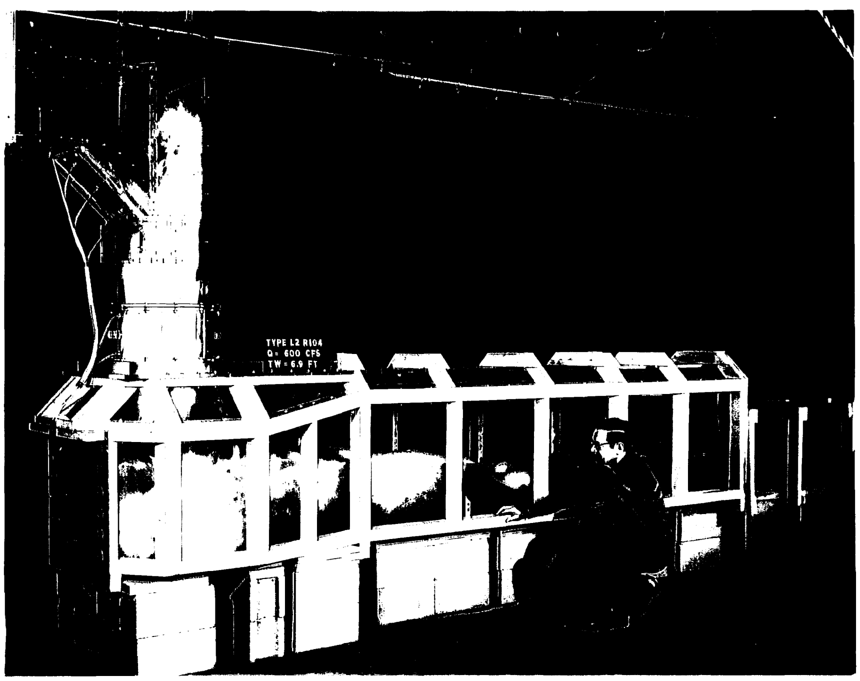
Frontispiece 1. Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 22 ft.
The final design.



Frontispiece 2. Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 6.9 ft.
The final design.

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PREFACE

Due to population growth and increasing industrialization in metropolitan areas, the problems of handling storm water and sanitary sewage have increased severely. One solution to the problem is the use of tunnels excavated or bored into rock layers beneath the ground surface for conveyance, storage, and purification of the storm water and sanitary sewage. The effluent is stored during periods when the capacity of the treatment plants is exceeded. It is subsequently pumped out or released from storage and treated as the demands on the plants diminish.

Each city has developed a solution unique to its particular problems and topographic features. The City of Rochester, New York, has developed the Combined Sewer Overflow Abatement Plan (CSOAP) as a solution to its problems. Conduits near the surface collect the storm water runoff and sewage and convey it to vertical dropshafts of various diameters. The water drops through shafts of various heights into a sump and deaeration chamber where energy is dissipated and entrained air removed. The air is returned to the surface through an air vent, and the water is conveyed at a reduced velocity through an exit conduit to the storage and conveyance tunnel.

Model studies were conducted previously at the St. Anthony Falls Hydraulic Laboratory on structures for the Culver-Goodman tunnel section, which is a part of the overall CSOAP project. One model study was concerned with the design of several dropshafts and another study with the design of a control structure. The purpose of the studies described in this report, "The Rochester Dropshafts Model Studies," was to develop the design for 40 dropshafts connecting surface conduits to a 26 mile long tunnel system located in the west side region of the CSOAP in Rochester, New York. Because the drop heights were relatively short (50 ft to 150 ft) and the rock cover inadequate, the sump and deaeration chamber height had to be minimized.

Features in this design which are different from previous designs are that the sump and deaeration chamber are lower in height, the deaeration is provided through a slotted false crown in the horizontal deaeration chamber, the air is returned above the false crown to the air vent side of the dropshaft, a vertically slotted weir is provided on the invert of the deaeration chamber for low-flow tailwater regulation to reduce impact pressures, and a bellmouth is located above the entrance to the exit conduit for better efficiency and reduced vorticity. The drop height is defined as the vertical distance between the invert of the dropshaft entrance conduit and the invert of the deaeration chamber. In structures with drop heights greater than 70 ft the pipe elbow type inlet is used, and for drop heights less than 70 ft the free trajectory inlet was developed to provide better jet dispersion. To study these problems and develop optimum designs for the 40 structures, two models were constructed at the St. Anthony Falls Hydraulic Laboratory.

The model tests described in this report were conducted for Lozier-Seelye-Tonais, A Joint Venture of Rochester, New York; and Harza Engineering Company of Chicago, Illinois. The model tests were sponsored by the Rochester Pure Waters District, Monroe County, New York, Department of Engineering. During the course of the model studies, several meetings were held at the St. Anthony Falls Hydraulic Laboratory and attended by representatives of the above organizations and the Laboratory. The models were demonstrated, various aspects of the project discussed, the various tests outlined, and the results reviewed.

Karl Nesbeitt, Senior Hydraulic Engineer, Harza, was the principal coordinator between the Laboratory and the above organizations. The study was under the immediate direction of Warren Dahlin, Scientist, and tests were conducted by Paul Rusk, Research Assistant. A silent-color motion picture summarizing the pertinent tests was prepared by Warren Dahlin and Karl Wikstrom. Various aspects of the project were reviewed by Joseph Wetzel, Assistant Director. This final report summarizes the results of the test program.

I. INTRODUCTION

The City of Rochester, New York, is developing the combined sewer overflow and abatement plan (CSOAP) to handle sanitary sewage and storm water. The West Side System contains 40 dropshafts with drop heights varying from 50 ft to 150 ft which are required to handle design discharges from about 150 to 900 cfs. The function of these dropshafts is to transport the water from one elevation and energy level to a lower elevation and energy level. Conduits near the ground surface collect the water and convey it to an elbow which deflects the water 90 degrees into the vertical shaft. The vertical shaft which has a slotted divider wall separating the falling water-air mixture and the released air returning to the surface, terminates in a sump. The sump is a large excavated and lined chamber. The water falling through the elbow and vertical shaft entrains considerable air and gains kinetic energy. The purpose of the sump and deaeration chamber is to dissipate some of the energy, to remove and collect the entrained air, and to direct the water at a reduced velocity into the exit conduit.

Because of the relatively low drops at many locations and the thin rock layers underneath the ground surface, hydraulically acceptable dropshaft designs developed in previous studies could not be used. The Rochester dropshafts model studies required the development of a new concept to fulfill the requirements. Through a series of model tests a hydraulically acceptable sump and deaeration chamber with a lower height was developed. Because of the lower height, air removal became a more serious problem. To provide for this, a false crown with air passages through it was positioned close to the top of the deaeration chamber.

The released air collected at the top of the deaeration chamber, passed through the air passages in the false crown to a chamber above, and then returned to the air vent in the vertical shaft. A portion of the rising air is drawn through the slots in the divider wall and re-entrained in the falling water with the excess air returning to the surface.

It is desirable to remove most of the entrained air from the water before it enters the tunnels. The entrapped air in the tunnels reduces the capacity for water storage and introduces the danger of high waterhammer head rise upon its sudden release which could cause damage to the system. The release of high velocity air at ground surface structures could also introduce hazards at these locations. The effectiveness of the sump and deaeration chamber in removing the entrained air was one factor considered in the evaluation of the various types tested.

For drop heights greater than about 70 ft, the pipe elbow type inlet was judged to be the optimum design, and a model with this inlet type was constructed to a scale of 1:12.52 as shown in Frontispiece No. 1. In structures with a drop height of less than about 70 ft, the overall height was lowered by eliminating the upper elbow, and providing a free-trajectory inlet. A model with this type of inlet was constructed to a scale of 1:8 as shown in Frontispiece 2. In both of these models the sump, deaeration chamber, and exit conduit were the same configuration. These models simulated a 12 ft diameter prototype dropshaft with a design discharge of 600 cfs and drops of 75.1 and 50.5 ft, respectively.

Another reason for constructing two models was to determine if any scale effects could be observed. To achieve more dispersion and air entrainment in the lower structures, the free-trajectory inlet was introduced and tested in the 1:8 model. By simply changing the scale of the 1:12.52 model to 1:14.61 and 1:8.35, this same model represented dropshafts of 14 and 8 ft diameters, with design discharges of 900 and 300 cfs, respectively. The purpose of the model studies was to evaluate the hydraulic performance of the initial designs, make any necessary revisions to develop optimum hydraulic designs, and stay within the geologic and economic constraints. Generally modifications were made, with limited documentation of each, to develop an optimum design. This consisted of visual observations and photographic documentation.

Photographic documentation included still photos, motion pictures, and color slides. This proved to be an excellent method of recording the overall hydraulic characteristics of the structures, and the air entrainment and release mechanisms. When an optimum design had evolved, more detailed observations were made, including the recording of static pressures or hydraulic gradelines, fluctuating pressures, air concentrations, water surface fluctuations, and energy spectrums.

In the prototype the tunnels will most likely be empty or will convey low discharges at the beginning of the storm and gradually fill, and in extreme storms they may fill completely. In the model, observations were made over the entire discharge range from a minimum flow to the maximum and a tailwater elevation range from uncontrolled to the maximum, at which time the system was flowing full and very little air entrained. The model was operated in a steady-state condition; that is, no flow or tailwater elevation changes were made during a particular test.

In both the prototype and the model, gravity is the predominant motion-producing force. For this type of system the greatest degree of dynamic similarity is obtained when the model-prototype relationships are established by the Froude law. The following expressions were used to convert dimensions and hydraulic quantities from model to prototype or vice versa. The letter L is the length in ft, Q the discharge in cfs, V the velocity in fps, P the pressure head in ft, T the time, and f the frequency. The subscripts m and p refer to model and prototype, respectively, and the subscript r denotes the ratio of model to prototype.

Quantity	Ratio	Scale Relation - Model:Prototype Prototype Dropshaft Diameter		
		12 ft	14 ft	8 ft
		Model Dropshaft Diameter = 11.5 in		
Length, L	$L_r = L_m/L_p$	1:12.52	1:14.61	1:8.35
Discharge, Q	$Q_r = L_r^{5/2}$	1:554.6	1:815.9	1:201.5
Velocity, V	$V_r = L_r^{1/2}$	1:3.538	1:3.822	1:2.890
Pressure, P	$P_r = L_r$	1:12.52	1:14.61	1:8.35
Time, T	$T_r = L_r^{1/2}$	1:3.538	1:3.822	1:2.890
Frequency, f	$f_r = 1/L_r^{1/2}$	1:0.2826	1:0.2616	1:0.3461
		Model Dropshaft Diameter = 18 in.		
Length, L	$L_r = L_m/L_p$	1:8.0	1:9.33	
Discharge, Q	$Q_r = L_r^{5/2}$	1:181.0	1:265.9	
Velocity, V	$V_r = L_r^{1/2}$	1:2.828	1:3.055	
Pressure, P	$P_r = L_r$	1:8.0	1:9.33	
Time, T	$T_r = L_r^{1/2}$	1:2.828	1:3.055	
Frequency, f	$f_r = 1/L_r^{1/2}$	1:0.3536	1:0.3273	

For example, in the 1:12.52 scale model, if the velocity is 1.0 fps, the corresponding velocity in the prototype will be 3.538 fps.

Complete similarity for the air entrainment and air removal processes cannot in general be obtained because the mechanism of entrainment, the size of bubbles, and the relative movement of the bubbles through the water are subject to forces other than gravity and depend more on such forces as surface tension and viscosity. However, the processes are qualitatively similar, and it is believed that the observations made in the model regarding the flow characteristics of the aerated mixture will be qualitatively correct. When the model indicates a large amount of air entrainment in the inlet and vertical shaft and effective air removal in the sump, the prototype behavior is expected to be similar, even though the quantities of air do not obey Froude law scaling.

II. CONCLUSIONS

A. Dropshafts Higher than about 70 Ft

Dimensions which are given below are for a dropshaft having a diameter of 12 ft and a design discharge of 600 cfs.

1. The optimum location for a single air inlet through the false crown is near the center of the deaeration chamber (Chart 1).

2. The divider wall extension is recommended for the final design.

3. Air slots through the false crown provide for more efficient air removal than one large air vent. Two ft air slots which satisfy both hydraulic and structural constraints are recommended.

4. The false crown in the deaeration chamber should extend the full length and not be blocked off.

5. The 4 ft radius bellmouth is an efficient inlet for the exit conduit and is recommended.

6. The use of appurtenances just upstream of the bellmouth to reduce the slight vorticity is not recommended. This vorticity occurs during a transitional stage when the tunnel system is full and the tailwater level is rising rapidly.

7. The incorporation of elbow or circumferential aerators is not recommended.

8. A 4 ft high slotted weir is recommended in the deaeration chamber to reduce the magnitude of fluctuating impact pressures at low tailwaters.

9. A 4 ft high stepped weir would become slippery and dangerous and is therefore not recommended.

10. The optimum design developed was type L2 R35 as shown on Chart 8 and is recommended as the final design. Hydraulically it is quite efficient and proved to be superior to previous designs, and also meets the economic and geologic constraints at the prototype sites.

11. Reducing the length of the deaeration chamber is not recommended.

12. Water surface fluctuations are mild and piezometric pressures are all positive and should be no problem in the structure.

13. Some fluctuating pressures do occur at critical locations on the divider wall, divider wall extension, crown, and sump invert and should be considered in the design.

14. Air concentration measurements indicate good dispersion of air near the bottom of the dropshaft.

15. By changing the model scale, the information obtained for the 12 ft diameter dropshaft can be interpolated and used in the design of 14 and 8 ft diameter dropshafts.

B. Dropshafts Lower than about 70 Ft

1. The optimum location for the transition is near the elbow as shown for Type L2 R100 on Charts 82 and 83. The Type L2 R101 with the transition moved upstream as shown on Chart 84 was also hydraulically acceptable, but for reasons of excavation and construction, it was decided that the optimum location was at the elbow.

2. The free-trajectory type inlet (Type L2 R102) shown on Chart 85 improves dispersion of air in the dropshaft and is recommended for the final design.

3. The elimination of the aeration box beneath the elbow (Type L2 R103) as shown on Chart 86 is recommended.

4. A 4 ft high weir in the deaeration chamber (Type L2 R104) as shown on Chart 87 is recommended to reduce the magnitude of impact pressures on the sump invert for low tailwaters. Some low pressure spikes still occur and should be considered in the design of the sump invert.

5. The Type L2 R104 as shown on Chart 87 is hydraulically acceptable and recommended for the final design.

III. DEVELOPMENT OF DROPSHAFTS HIGHER THAN ABOUT 70 FT

A. Description of Model

The initial geometry investigated was constructed according to Harza Engineering Company Drawing No. 1329 HYD 101M, dated January 6, 1981, and was designated as Type L2 R1 dropshaft. The dimensions and layout of this type are shown on Chart 1. The 1:12.52 model was fabricated from transparent lucite so that flow characteristics in the structure could be observed and photographed. The model components were fabricated in the Laboratory shop and assembled at the model site as shown in Photo 1. The components modeled were the 12 ft diameter entrance conduit, 12 ft diameter pipe elbow with an invert radius of 18 ft as shown in Photo 2, a 12 ft diameter dropshaft with a slotted divider wall, a sump 24 ft wide by 37.5 ft long, a deaeration chamber 12 ft wide by 80.5 ft long, and a 12 ft exit conduit. The sump and deaeration chamber are 22 ft high, and the drop height from invert to invert is 75.1 ft. The top of the false crown is 2.5 ft below the true crown.

The water supply for the models was obtained from the Mississippi River through the Laboratory supply system. The water was controlled by valves in the 12 inch supply line, and the discharge was measured by means of a calibrated 6 inch diameter orifice meter. The same meter was used for both models. To maintain the tailwater at prescribed elevations a butterfly valve was installed in the model outlet pipe. The butterfly valve was installed with its axis horizontal so that the valve plate opened at the crown of the tunnel. Thus, any air collecting at the crown would be swept out, simulating air movement in the prototype tunnel.

The design discharge for the 12 ft diameter prototype dropshaft was 600 cfs. Discharges observed in the model were 200, 400, 600, and 800 cfs. For each of these discharges the tailwater elevation was uncontrolled (tailwater valve wide open) and then maintained at the selected elevations of 10, 22, 30, 45, and 75 ft while observations and necessary documentation were made. The reference datum is El. 0.0 at the invert of the deaeration chamber.

For measuring pressures a number of pressure taps were drilled into the model at selected locations. Normally these taps would be connected by plastic tubes to a bank of piezometer tubes where the hydraulic gradelines would be observed. For measuring instantaneous pressure fluctuations a pressure transducer was connected to the desired tap. Two methods were used. At locations where the fluctuation frequencies were relatively high, a 25 psi Kulite transducer with a sensing area of 0.085 in. diameter was flush mounted and through an electrical circuit connected to a Tektronic T 912 storage oscilloscope where the fluctuations were displayed. The frequency response of the 25 psi Kulite transducer used was 10 kHz in air and flush mounted, and the Tektronic T 912 storage oscilloscope has a frequency response to at least 10 mHz. When the transducer was used in water as in the model, the frequency response would be somewhat lower. For convenience, in locations where the fluctuating frequencies are relatively low, a larger 25 psi CEC transducer with a sensing area of about 0.5 in. diameter was mounted in a lucite block and connected to a tap with a short, small diameter tube. The output was transmitted to a Sanborn amplifier and strip chart recorder which utilized a thermo pen to trace the record on heat sensitive paper.

The frequency response of the 25 psi CEC pressure transducer used was 5-10 kHz in air and flush mounted, the Sanborn amplifier 600 Hz, and the thermo pen 125 Hz for one-half scale deflection. When the transducer was used in water and chamber mounted as in the model, the frequency response would be lower, but by keeping the chamber and pressure line small, the transducer frequency response should be higher than the response of the amplifier.

At critical locations spectral analysis was made to determine loading frequencies for use in developing structural designs. A flush mounted 25 psi Kulite transducer was installed and connected to a Nicolet 444A computing spectrum analyzer which gave a spectrum display of frequency versus energy. The frequency response of the transducer was 10 kHz, and the spectrum analyzer has an adjustable frequency range up to 100 kHz.

Air concentration measurements in the models were made with an electrical instrument previously developed at the Laboratory for measuring air concentrations in percent by volume in flowing air-water mixtures. A plastic rod supporting a pair of electrical probes was inserted through ports into the dropshaft so that measurements could be made, not at a point, but in a small region of the flow. The probe was connected to an electrical circuit and read-out meter. The method consists basically of measuring the difference between the conductivity of a mixture of air and water and water alone.

B. Development of Optimized Structure

The original model was constructed according to the plans on Chart 1 and designated as Type L2 R1 dropshaft. This model is shown in operation in Photos 3 and 4 with the design discharge of 600 cfs and tailwater elevations of 7.1 and 22 ft, respectively. Through a series of 37 revisions which are sketched on Charts 2-7, an optimized structure with good hydraulic characteristics was developed. The recommended final design is outlined in detail on Chart 8 and shown in operation in Frontispiece 1. The revisions leading up to the final design are discussed below.

1. Alternate Air Vents

The original model (Type L2 R1) as shown on Charts 1 and 2 had alternate air vent 1 open near the middle of the deaeration chamber. The air vent was the full 12 ft width of the chamber and 10 ft long. With the air vent in this location, the collected air passed through the vent in a reasonable manner, although some of the air which passed by the vent was drawn into the exit conduit. The air entered the chamber above the false crown in strong spurts and some surging took place. This is shown in Photo 4 with a flow of 600 cfs and tailwater elevation of 22 ft, which is the elevation of the deaeration chamber crown. Observations were also made with the 10 ft long air vent at location 2 (Type L2 R2) at the upstream end of the deaeration chamber and location 3 (Type L2 R3) near the downstream end as shown on Chart 2. With the air vent in position 2, considerable air passed by the vent as shown in Photo 5; some returned and escaped through the vent, but most of the air was drawn into the exit conduit. With the air vent in position 3, considerable turbulence and a pumping action occurred at the vent, resulting in air being drawn into the exit conduit (Photo 6). Observations were made with both air vents 1 and 3 open (Type L2 R4). This was not acceptable as the water-air mixture passed up through vent 1, through the air chamber, down through vent 3, and into the exit conduit. Observations showed that the air was released most efficiently with the air vent in location 1 (Type L2 R1), although some improvements were needed in this design. In Type L2 R5, a divider wall extension was installed as shown on Chart 2. In previous model studies it was shown that this extension effectively contained the falling water from the dropshaft, resulting in somewhat better air release in the sump and deaeration chamber (Photo 7).

In Type L2 R6 and L2 R7, the false crown downstream of the air vent was removed and a cut-off wall placed at the downstream end of the slot (Chart 2). This resulted in considerably more turbulence at the downstream end of the deaeration chamber, and comparatively more air was drawn into the exit conduit, as shown in Photo 8. Also, the surges above the false crown towards the air vent became stronger. Because of these adverse effects, it was decided to keep the false crown the full length of the deaeration chamber.

2. One Foot Air Slots

In the tests with the 10 ft long air vent, it was observed that the air passed through the vent in strong spurts and mostly at the upstream end. This caused surging in the chamber above the false crown, and it was felt that the spurts could erode the crown. To reduce this action, a series of ten 1 ft slots spaced 1 ft apart were installed at the Alternate 1 location as shown in the sketch of Type L2 R8 on Chart 2. This did reduce the intensity of the air spurts through the false crown and the surging in the chamber above. Some air was carried downstream past the slots and collected below the false crown. As the volume and pressure of this air increased, some air was forced back to the slots, but most of it entered the exit conduit. In an attempt to improve the performance, a cut-off wall and air vent pipe was installed as indicated in the sketch of Type L2 R9 on Chart 3. Observations showed this revision to be ineffective. Next, five more 1 ft slots were added downstream of the others for a total of fifteen 1 ft slots as shown for Type L2 R10 on Chart 3. Observations showed this arrangement to be quite effective as shown in Photo 9. Although more air passed through the upstream slots than the downstream slots, all the slots were used for effective air passage. The downstream slots were sufficiently close to the end of the chamber so that air collected there built up and returned to the last slot, thus escaping to the chamber above the false crown. Very little air entered the exit conduit as shown in Photo 9. This slot geometry was quite effective hydraulically and was recommended for the final design. The need for the dead-end chamber above the false crown and downstream of the slots was questioned so a cut-off wall was placed as shown for Type L2 R11 on Chart 3. This addition caused an increase in surging above the false crown, and a pumping action occurred at the cut-off wall which caused an increase in air entering the exit conduit. The cut-off wall is therefore not recommended. Although the dead-end chamber may require some cleaning of debris, it is beneficial to the efficient operation of the structure and should be retained in the final design.

3. Entrance to Exit Conduit

All of the above model types have a sharp edged entrance to the exit conduit and observations showed that some slight vorticity occurred in that area when the tailwater elevation was about 16 to 22 ft, and a zone of separation occurred in the exit conduit for all tailwater elevations above 12 ft as shown in Photo 10. This separation indicates an inefficient entrance and the need for improvements in this area. Several appurtenances were tested in the entrance area including 1 by 1 ft roughness strips on the end wall (Type L2 R12), a 2 ft radius bellmouth over the entrance (Type L2 R13), a 4 ft radius bellmouth over the entrance (Type L2 R14), a 4 ft radius cylindrical surface over the entrance (Type L2 R15), and a flat plate at a 45 degree angle over the entrance (Type L2 R16). All of these types are shown on Charts 3 and 4. Most of these showed little or no improvement in the flow characteristics with the exception of the 4 ft radius bellmouth (Type L2 R14) which proved to be an efficient entrance to the exit conduit. Photo 11 shows the model in operation with the design discharge of 600 cfs and the tailwater elevation at 16 ft with the sharp edged entrance. The zone of separation is quite apparent. The 4 ft radius bellmouth is shown outside of the model in Photo 11. When the bellmouth is placed over the entrance in the model, the improvement is quite evident as seen in Photo 12. The 4 ft radius bellmouth (Type L2 R14) was recommended for the final design. The hydraulic characteristics of this type are shown in Photos 13 and 14. A slight vorticity still occurred occasionally in the tailwater range from 16 to 22 ft and may be seen on the left side of the deaeration chamber in Photo 12 but was not considered a serious problem. This vorticity could be reduced or practically eliminated by the use of roughness in the area just upstream of the bellmouth entrance. Appurtenances tested in this area are shown in the sketches for dropshaft Types L2 R17 - L2 R23 on Chart 5. The most effective device was the perforated screens (Type L2 R22) which practically eliminated the vorticity. In discussions with the designing engineers, it was decided that the benefit derived from the use of the screens did not warrant the additional cost involved. Also, the screens would be subject to clogging and were not recommended for the final design.

4. Elbow and Circumferential Aerators

The use of aerators in dropshafts higher than about 70 ft was considered to improve dispersion and entrain additional air. Two locations for the aerators were investigated in the model. One location was in the elbow itself and the other in the vertical shaft immediately downstream of the elbow.

Three geometries of elbow aerators with heights of 0.5 ft (Type L2 R24), 1.0 ft (Type L2 R25), and 1.5 ft (Type L2 R26) were individually placed in the upper pipe elbow at the location shown on Chart 6 and the flow patterns were observed and compared. Photo 15 shows the flow pattern in the elbow, vertical shaft and sump with the 1.0 ft high elbow aerator in place (Type L2 R25) and may be compared to Photo 13. With the elbow aerator in place (Photo 15) it appears that more air may be entrained in the elbow but the dispersion in the vertical shaft does not appear as complete. Without the elbow aerator (Photo 13) the flow follows the elbow invert smoothly and disperses reasonably well in the vertical shaft.

Three geometries of circumferential aerators with heights of 0.5 ft (Type L2 R27), 1.0 ft (Type L2 R28), and 1.5 ft (Type L2 R29) are individually placed at the top of the vertical shaft at the location shown on Chart 6, and the flow patterns observed and compared. Photo 16 shows the flow pattern with a circumferential aerator with a height of 1.0 ft (Type L2 R28) in place and which may be compared to Photo 15 (1.0 ft high elbow aerator) and Photo 13 (no aerators). With the circumferential aerator in place, the flow pattern in Photo 16 shows poor dispersion in the vertical shaft as the falling jet is concentrated along the slotted divider wall down to the bottom of the shaft. The dispersion of the jet then has to take place in the sump, and the vertical shaft is not utilized.

It appears that the use of aerators may increase somewhat the quantity of air entrained, but dispersion in the vertical shaft seems poorer and results in undesirable flow patterns. The use of aerators for higher drop structures was rejected.

5. Two Foot Air Slots

Although the 1 ft slots spaced 1 ft apart performed well from the hydraulic point of view, structural engineers anticipated difficulty in constructing the 1 ft slots in the prototype. Consequently, they proposed 2 ft slots with a 2 ft spacing. The model was revised by replacing the fifteen 1 ft slots spaced 1 ft, with seven 2 ft slots spaced 2 ft apart. Initially the slots had square edges (Type L2 R30) but were later revised so that the upstream lower edges of the slots had a 0.5 ft radius (Type L2 R32). The flow pattern in the deaeration chamber with 2 ft slots is shown in Photo 17 and may be compared to Photo 14 which shows the pattern with the 1 ft slots. There appears to be little significant difference between the two flow patterns; the 2 ft slots pass the released air about as efficiently as the 1 ft slots. Therefore, the 2 ft slots were hydraulically acceptable and recommended for the final design.

6. Weirs

The invert of the sump is subjected to considerable impact and sometimes cavitating pressures by the falling water-air mixture from the vertical shaft. In past model studies, the use of weirs to create pools of water in the impact area and thus reduce the magnitude of impact pressures, has proven to be effective. The use of weirs was also investigated in this study. Two weir locations were selected for the studies. One was at the junction of the sump and deaeration chamber, and weir heights of 4 ft (Type L2 R33) and 8 ft (Type L2 R34) were investigated. The other location was 20 ft downstream of the junction, and again weir heights of 4 ft (Type L2 R35) and 8 ft (Type L2 R36) were investigated. These types are sketched on Chart 7. Studies were made and the results indicated that the optimum location was 20 ft downstream from the sump and deaeration chamber junction, and the optimum height was 4 ft.

With the weir at the junction, the high velocity flow carried considerable quantities of entrained air over the weir, and the air was kept entrained for a considerable distance into the deaeration chamber as shown in Photo 18. With the 4 ft weir 20 ft downstream in the deaeration chamber, most of the air was released before reaching the weir and was less of a problem for removal as shown in Photo 19. If the weir height was raised to 8 ft as shown in Photo 20, the flow over the weir seemed to keep more air entrained. At higher tailwater elevations, the 8 ft weir tended to have an undesirable choking effect on the flow. Although the 8 ft weir would reduce impact pressures more than the 4 ft weir, the 4 ft weir was selected for inclusion in the final design because of this choking effect. A 4 ft high stepped weir as shown for Type L2 R37 on Chart 7 was suggested to allow easy passage for workmen. This weir was examined briefly and was hydraulically acceptable. It was later rejected on the basis that steps would become extremely slippery and dangerous.

7. The Final Design

The final design for dropshafts greater than about 70 ft that evolved from the extensive model studies is presented on Chart 8. This design is quite effective in energy dissipation and deaeration, is hydraulically acceptable, and meets the geologic and economic constraints at the prototype sites. The geometric features added to the original design were the divider wall extension, the slotted weir, the slots in the false crown, and the bellmouth over the entrance to the exit conduit. It was judged that seven 2 ft slots spaced 2 ft apart were the optimum design for air passage, and therefore were included in the final design.

Photos 21 through 30 are a series of photos showing the hydraulic characteristics of the final design for the design discharge of 600 cfs and tailwater elevations of 7.1 (uncontrolled), 10, 22, 30, 45, and 75 ft. Close-up views of the elbow are shown in Photo 22 for a tailwater of 7.1 ft and Photo 30 for a tailwater of 75 ft. Photos 24 through 26 show the effectiveness of the sump and deaeration chamber in removing the entrained air for a tailwater elevation of 22 ft. At higher tailwater less air is entrained and removal is less of a problem as shown in Photos 27 through

30. For lower discharges such as 400 cfs shown in Photos 31 and 32, less air is entrained and removal is no problem. For higher discharges up to 800 cfs, which is 200 cfs more than the design discharge, considerably more air is entrained as shown in Photos 33 and 34, but the air removal is still fairly efficient.

8. Reducing the Length of the Deaeration Chamber

The initial model program included tests on a structure with the deaeration chamber shortened 30 ft. The model was fabricated with a 30 ft removable section at the downstream end of the deaeration chamber as shown in Photo 26. This section was to be removed and replaced with a section of exit conduit. In operating the model it was observed that an occasional burst of air bubbles similar to those occurring in Photos 24 through 26 was carried downstream a distance of 30 ft from the end of the deaeration chamber and was sufficiently deep to enter the exit conduit, if the exit conduit started at that location. Therefore it was decided that the deaeration chamber should not be shortened. Physically shortening of the deaeration chamber in the model was eliminated from the test program.

C. Water Surface Fluctuations

To provide information for the design of the slotted divider wall between the falling water-air mixture in the vertical shaft and the air rising in the air vent, water surface fluctuations were observed in the Type L2 R32 dropshaft. Observations were made for discharges from 200 through 800 cfs and tailwater elevations from uncontrolled up to 75 ft. This information is presented on Charts 9 through 16. On each chart the fluctuations are shown for both the dropshaft side and the air vent side of the wall. The hatched area is the visually observed range of general surging, and the x's are visually observed individual maximum and minimum readings. If none are shown as on Charts 9 and 10, then no individual readings beyond the general surging were observed. For both an uncontrolled tailwater and a tailwater elevation of 10 ft, no fluctuations are shown for the air vent as the water does not enter the vent until the tailwater elevation reaches about 22 ft. For example, with the design discharge of 600 cfs and uncontrolled tailwater of 7.1 ft, the surging on the dropshaft side varied from El. 9 to 16 ft on the dropshaft side with nothing on the air vent side as shown on Chart 13. For a tailwater elevation of 22 ft, the fluctuations on the dropshaft side varied from El. 22 to 32 ft and from El. 20 to 35 ft on the air vent side (Chart 13). The water surface was not consistently higher on one side of the divider wall than on the other side, and long period oscillations were noted, but could be the reverse for a period of time. It could be at El. 32 ft on the dropshaft side and El. 20 ft on the air vent side for a differential of 12 ft; or it could be El. 22 ft in the dropshaft and El. 35 ft in the air vent for a differential of 13 ft on the opposite side. For 600 cfs and a tailwater elevation of 30 ft, the maximum range in the dropshaft side was from El. 28 to 42 ft and El. 25 to 45 ft in the air vent (Chart 14). This would result in a maximum head differential of 17 ft in either direction. For 600 cfs and a tailwater elevation of 45 ft the observed maximum range was from El. 47 to 58 ft in the dropshaft and El. 50 to 64 ft in the air vent for maximum differentials of 17 and 8 ft

(Chart 14). At a tailwater elevation of 75 ft very little surging took place (Chart 14). For lower flows of 200 and 400 cfs the water surface fluctuations were somewhat less as shown on Charts 9 through 12. For a higher flow of 800 cfs, the water surface fluctuations were somewhat higher as indicated on Charts 15 and 16. Maximum differentials observed were 19, 17, and 23 ft for tailwater elevations of 20, 30, and 45 ft, respectively.

D. Piezometric Pressures

Piezometric pressures or hydraulic gradelines were recorded for Type L2 R32 and presented on Charts 17 through 20 and Type L2 R35 and presented on Charts 21 through 24. Type L2 R35 is the final design and includes the 4 ft high slotted weir; whereas, Type L2 R32 is the same except it has no weir. On all these graphs, the abscissa is the distance along the taps in feet, and the ordinate is elevation in feet. The base line shows the tap number and distance locations. A better perspective of the tap locations may be seen on Chart 8. The piezometric pressures or hydraulic gradelines were recorded from the bank of piezometer tubes on the manometer board for discharges of 200, 400, 600 (design flow), and 800 cfs; and for tailwater elevations of uncontrolled, 10, 22, 30, 45, and 75 ft. The pressures plot in a consistent manner and all pressures were positive for both dropshaft types. Slight variations occur between the two types. On Charts 21 through 24 for Type L2 R35 which has the slotted weir, the effect of the weir can be seen in the pressures for Taps 27 through 32 for the uncontrolled tailwater condition and each discharge. This is caused by the increase in velocity over the weir and the resultant lower depths of flow over the weir and immediately downstream. This effect is essentially drowned out at the 10 ft tailwater elevation. The effect of the weir on the piezometric or average pressures in the impact area under the dropshaft are not readily apparent and no definite trend can be noticed. The beneficial effects of the weir are more apparent in the pressure fluctuation studies presented in the following section.

E. Fluctuating Pressures

Two methods of measuring pressure fluctuations were used as described earlier in Section III-A. The Kulite transducer with a sensing area of 0.085 inch diameter was flush mounted at locations where higher fluctuations and higher frequencies were expected. The normal procedure was to store the pressure fluctuation record on the screen of the storage oscilloscope for one minute and photograph it. It was observed that some higher frequency fluctuations were not stored on the screen, and it was decided that they should be recorded and documented in some manner. To accomplish this, the screen was visually watched continually for a period of time, generally 5 minutes, and the magnitude of the individual spikes estimated and recorded. This was done separately for both maximum and minimum spikes.

Pressure fluctuation data were needed for structural design purposes. Tap locations were installed in areas of anticipated high fluctuations. Tap 45 is located in the divider wall at the upstream end of the air chamber above the false crown (Chart 8). In this area the surging water-air mixture is deflected 90 degrees into the vertical air shaft and thought to be a critical area. Observations were made on Type L2 R14 (1 ft slots) and Type L2 R32 (2 ft slots) for the design discharge of 600 cfs and tailwater elevations of 22, 30, 45, and 75 ft and presented on Charts 25 through 28. The hatched areas are the ranges from oscilloscope photos for a model time record of 1 minute. The x's are visually observed maximum and minimum readings not recorded on the oscilloscope and generally observed for a model time of 5 minutes. The horizontal time scales shown are for these visually observed readings. A summary of typical pressure fluctuations is tabulated on Chart 29 showing the maximum and minimum range from the photos and the maximum and minimum visually observed readings. There is no significant difference in the data for Type L2 R14 (1 ft slots) and Type L2 R32 (2 ft slots). For example, with the tailwater at 22 ft, for Type L2 R14 the range is 40 to 14 ft and the observed maximum and minimum readings are 60 and 14 ft. For Type L2 R32 the range is 38 to 16 ft and observed maximum and minimum readings are 60 and 16 ft. As the tap is at El. 23 ft, these minimum readings result in negative pressure heads of -9 and -7 ft. Some larger differences in the minimum observed readings are noted for tailwaters of 30 and 45 ft, but this includes only 2 readings to El. 10 ft and 1 reading to El. 20 ft, respectively. These readings result in negative pressure heads of -13 and -3 ft, but occur infrequently.

Observations were made on Type L2 R14 at tap location 46 which is located on the bottom side of the false crown (El. 18.5 ft) and just upstream of the slots (Chart 8). Fluctuations were recorded for a flow of 600 cfs and tailwater elevations from 22 to 75 ft as shown on Chart 30. For a tailwater elevation of 22 ft the range is 32 to 12 ft with a maximum reading of El. 36 in a 2 minute period. The minimum range to El. 12 ft is a negative pressure head of -6.5 ft. For other tailwater elevations, the ranges are shown on Chart 30 and no readings were observed outside of these ranges.

Another critical area is on the true crown of the deaeration chamber above the first upstream slot through the false crown. In Type L2 R32, Tap 47 was installed at this location as shown on Chart 8. Measurements were made for flows of 400 and 600 cfs and tailwater elevations of 22, 30, 45 and 75 ft as shown on Charts 31 through 34. Chart 35 gives a summary of the data for Tap 47. For both flows of 400 and 600 cfs and a tailwater elevation of 22 ft, the range from the photos was from El. 48 to 16 ft with visually observed spikes up to El. 80 ft and down to El. -4 ft. This is a negative pressure head of -26 ft which is close to the cavitating pressure head of about -34 ft. For 600 cfs and a tailwater elevation of 30 ft, spikes to El. 10 ft were observed or a negative pressure head of -12 ft. The observed peaks vary from El. 80 to 88 ft for 600 cfs, and from El. 70 to 80 ft for 400 cfs.

The divider wall extension is another critical component of the structure as it is subjected to the falling water-air mixture down the dropshaft. To investigate the pressures in Type L2 R35, Tap 48 was installed in the extension as shown on Chart 8. Measurements were made for discharges from 200 to 800 cfs and tailwater elevations from uncontrolled to 75 ft. Chart 36 and 37 show photos taken of the stored pressure fluctuation records on the oscilloscope screen for a flow fo 600 cfs. The trace was set to sweep across the scope in 1 second, fly back, and start again. Each succeeding trace was superimposed over the past record until a model time record of 1 minute was reached and the recording stopped. The envelop on the photos is the stored record of all the traces and the lighter narrow trace is the last individual sweep. Charts 38 through 40 show the approximate range taken from the oscilloscope photos of Charts 36 and 37 and also the visually observed readings if they occurred. Charts 41 and 42 show the oscilloscope photos for 200 cfs and tailwater elevations from 3.7 to 75 ft, and Chart 43 the range and visually observed readings for the critical tailwater elevations of 3.7 and 10 ft. The records for discharges of 400 and 800 cfs are not presented, but the complete summary for all flows and tailwaters is presented on Chart 44. Maximum peaks to El. 200 ft occurred for a flow of 200 cfs. For a 600 cfs flow the maximum peaks varied from El. 100 to 114 ft. Minimum spikes to cavitation pressures occurred for all flows with the lowest spikes down to El. -40 ft occurring for flows of 600 and 800 cfs. This is a negative pressure head of -56 ft. This is scaled from the model values by multiplying by the length ratio. Actually in the prototype these values would not occur because when the negative pressure heads approach -34 ft cavitation would occur.

The most critical area for fluctuating pressures is probably the impact area on the sump invert beneath the dropshaft. Taps 17, and 19 through 21, were installed in this area as shown on Chart 8. The pressures at Tap 20 at the junction of the dropshaft centerline and the centerline of the sump and deaeration chamber were investigated first and these pressures were particularly interesting because they showed the desirable effect of the 4 ft high slotted weir. Measurements were made on Type L2 R32 (without weir) and Type L2 R35 (with 4 ft weir) for the design discharge of 600 cfs and tailwater elevations from 7.1 to 75 ft. The results for Type L2 R32 are presented on Charts 45 through 50 and for Type L2 R35 on Charts 51 through 55. For Type L2 R35, discharges of 200, 400 and 800 cfs were also used and pressure recorded at Tap 20 (Charts 56 through 61). A summary of typical pressure fluctuations at Tap 20 is presented on Chart 62.

In comparing the data for Type L2 R32 (no weir) and Type L2 R35 (4 ft weir) a noticeable reduction in the amplitude of the pressure fluctuations is evident. This may be seen by comparing Charts 47 and 53. For a flow of 600 cfs and tailwater of 7.1 ft, Type L2 R32 had a range from El. 115 to 5 ft and maximum and minimum spikes to El. 170 ft and El. -30 ft, as compared to Type L2 R35 which had a range from El. 96 to 4 ft and maximum and minimum spikes to El. 124 ft and El. -10 ft. This is a considerable reduction in both the range of the fluctuations and the maximum and minimum spikes observed as shown on Charts 47 and 53. Even at higher tailwaters a slight reduction in the magnitude of the pressure fluctuations is noticeable.

The elevation of Tap 20 is 0 ft. For Type L2 R32 at 600 cfs, the minimum spike to El. -30 ft or a negative pressure head of -30 ft is close to cavitation, and for Type L2 R35 the negative pressure head reaches -10 ft. Even with the 4 ft weir in place (Type L2 R35) spikes reach to El. -30 ft or a negative pressure head of -30 ft for lower flows of 200 and 400 cfs and low tailwaters as shown on Chart 62.

If the system is empty when the flow starts, the initial jet of water can cause much higher pressure spikes. For example, those shown on the top record of Chart 50 reached El. 160 ft, as compared to a steady-state flow condition shown on the bottom of Chart 45. The record on the bottom of Chart 50 shows spikes up to El. 220 ft occurring when the flow is turned off rapidly. The records on Chart 50 are for Type L2 R32 which has no weir. With the weir in place (Type L2 R35) these extreme spikes will occur over a much shorter period of time as the pool formed by the weir will fill much quicker than the entire system.

Pressure fluctuation measurements were also made at Taps 17, 19, and 21 in the impact area for Type L2 R35 (Chart 8). These data are presented on Charts 63 through 69 for a flow of 600 cfs. At Tap 17 for a tailwater elevation of 7.1 ft, the range was from El. 116 to 6 ft with maximum and minimum spikes to El. 138 ft and -20 ft (Chart 69) which are somewhat greater than for Tap 20. At Tap 19 the range was from El. 48 to -8 ft with spikes to El. 70 ft and El. -16 ft. At Tap 21 the range was from El. 26 to -4 ft with spikes to El. 36 ft and El.-16 ft.

Although the weir may cause inconveniences for access in the prototype, the beneficial effects of the weir would seem to outweigh these inconveniences, and the weir is recommended for inclusion in the final design.

In areas where the pressure fluctuations and frequencies were expected to be lower, the chamber mounted CEC transducer and Sanborn strip recorder were used. A survey was made of pressure fluctuations in the elbow (Taps 6 and 7), the dropshaft (Taps 9 and 11), the sump outside of the high impact area beneath the dropshaft (Taps 13, 15, 16, 18, 22, 23, and 25), the deaeration chamber (Taps 27 and 29), and the exit conduit (Tap 33). The locations are shown in Chart 8. Records of pressure fluctuations taken at these taps for Type L2 R35 and the design discharge of 600 cfs are presented on Charts 70 through 76 and a summary of this data on Chart 77. At most of these locations the fluctuations and surging are minimal. Some fluctuations were observed in the dropshaft at Taps 9 and 11 as shown on Chart 71 when the tailwater was at El. 45 ft, which is close to the tap elevation. Also at Taps 16, 18, 22, and 23, which are near the impact area beneath the dropshaft, some fluctuations were observed, as shown on Charts 73 and 74. Pressure fluctuations in areas other than the critical impact areas appear minimal and should be of no major structural concern.

F. Air Concentrations

Air concentration measurements were made in the dropshaft for Type L2 R35 at Taps 37 through 44 (Chart 8) using the resistance type probe described earlier. Chart 78 shows air concentrations measured for a flow of 600 cfs and tailwater elevation of 7.1 ft and the values are given in percent air by volume. The percent air is

$$K = \left(\frac{v_A}{v_A + v_W} \right) \times 100 ,$$

where v denotes volume. Although these readings are for a tailwater elevation of 7.1 ft, they would not change until the tailwater elevation was above 22 ft and backing up into the dropshaft. The air vent contains 100 percent air. In the dropshaft at Tap 37 the air content varies from 10 percent at the upstream wall to 95 percent at the divider wall, which indicates incomplete mixing at the top of the dropshaft. As the water-air mixture falls down the shaft, dispersion takes place so that at the bottom of the shaft at Tap 40 the mixture is fairly homogeneous with percentages varying from 60 to 84 percent. When the tailwater was raised to El. 45 ft (between Tap 37 and 38), the overall air content was reduced as shown on Chart 79. At Tap 37 near the top, the mixture is not homogeneous with percentages varying from 5 to 60 percent. At Tap 40 near the bottom, the mixture is fairly homogeneous varying from 30 to 40 percent indicating good dispersion in the dropshaft. When the tailwater was raised to El. 75 ft, only 0 to 2 percent air was present in both the dropshaft and air vent.

G. Interpolations to Other size Dropshafts

The purpose of this model study was to provide information for the design of 40 dropshafts of various diameters determined by the design discharge at each particular site. The dropshafts were separated into three groups with design discharges of 300, 600, and 900 cfs with diameters of 8, 12, and 14 ft, respectively. The model studies described so far in this report have been based on a 1:12.52 model of a 12 ft diameter dropshaft with a drop height of 75.1 ft and a design discharge of 600 cfs (Chart 8). The model dropshaft diameter was 11.5 inches, and the drop height was 6.0 ft. This same model can conveniently represent a 14 ft diameter prototype dropshaft with a drop height of 87.6 ft and a design discharge of 900 cfs, resulting in a scale of 1:14.61 (Chart 80). All the dimensions for the 1:12.52 model on Chart 8 can be transposed to the dimensions for the 1:14.61 model on Chart 80 by multiplying by the ratio of the length ratios. For example, using the diameter of 12 ft,

$$12 \times \frac{14.61}{12.52} = 14$$

transposes to a diameter of 14 ft. All of the quantities listed on page 3 can be transferred in the same manner. The design discharge of 600 cfs in the 1:12.52 model,

$$600 \times \frac{815.9}{554.6} = 883$$

equals 883 cfs or nearly the design discharge of 900 cfs in the 1:14.61 model. Thus for all practical purposes, the photos showing the design flow of 600 cfs in the 1:12.52 model would also be showing the design flow of 900 cfs in a 1:14.61 model. This can be seen by comparing Photos 35 and 36 with Photos 19 and 25. Pressure readings could also be transposed in this manner and used for design purposes. With the drop height increased to 87.6 ft, dispersion in the dropshaft would be similar or possibly somewhat better.

This same model can conveniently represent an 8 ft diameter prototype dropshaft with a drop height of 50.1 ft and a design discharge of 300 cfs resulting in a scale of 1:8.35 as shown on Chart 81. All the dimensions on Chart 8 have been transposed to the dimensions for the 1:8.35 model on Chart 81 by the ratio 8.35/12.52 with the exception of the space between the false crown and true crown, and the space for the air vent. If these spaces were scaled down, access would not be possible; therefore, these spacings were made of such a dimension to provide for suitable access. This slight change in the false crown and air-vent divider wall spacings would probably not affect the model observations significantly. In this case a drop height of 50.1 ft is modeled. A flow of 800 cfs in the 1:12.52 model,

$$800 \times \frac{201.5}{554.6} = 291$$

equals 291 cfs or nearly the design discharge of 300 cfs in the 1:8.35 model. Therefore photos of the 1:12.52 model showing flows of 800 cfs would be a good representation of the design flow of 300 cfs in the 1:8.35 model. Pressure values could be transposed by a ratio of the length ratios.

IV. DEVELOPMENT OF DROPSHAFTS LOWER THAN ABOUT 70 FT

A. Description of Model

To develop the design of dropshafts lower than about 70 ft, a 1:8 scale model was constructed according to the drawing on Chart 82 and was designated as Type L2 R100. The structure is shown in Photo 37. The model components were fabricated in the laboratory shop and assembled at the model site (Photo 37). For this model the dropshaft diameter, sump, deaeration chamber, and exit conduit are the same prototype dimensions as for the 1:12.52 model of the final design Type L2 R35 shown on Chart 8. The differences are in the inlet conduit, elbow, and dropshaft length (Charts 82 and 83). The changes in the inlet conduit and elbow were necessary because of the lower drop height of 50.5 ft. The entrance conduit diameter was reduced to 9 ft and a transition from round to square placed just upstream of the elbow (Photo 38). A quarter cylinder elbow with an invert radius of 9 ft guided the flow from the transition into the vertical shaft. A 3.5 ft high aeration box was installed below the elbow to provide for better aeration of the falling jet (Photo 38). The water-air mixture dropped through the shorter vertical shaft into the sump and dearation chamber. Photo 39 shows the air slots in the false crown and Photo 40 the bellmouth over the entrance to the exit conduit. This model was constructed with pressure taps and air ports similar to the first model. The location of these taps and air ports are shown on Chart 82. The 1:8 model was connected to the same 12 inch supply line and calibrated 6 inch diameter orifice meter as the 1:12.52 model. A butterfly valve was installed at the downstream end of the exit conduit to control the tailwater elevation.

The design discharge for this type was 600 cfs. Observed in the model were discharges of 200, 400, 600 and 800 cfs. For each of these discharges the tailwater was uncontrolled (tailwater valve wide open) and then maintained at the selected elevations of 10, 22, 30, and 45 ft while observations and necessary documentation were made.

B. Development of Optimized Structure

1. Quarter Cylinder Elbow

The original 1:8 model was constructed according to Charts 82 and 83 as described above and designated as Type L2 R100. The sump and deaeration chamber design was developed in the 1:12.52 model and verified in the larger 1:8 model. No changes were made in the sump and deaeration chamber as it proved just as effective in the 1:8 model with the lower drop heights. With the lower drop heights air entrainment and dispersion is not complete and the major efforts were concentrated on this problem.

Photo 41 shows the flow pattern in the inlet, dropshaft, and sump for the design discharge of 600 cfs and uncontrolled tailwater of 6.8 ft.

An alternate location of the transition 36.5 ft upstream of the elbow was suggested as shown on Chart 84 and designated as Type L2 R101. The model was revised to this geometry and observations made. Photo 42 shows the Type L2 R101 in operation with the design discharge of 600 cfs and tailwater elevation of 6.9 ft and may be compared to Photo 41. There appears to be little significant difference between the two types.

2. Free Trajectory Elbow

In consultations with Harza personnel it was decided that the optimum location for the transition was near the elbow as specified for Type L2 R100 and shown on Chart 83. It was also decided that the dispersion in the dropshaft should be improved to cause more air entrainment. As a result, the free trajectory inlet outlined on Chart 85 was introduced. The quarter cylinder in the elbow was removed and replaced by a 1 ft step and a sloping flat plate from the step to the bottom of the elbow. The revised model, designated as Type L2 R102, is shown in operation in Photos 43 and 44 with the design discharge of 600 cfs and tailwater elevation of 6.9 ft. The photos show the jet breaking away from the boundary at the step and remaining a free jet until it impinges on the divider wall. The jet strikes the divider wall somewhat higher for this type with most of the flow deflected downward into the vertical shaft with some deflected upward along the wall. It appears that more air is entrained and dispersion somewhat improved. However, some flow is deflected into the aeration box beneath the elbow as shown in Photo 44. This is undesirable as the box could be damaged. The benefits of the aeration box were questionable; therefore, it was decided to block off the box and observe the changes in the flow pattern. This resulted in the elbow geometry shown on Chart 86 and designated as Type L2 R103. With the aeration box blocked off, the resultant flow patterns are shown in Photos 45 through 47. There does not appear to be any significant changes in the overall flow pattern as shown in Photos 45 and 46, but the undesirable turbulence in the box has been eliminated as shown in Photo 47. Aeration and dispersion of the jet appear to be good. It was decided that the aeration box should be eliminated from the design. The free trajectory inlet (Type L2 R103) was judged to be the optimum inlet geometry and included in the final design.

With this free trajectory type of inlet the jet strikes the divider wall at a higher elevation and as a solid jet as shown in Photo 48. Thus, the divider wall has to be designed to withstand higher impact forces than designs with the pipe elbow inlet.

3. The Final Design

Up to this point in the model studies on the 1:8 model, no weir has been used in the deaeration chamber. Because of its proven value in the 1:12.52 model, it was decided to include a slotted weir in the 1:8 model of lower drop structures. The final design for drops lower than about 70 ft is shown on Chart 87 and includes the free-trajectory inlet without the aeration box beneath the elbow, and the sump and deaeration chamber including the slotted false crown, slotted weir, and bellmouth. A minor revision was also made to the upper slot and wedge of the divider wall. Initially both slots had an opening of 1.75 ft as shown in Section C-C on Chart 87. It was discovered that for low flows below 100 cfs, the jet would impinge in the area of the upper wedge and slot, with some of the flow spurting through the slot into the air vent. Although not a serious problem, it was remedied by lowering the upper wedge by 1.75 ft and reducing the upper slot height to 1 ft as shown in Section G-G on Chart 87. The final design was designated as Type L2 R104.

The flow patterns through this structure are shown in Frontispiece 2 and Photos 48 through 60 and demonstrate the effectiveness of the structure in aeration and dispersion in the inlet and dropshaft, and energy dissipation and air removal in the sump and deaeration chamber. Photos 48 through 55 show the flow patterns for the design discharge of 600 cfs and various tailwater elevations from 6.9 to 45 ft. Photo 46 shows a flow of 28 cfs through the slotted weir. A flow of 400 cfs is shown in Photos 57 and 58. Even at 800 cfs, which is 200 cfs more than the design flow, the structure is effective in energy dissipation and air removal as shown in Photos 59 and 60.

C. Piezometric Pressures

Piezometric pressures were recorded on the 1:8 model, for Type L2 R100 and the final design Type L2 R104, and for discharges of 200, 400, 600, and 800 cfs. For each flow the tailwater elevation was uncontrolled, and then maintained steady at 10, 22, 30 and 45 ft. The results are presented for Type L2 R100 on Charts 88 through 91 and for Type L2 R104 on Charts 92 through 95. For Type L2 R100 the data taken at Taps 8 and 9 are to be noted. These taps are located in the quarter cylinder in the upper elbow, and negative pressures occur for flows of 400, 600, and 800 cfs as shown on Charts 89 through 91. No negative pressures occurred on the 1:12.52 model of the final design L2 R35 which had the pipe elbow with an invert radius of 1.5 D or 18 ft. Two factors that may contribute to these negative pressures are (1) the inlet conduit was reduced from 12 to 9 ft with the design discharge remaining at 600 cfs, and (2) to minimize the height, the elbow invert radius was reduced to 1D or 9 ft. Other factors of minor importance could be the transition just upstream of the elbow and the quarter cylinder in the elbow. It is not important to dwell on these negative pressures as this inlet design was not included in the final design, but it does reinforce the decision to use the free-trajectory inlet in the final design.

The piezometric pressures for the final design, Type L2 R104, are presented on Charts 92 through 95. All the pressures are positive and plot in a consistent manner similar to other models. In comparing Charts 92 through 95 (Type L2 R104) with Charts 88 through 91 (Type L2 R100), the differences noted are the negative pressures at Taps 8 and 9 for Type L2 R100 and some slight variations in the pressures in the impact area at Taps 19 through 23.

D. Fluctuating Pressures

A survey of fluctuating pressures was made on the 1:8 model similar to that made on the 1:12.52 model. In areas of anticipated high frequencies and fluctuations, the Kulite transducer was flush mounted and connected to the storage oscilloscope, and in other areas the chamber mounted CEC transducer and Sanborn strip recorder was used.

In Type L2 R100, which has the quarter cylinder in the elbow, the jet tends to pull away from the curve about 2/3 of the way down and shoots across the dropshaft impinging on the divider wall. The divider wall has to withstand these impact forces. To provide information for design purposes, Tap 39 was installed in the divider wall at El. 40.5 ft (Chart 82). This was in the area where the main jet impinged on the divider wall and the maximum fluctuations expected. A flush mounted Kulite transducer was installed in the tap and measurements made. Charts 96 through 98 show the data for a discharge of 400 cfs and Charts 99 through 101 for 600 cfs. Charts 96, 99, and 100 show the oscilloscope photos. Charts 97, 98, and 101 show the ranges from these photos for a model time of 1 minute, and any visually observed maximum and minimum readings if they occurred for a model time of 5 minutes. The horizontal time scales refer to the visually observed readings and on these charts the spacing between the minute marks are varied depending on the number of readings observed. For the 400 cfs flow, spikes reached El. 150 ft and El. 10 ft or a negative pressure head -30.5 ft (Charts 97 and 98). This is close to the cavitation pressure head of -34 ft and should be considered in the design. For the 600 cfs flow spikes reached El. 120 ft and El. 20 ft or a negative pressure head of -20.5 ft as shown on Chart 101. This information is summarized on Chart 110.

With the free-trajectory inlet as in Type L2 R104 the main jet strikes the divider wall at a higher elevation as shown in Photo 48. The putty plug shown in the center of the picture is the location of Tap 39 at El. 40.5 ft and was about in the center of the jet for Type L2 R100. Now the center of the jet is at about El. 44.7 ft. Charts 102 through 105 show the results of pressure fluctuations taken at the Tap 39 location. At flows of 400 and 600 cfs, fluctuations were minimal as shown on Charts 104 and 105. It was observed that if the flow was decreased to 330 cfs, the center or top of the jet was at the tap elevation, and higher fluctuations occurred. The results for this critical flow of 330 cfs are shown on Charts 102 and 103. Maximum peaks to El. 120 ft and minimums to El. 20 ft or a negative pressure head of -20.5 ft occurred. It was reasoned that higher pressure fluctuations might occur at a location where the top of the jet hits the divider wall as a slapping action takes place there. Tap 40 was installed in this area at El. 44.7 ft (Chart 87). This tap is not shown in Photo 48. Data taken at this tap for flows of 400 and 600 cfs are presented on Charts 106 through 109. Maximum readings were observed for a flow of 600 cfs and tailwater elevation of 6.9 ft and reach to El. 88 ft and down to El. 36 ft which is a negative pressure head of -8.7 ft. These fluctuations were not as high as anticipated. The angle of impingement of the jet is higher for the free-trajectory inlet which may account for this or the tap may not be precisely at the point of the highest fluctuations. A summary of the pressure fluctuations on the divider wall is presented on Chart 110.

Pressure fluctuation measurements were made on the sump invert beneath the dropshaft at Taps 18, and 20 through 22 (Chart 87) using the flush mounted Kulite transducer. For Type L2 R100, measurements were made at Tap 21 (Charts 111 through 116) and Tap 22 (Charts 117 through 120) for discharges from 200 to 800 cfs. A summary of the data is presented on Chart 121. At Tap 21, which is in the center, the extremes occurred for a flow of 400 cfs and tailwater elevation of 5.8 ft, and varied from El. 90 ft to El. -10 ft or a negative pressure head of -10 ft. For the same flow conditions at Tap 22, which is on the left side, the range observed was from El. 60 to -24 ft or a negative pressure head of -24 ft.

For Type L2 R101, observations were also made on Taps 21 and 22 for flows from 200 to 800 cfs and tailwaters from uncontrolled to El. 45 ft. Charts 122 through 127 show the recordings for the design discharge of 600 cfs, and Chart 128 presents the summary for all discharges. At Tap 21, peaks to El. 70 ft were observed for a flow of 200 cfs and tailwater of 4.1 ft. Minimums to El. -20 ft or a negative pressure head of -20 ft were observed for various flow conditions as shown on Chart 128.

Charts 129 through 142 show the data taken on the sump invert for Type L2 R104, the final design for the low drop structures. At Tap 21 in the center, measurements were made for all flows from 200 to 800 cfs and tailwater elevations from uncontrolled to 45 ft. At Taps 18, 20, and 22 measurements were made for the design discharge of 600 cfs and tailwaters from uncontrolled to 45 ft. A summary of the information is presented on Chart 143. Extreme fluctuations occur at Tap 21 for a flow of 600 cfs and tailwater elevation of 6.9 ft, and reach maximums up to El. 84 ft and minimums down to El. -30 ft or a negative pressure head of -30 ft. These low values approach the cavitation pressure head of -34 ft and should be considered in the design of the sump invert.

In areas outside of the impact area beneath the dropshaft, the chamber mounted CEC transducer was used to record the pressure fluctuations. A survey was made in the elbow (Tap 10), the dropshaft (Tap 11), the sump (Taps 13-17, 19, 23, 24, and 26), the deaeration chamber (Taps 28 and 30), and the exit conduit (Tap 35). Records of pressure fluctuations taken at these taps for Type L2 R104, the final design, and the design discharge of 600 cfs and various tailwaters are presented on Charts 144 through 150. A summary of the information is presented on Chart 151. Examination of the records show some relatively low fluctuations at Tap 11 in the dropshaft (Chart 144) and Taps 16, 17, 23, and 24 in the sump (Charts 146 through 149). Some surging takes place in the sump and deaeration chamber as shown for Taps 26, 28, 30, and 35 in Charts 149, 147, and 150. These pressure fluctuations appear relatively low and should be of no major structural concern.

E. Air Concentrations

Air concentration measurements were made in the dropshaft for Type L2 R104, the final design. As the dropshaft is short in this model, measurements were made at only one elevation, that is, Taps 41 and 42 (Chart 87). Charts 152 through 155 show the air concentrations in the dropshaft for flows from 200 to 800 cfs and tailwaters from uncontrolled to El. 45 ft. For the design discharge of 600 cfs and tailwater at El. 6.9 ft, the air concentrations vary from 55 to 92 percent in the dropshaft and is 100 percent air in the air vent (Chart 154). At a tailwater elevation of 30 ft the percentages vary from 20 to 35 percent in the dropshaft and 30 to 40 percent in the air vent; at a tailwater elevation of 45 ft percentages vary from 15 to 20 percent and 14 to 25 percent, respectively. The dispersion appears relatively good. In analyzing the data, the only definite trend that can be established is that as the tailwater elevation is raised, the air concentrations go down. It is difficult to establish exact trends as the values given are sometimes the averages of quite large fluctuations in air concentrations.

F. Energy Spectrums

Energy spectrums were recorded on the divider wall where the incoming jet impinges and on the sump invert where the falling water-air mixture impinges. The spectrums were recorded using the flush mounted Kulite transducer which was connected to a Nicolet 444A computing spectrum analyzer. Chart 156 explains the information in the margins around the spectrum displays. Typical spectrum displays of frequency versus energy are presented on Charts 157 through 171. Charts 157 through 164 show spectrums at Taps 39 and 40 on the divider wall and Charts 165 through 171 show spectrums at Taps 20 and 21 on the sump invert for different type dropshafts and various flow conditions. Because of space limitations, only pertinent displays are presented in this report. Chart 172 shows how to determine spectrum values.

The spectrum scales are given in model dimensions. The abscissa is the full scale frequency range selected in the model and may be 1000, 200, 100, or 10 Hz as indicated. Initially observations were made at all four ranges, but the most meaningful spectrums were obtained at 1000 and 200 Hz and subsequent spectrums were taken at only these two frequencies and presented in this report. This scale is converted to prototype frequency by

$$fp = fm \sqrt{Lr} = 0.3536 \ fm$$

If the full scale frequency range in the model was 1000 Hz, the prototype frequency range would be 353.6 Hz.

The ordinate is given in volts rms, and the full scale readings are equal to

$$\text{Sensitivity/Gain} = \frac{0.1 \ v}{512} = 1.953 \text{x} 10^{-4} \ v$$

It is necessary to take the weighted noise bandwidth into consideration. The bandwidth varies in a specified manner with the frequency range chosen for the abscissa, and the above constant is divided by the square root of the bandwidth. To convert the ordinate from volts to pressure head, the calibration of the pressure transducer in model units is used. This calibration was measured to be $14.32\mathrm{x}10^{-4}$ v/ft. Thus, for a model frequency range of 1000 Hz, the full scale ordinate in the model becomes, for the bandwidth of 3.8 Hz,

$$\frac{1.953\mathrm{x}10^{-4}}{\sqrt{3.8}} \mathrm{x} \frac{1}{14.32\mathrm{x}10^{-4}} = 0.0700 \ \mathrm{ft}_m / \sqrt{\mathrm{Hz}}$$

To obtain full-scale prototype units, the pressure head, H , scales with the length ratio and the frequency as $L_r^{-1/2}$. Therefore, the model rms pressure head divided by $\sqrt{\mathrm{Hz}}$ should be multiplied by $L_r^{5/4}$ or 13.454. The conversion factors for other frequency ranges are listed below:

Abscissa, full scale, Hz		Bandwidth, Hz	Ordinate, full scale, prototype
Model	Prototype	Model	Hrms/ $\sqrt{\mathrm{Hz}}$
1000	353.61	3.8	0.941
200	70.72	0.75	2.119
100	35.36	0.38	2.977
10	3.54	0.038	9.413

An example of the use of the conversion factors is given in Chart 172 which is a duplication of the top spectrum on Chart 159. Suppose we wish to find the rms amplitude at Point A at the model frequency of 24 Hz. The ordinate scale is divided into 10 parts, so that the ordinate for Point A is 0.25. Multiplying this value by the full scale, prototype value for the model frequency range of 200 Hz gives the prototype Hrms/$\sqrt{\mathrm{Hz}}$ of 0.53 ft/$\sqrt{\mathrm{Hz}}$ at the prototype frequency of 8.49 Hz. The same procedure can be followed to determine heads at any other discrete frequency. It should be noted that these values represent only the fluctuating component of the pressure head.

In recording the spectrum, the cursor was set to the peak amplitude observed and the magnitude of this peak is shown on the spectrums near the top left corner. This value in volts may be divided by the full scale display reading of $1.953\mathrm{x}10^{-4}$ volts to obtain an accurate location on the ordinate. In the example, the ordinate so determined is 0.47, which when multiplied by the scale factor of 2.119 gives a peak of about 1 ft rms/$\sqrt{\mathrm{Hz}}$ prototype. The model frequency at the cursor location is given in the upper right corner as 1 Hz, which corresponds to a prototype frequency of 0.35 Hz.

In examining the spectrums the absence of relatively high spikes is noted. High spikes indicating high energy at a discreet frequency could cause damage to the prototype structure if this spike occurred at the natural frequency of the structure.

G. Interpolation to Other Size Dropshafts

The model studies on the 1:8 model just described represented a dropshaft diameter of 12 ft (11.5 in. model) with a drop from invert to invert of 50.5 ft and a design discharge of 600 cfs. This same 18 inch diameter model can conveniently represent a 14 ft diameter prototype dropshaft with a drop of 58.9 ft and a design discharge of 900 cfs. The model scale is then 1:9.33. All the dimensions for the 1:8 model of the final design Type L2 R104 on Chart 87 can be transposed to the dimensions for the 1:9.33 model on Chart 173 by multiplying by the ratio of the length ratios. For example, the diameter of 12 ft:

$$12 \times \frac{9.33}{8.0} = 14$$

transposes to a diameter of 14 ft. The design discharge of 600 cfs in the 1:8 model:

$$600 \times \frac{265.9}{181.0} = 881$$

equals 881 cfs or nearly the design discharge of 900 cfs in a 1:9.33 model. The photos showing the design discharge of 600 cfs in the 1:8 model would be a good representation of the design flow of 900 cfs in the 1:9.33 model. All of the quantities listed on page 3 can be transferred in the same manner. Therefore the information presented for the 1:8 model of a 12 ft diameter dropshaft can be transposed and used for the design of a low drop 14 ft diameter dropshaft.

LIST OF PHOTOGRAPHS

Frontispiece 1	Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 22 ft. The final design.
Frontispiece 2	Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The final design.
PHOTO 1	Type L2 R1 dropshaft. The completed model ready for testing and the personnel responsible for its construction.
PHOTO 2	Type L2 R1 dropshaft. The pipe elbow inlet.
PHOTO 3	Type L2 R1 dropshaft, Q = 600 cfs, T.W. = 7.1 ft. Alternate air vent 1 open.
PHOTO 4	Type L2 R1 dropshaft, Q = 600 cfs, T.W. = 22 ft. Alternate air vent 1 open.
PHOTO 5	Type L2 R2 dropshaft, Q = 600 cfs, T.W. = 22 ft. Alternate air vent 2 open.
PHOTO 6	Type L2 R3 dropshaft, Q = 600 cfs, T.W. = 22 ft. Alternate air vent 3 open.
PHOTO 7	Type L2 R5 dropshaft, Q = 600 cfs, T.W. = 22 ft. The deaeration chamber with alternate air vent 1 open.
PHOTO 8	Type L2 R7 dropshaft, Q = 600 cfs, T.W. = 22 ft. The deaeration chamber with cut-off wall and air vent pipe.
PHOTO 9	Type L2 R10 dropshaft, Q = 600 cfs, T.W. = 22 ft. The deaeration chamber with 1 ft air slots.
PHOTO 10	Type L2 R10 dropshaft, Q = 600 cfs, T.W. = 22 ft. Exit conduit with sharp edged entrance.
PHOTO 11	Type L2 R10 dropshaft, Q = 600 cfs, T.W. = 16 ft. Exit conduit with sharp edged entrance.
PHOTO 12	Type L2 R14 dropshaft, Q = 600 cfs, T.W. = 16 ft. Exit conduit with bellmouth entrance.
PHOTO 13	Type L2 R14 dropshaft, Q = 600 cfs, T.W. = 22 ft. The inlet, dropshaft, and sump.

PHOTO 14	Type L2 R14 dropshaft, Q = 600 cfs, T.W. = 22 ft. The deaeration chamber with 1 ft air slots.
PHOTO 15	Type L2 R25 dropshaft, Q = 600 cfs, T.W. = 22 ft. The inlet, dropshaft, and sump with an elbow aerator.
PHOTO 16	Type L2 R28 dropshaft, Q = 600 cfs, T.W. = 22 ft. The inlet, dropshaft, and sump with a circumferential aerator.
PHOTO 17	Type L2 R32 dropshaft, Q = 600 cfs, T.W. = 22 ft. The deaeration chamber with 2 ft air slots.
PHOTO 18	Type L2 R33 dropshaft, Q = 600 cfs, T.W. = 7.1 ft. A 4 ft weir at the junction of the sump and deaeration chamber.
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PHOTO 20	Type L2 R36 dropshaft, Q = 600 cfs, T.W. = 7.1 ft. An 8 ft weir in the deaeration chamber.
PHOTO 21	Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 7.1 ft. The final design.
PHOTO 22	Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 7.1 ft. The pipe elbow inlet.
PHOTO 23	Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 10 ft. The final design.
PHOTO 24	Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 22 ft. The final design.
PHOTO 25	Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 22 ft. The sump and deaeration chamber.
PHOTO 26	Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 22 ft. The deaeration chamber.
PHOTO 27	Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 30 ft. The final design.
PHOTO 28	Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 45 ft. The final design.
PHOTO 29	Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 75 ft. The final design.
PHOTO 30	Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 75 ft. The pipe elbow inlet.

PHOTO 31 Type L2 R35 dropshaft, Q = 400 cfs, T.W. = 5.3 ft. The sump and deaeration chamber.

PHOTO 32 Type L2 R35 dropshaft, Q = 400 cfs, T.W. = 22 ft. The sump and deaeration chamber.

PHOTO 33 Type L2 R35 dropshaft, Q = 800 cfs, T.W. = 8.5 ft. The final design.

PHOTO 34 Type L2 R35 dropshaft, Q = 800 cfs, T.W. = 22 ft. The final design.

PHOTO 35 Type L3 R1 dropshaft, Q = 900 cfs, T.W. = 8.4 ft. The sump and deaeration chamber.

PHOTO 36 Type L3 R1 dropshaft, Q = 900 cfs, T.W. = 26 ft. The sump and deaeration chamber.

PHOTO 37 Type L2 R100 dropshaft. The completed model ready for testing and the personnel responsible for its construction.

PHOTO 38 Type L2 R100 dropshaft. The transition, 1/4 cylinder elbow, and the aeration box.

PHOTO 39 Type L2 R100 dropshaft. The air slots in the false crown.

PHOTO 40 Type L2 R100 dropshaft. The bellmouth.

PHOTO 41 Type L2 R100 dropshaft, Q = 600 cfs, T.W. = 6.8 ft. The inlet, dropshaft, and sump.

PHOTO 42 Type L2 R101 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The inlet, dropshaft, and sump with the transition moved upstream.

PHOTO 43 Type L2 R102 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The free trajectory inlet, dropshaft, and sump.

PHOTO 44 Type L2 R102 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The free trajectory inlet and dropshaft.

PHOTO 45 Type L2 R103 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The free trajectory inlet with aeration box blocked off.

PHOTO 46 Type L2 R103 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The free trajectory inlet, dropshaft, and sump.

PHOTO 47 Type L2 R103 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The dropshaft with the aeration box blocked off.

PHOTO 48 Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 22 ft. The impact area on the divider wall.

PHOTO 49	Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The final design.
PHOTO 50	Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 10 ft. The final design.
PHOTO 51	Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 22 ft. The final design.
PHOTO 52	Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 22 ft. The deaeration chamber.
PHOTO 53	Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 22 ft. The air passing through the slots.
PHOTO 54	Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 30 ft. The final design.
PHOTO 55	Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 45 ft. The final design.
PHOTO 56	Type L2 R104 dropshaft, Q = 28 cfs, The flow through the slotted weir.
PHOTO 57	Type L2 R104 dropshaft, Q = 400 cfs, T.W. = 5.8 ft. The final design.
PHOTO 58	Type L2 R104 dropshaft, Q = 400 cfs, T.W. = 22 ft. The final design.
PHOTO 59	Type L2 R104 dropshaft, Q = 800 cfs, T.W. = 7.5 ft. The final design.
PHOTO 60	Type L2 R104 dropshaft, Q = 800 cfs, T.W. = 22 ft. The final design.

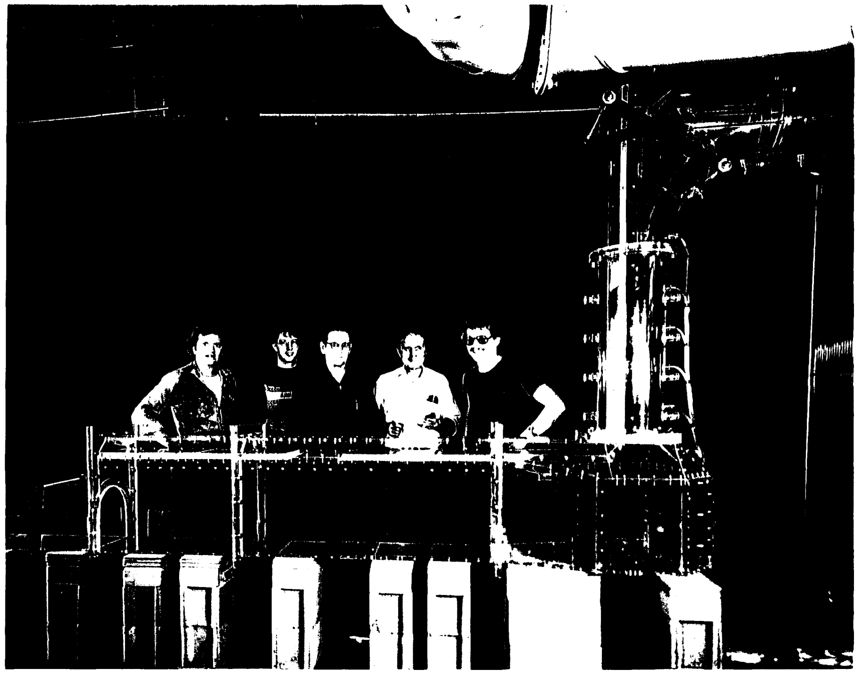

Photo 1. Type L2 R1 dropshaft.
The completed model ready for testing and the personnel responsible for its construction.

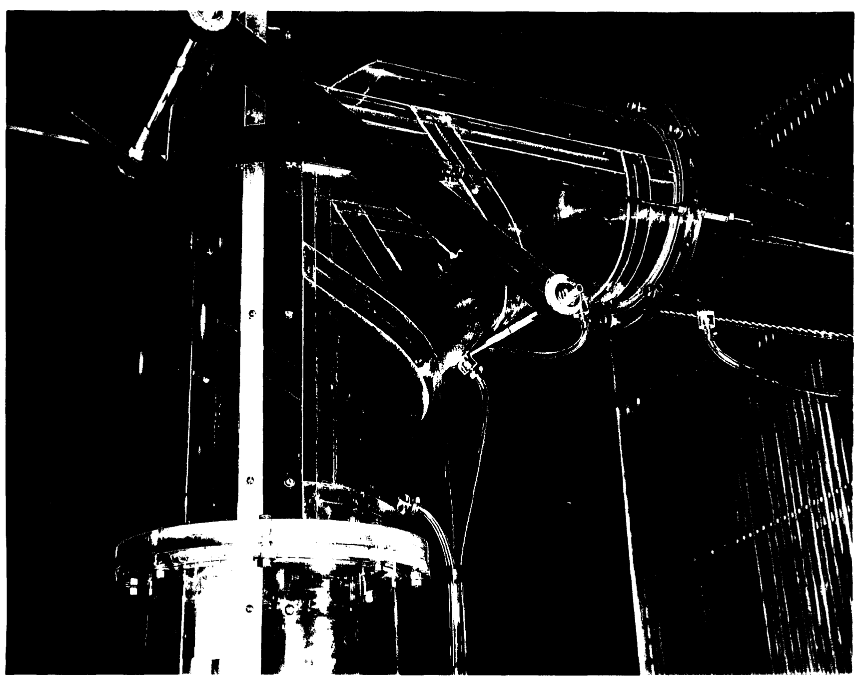

Photo 2. Type L2 R1 dropshaft.
The pipe elbow inlet.

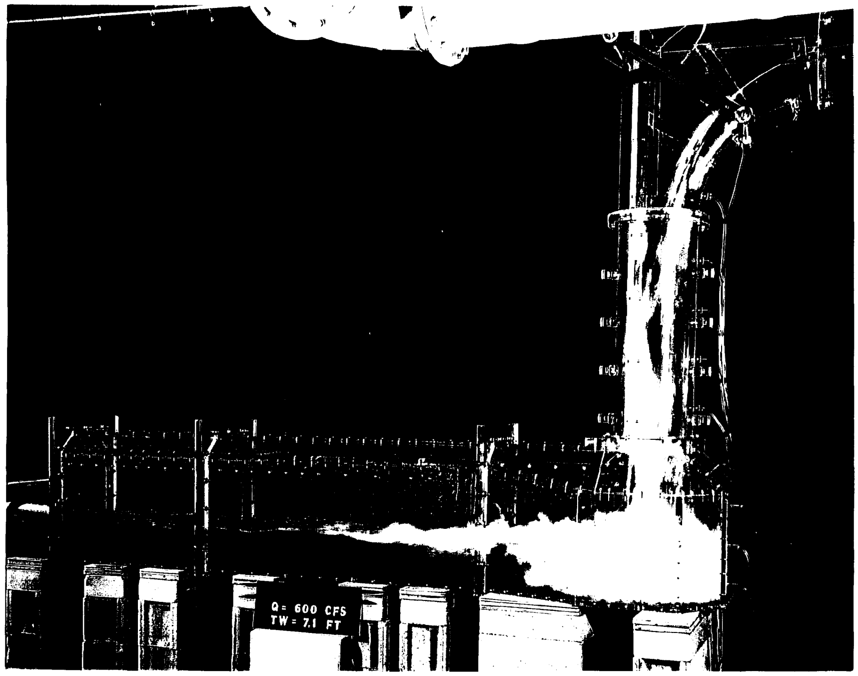

Photo 3. Type L2 R1 dropshaft, Q = 600 cfs, T.W. = 7.1 ft.
Alternate air vent 1 open.

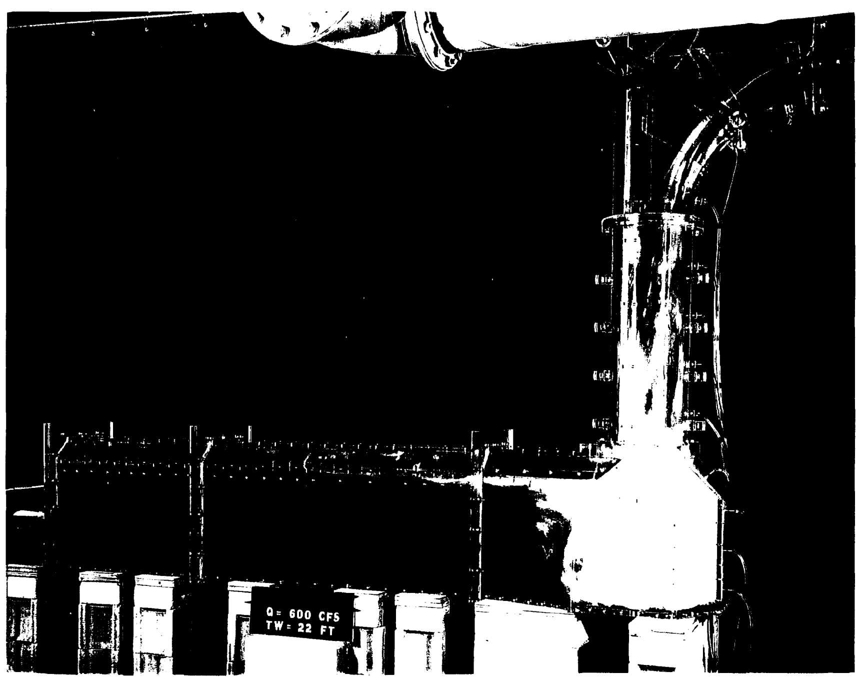

Photo 4. Type L2 R1 dropshaft, Q = 600 cfs, T.W. = 22 ft.
Alternate air vent 1 open.

Photo 5. Type L2 R2 dropshaft, Q = 600 cfs, T.W. = 22 ft. Alternate air vent 2 open.

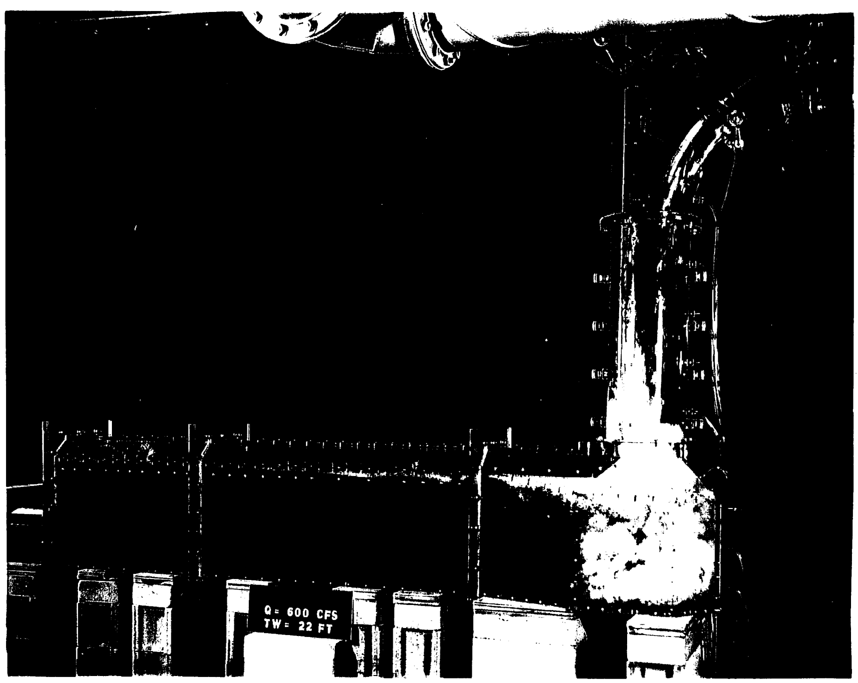

Photo 6. Type L2 R3 dropshaft, Q = 600 cfs, T.W. = 22 ft. Alternate air vent 3 open.

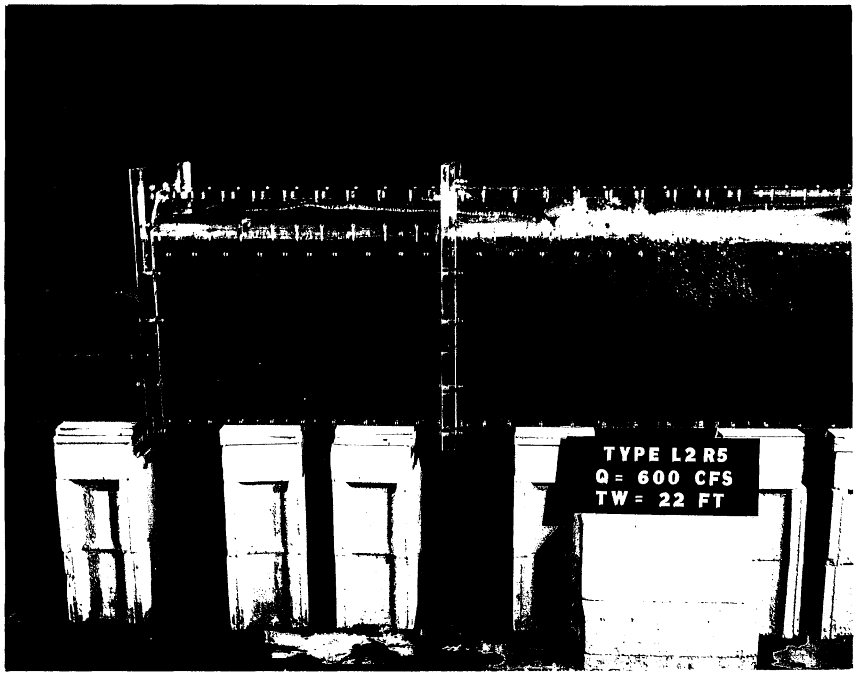

Photo 7. Type L2 R5 dropshaft, Q = 600 cfs, T.W. = 22 ft.
The deaeration chamber with alternate air vent 1 open.

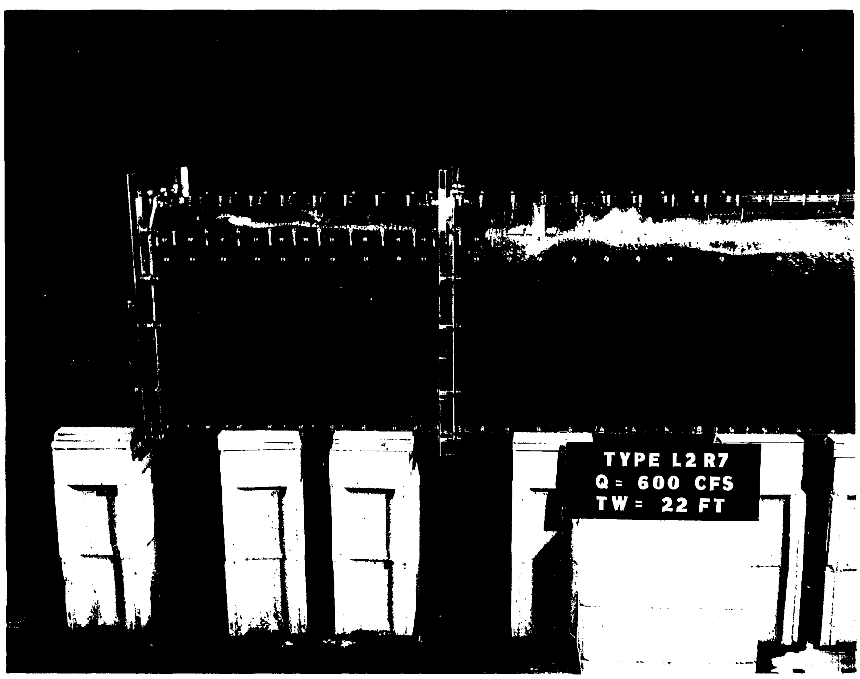

Photo 8. Type L2 R7 dropshaft, Q = 600 cfs, T.W. = 22 ft.
The deaeration chamber with cut-off wall and air vent pipe.

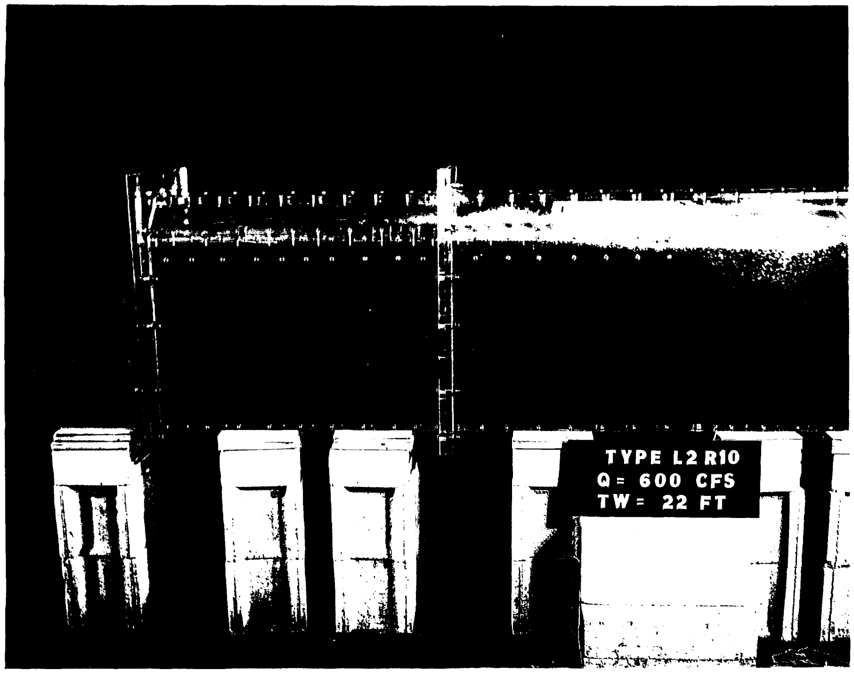

Photo 9. Type L2 R10 dropshaft, Q = 600 cfs, T.W. = 22 ft. The deaeration chamber with 1 ft. air slots.

Photo 10. Type L2 R10 dropshaft, Q = 600 cfs, T.W. = 22 ft. Exit conduit with sharp edged entrance.

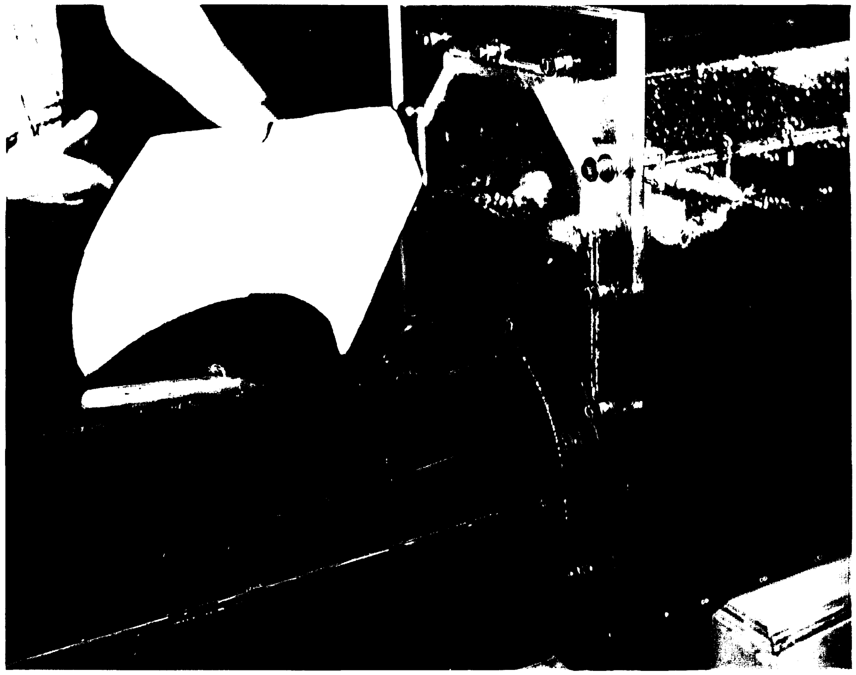

Photo 11. Type L2 R10 dropshaft, Q = 600 cfs, T.W. = 16 ft.
Exit conduit with sharp edged entrance.

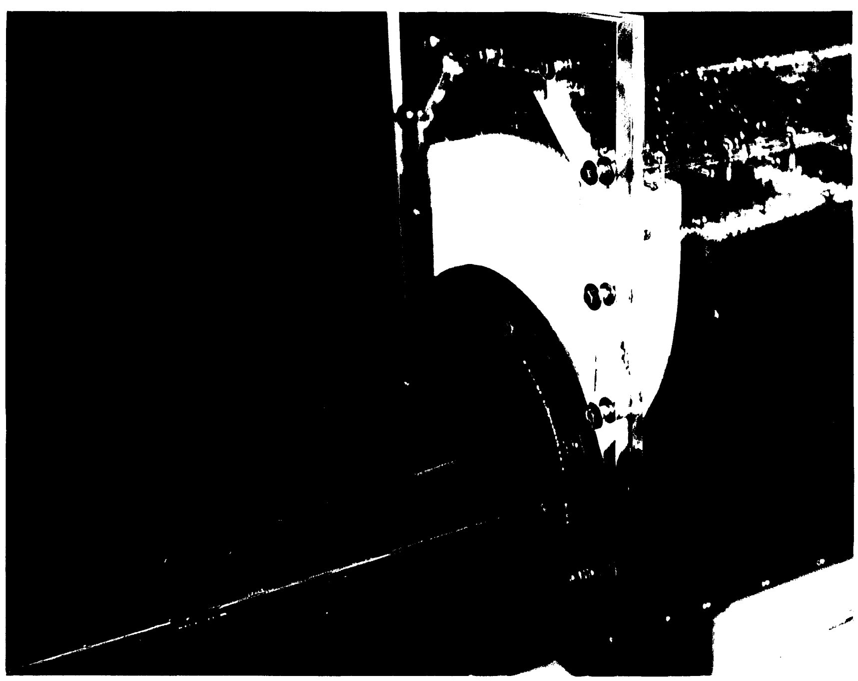

Photo 12. Type L2 R14 dropshaft, Q = 600 cfs, T.W. = 16 ft.
Exit conduit with bellmouth entrance.

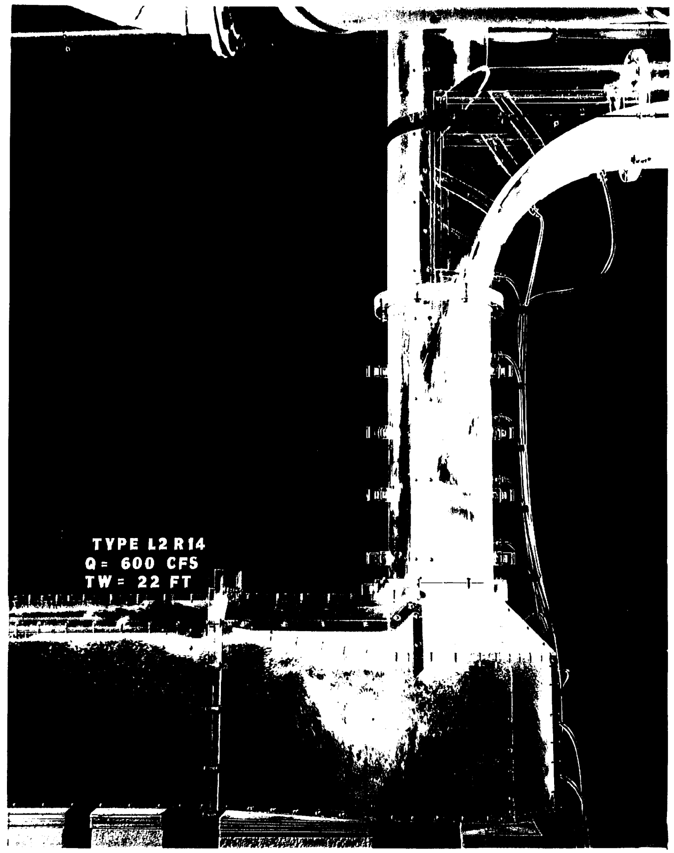

Photo 13. Type L2 R14 dropshaft, Q = 600 cfs, T.W. = 22 ft. The inlet, dropshaft, and sump.

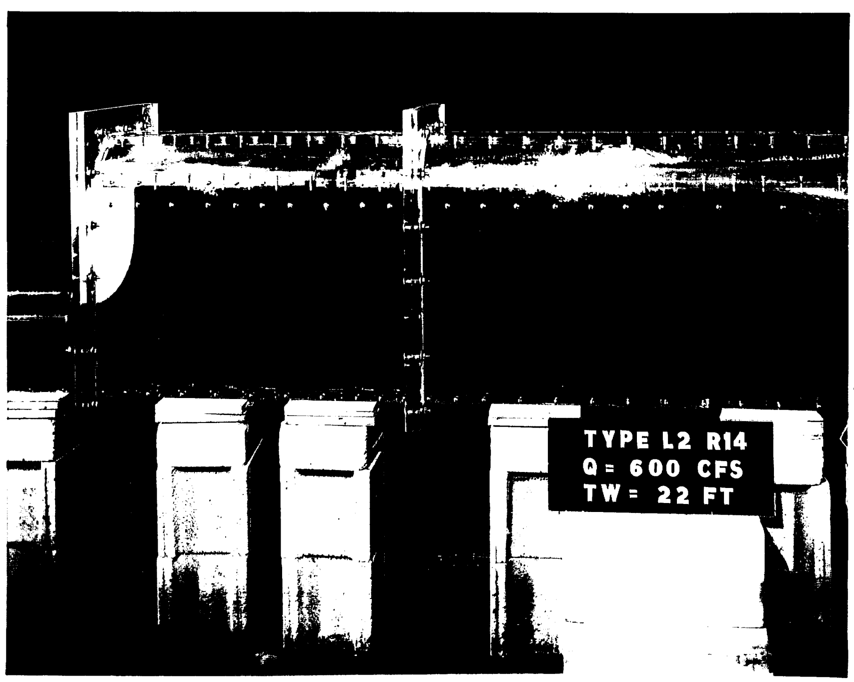

Photo 14. Type L2 R14 dropshaft, Q = 600 cfs, T.W. = 22 ft. The deaeration chamber with 1 ft. air slots.

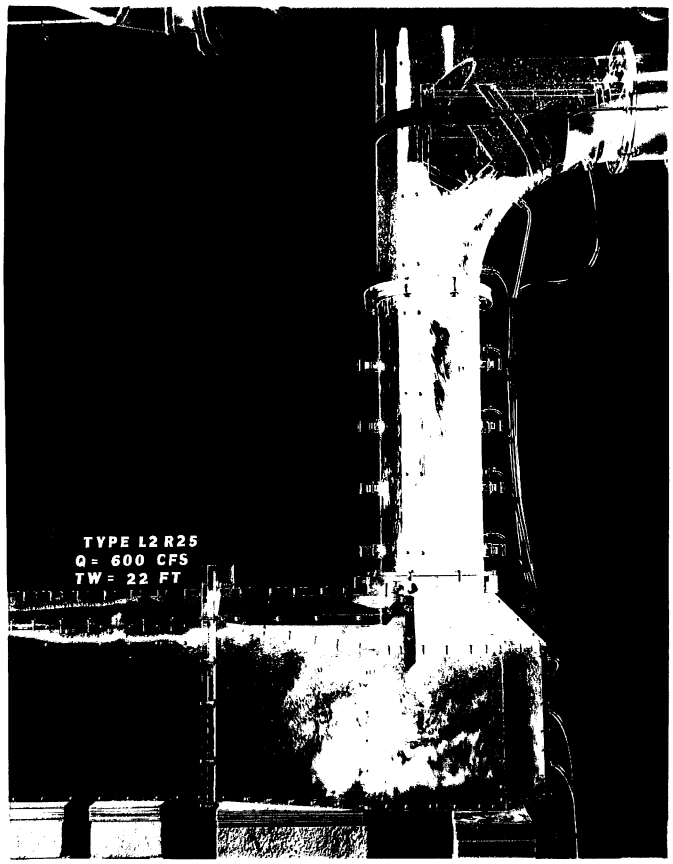

Photo 15. Type L2 R25 dropshaft, Q = 600 cfs, T.W. = 22 ft. The inlet, dropshaft, and sump with an elbow aerator.

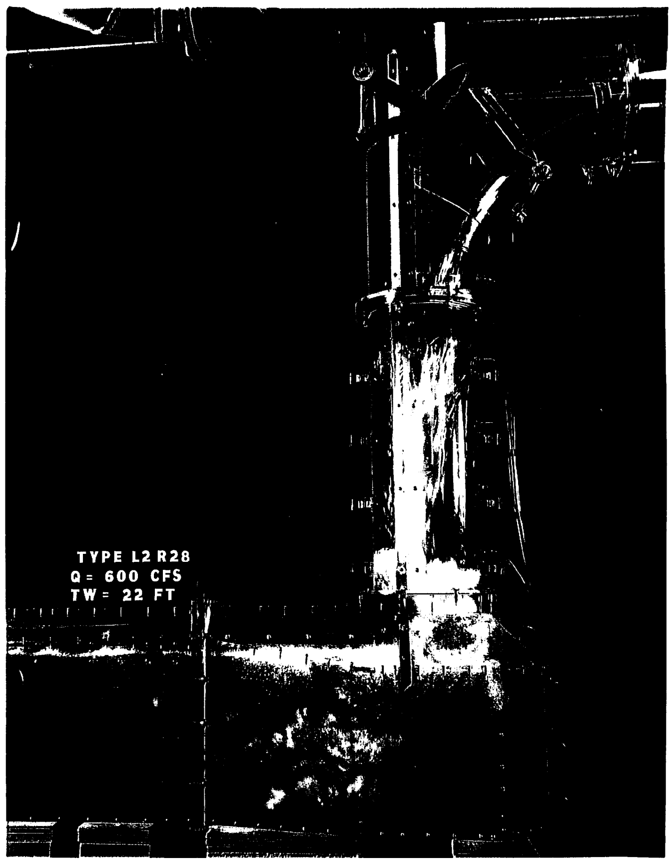

Photo 16. Type L2 R28 dropshaft, Q = 600 cfs, T.W. = 22 ft.
The inlet, dropshaft, and sump with a circumferential aerator.

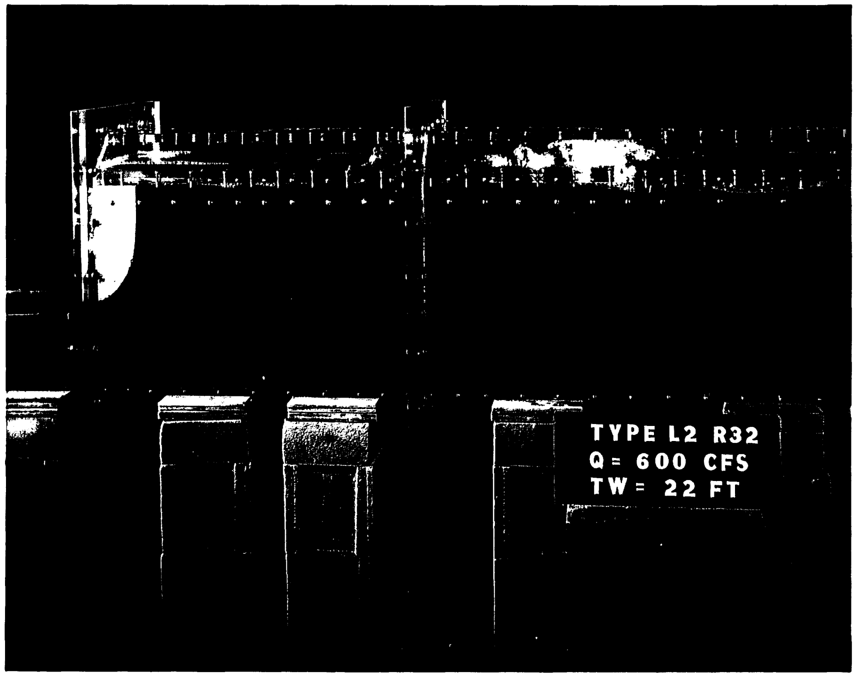

Photo 17. Type L2 R32 dropshaft, Q = 600 cfs, T.W. = 22 ft. The deaeration chamber with 2 ft air slots.

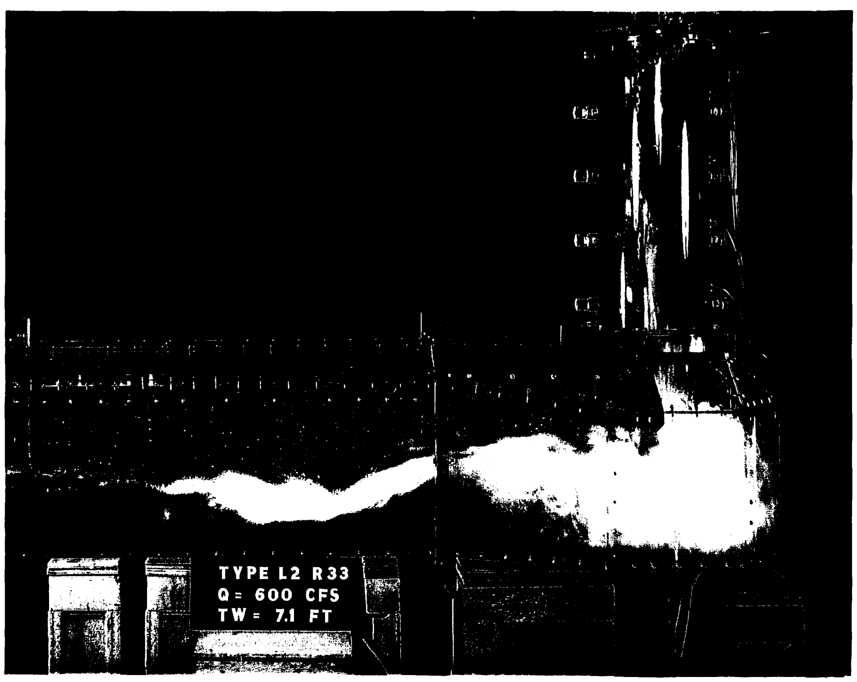

Photo 18. Type L2 R33 dropshaft, Q = 600 cfs, T.W. = 7.1 ft. A 4 ft. weir at the junction of the sump and deaeration chamber.

Photo 19. Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 7.1 ft. A 4 ft. weir in the deaeration chamber.

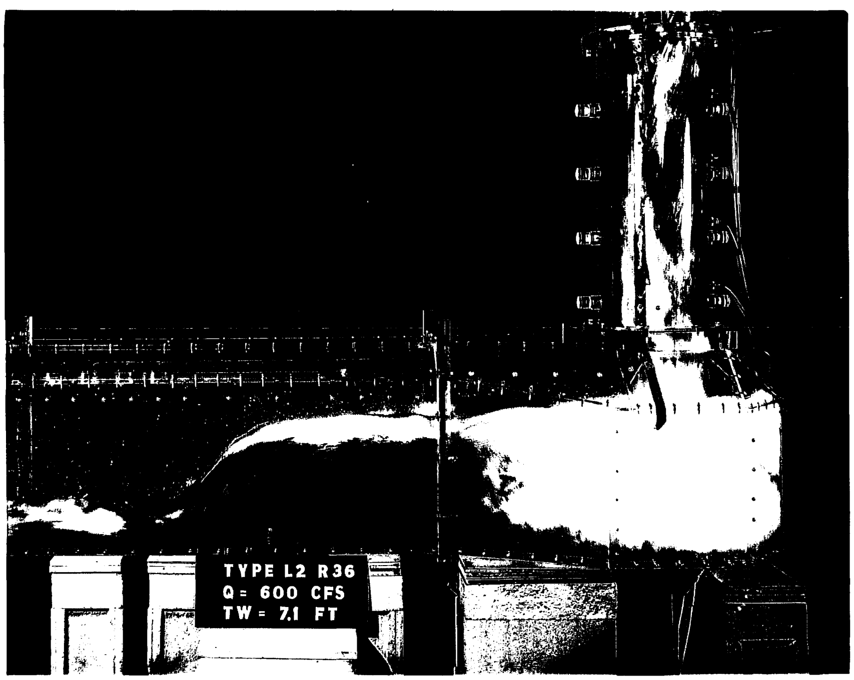

Photo 20. Type L2 R36 dropshaft, Q = 600 cfs, T.W. = 7.1 ft. An 8 ft. weir in the deaeration chamber.

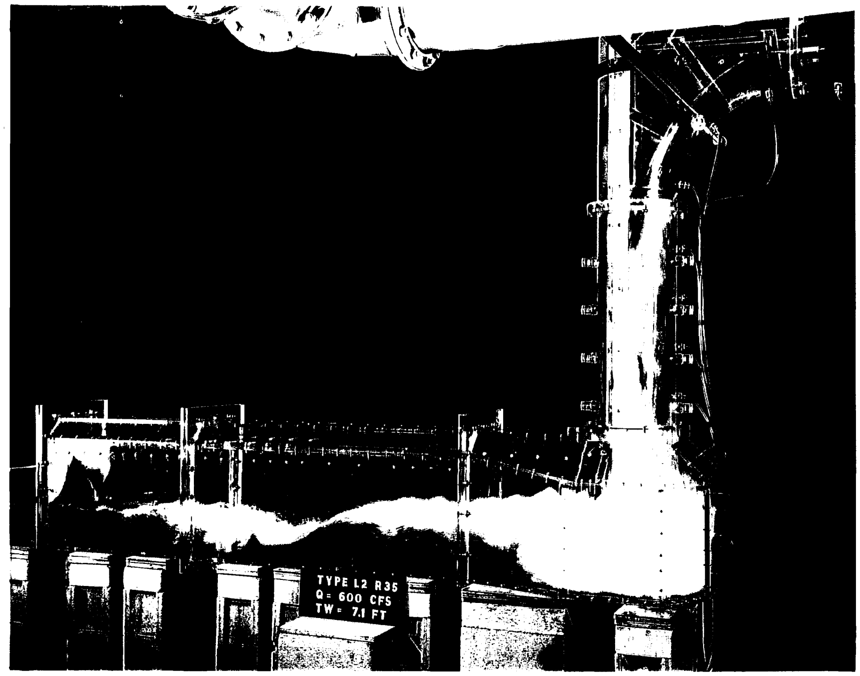

Photo 21. Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 7.1 ft. The final design.

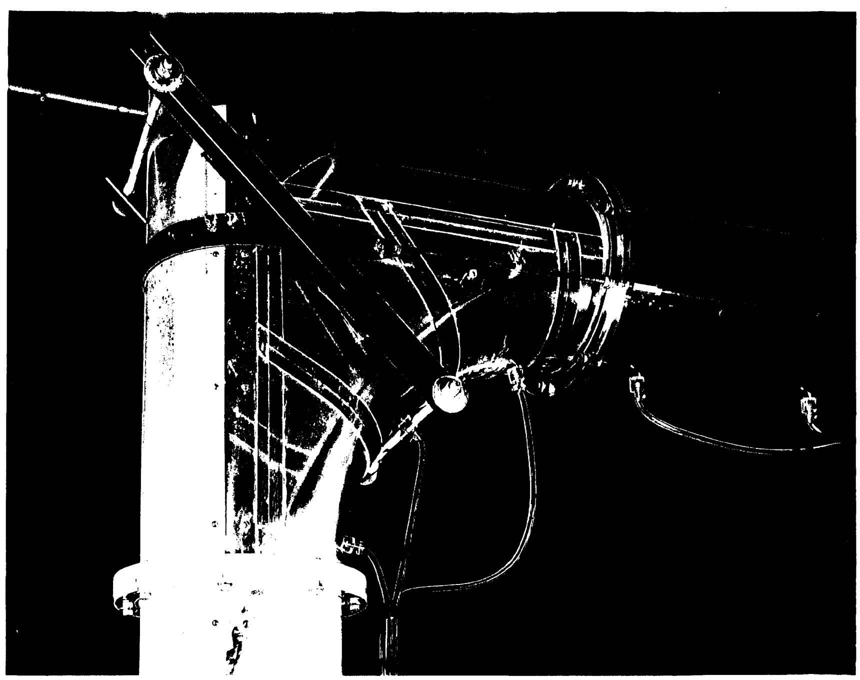

Photo 22. Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 7.1 ft. The pipe elbow inlet.

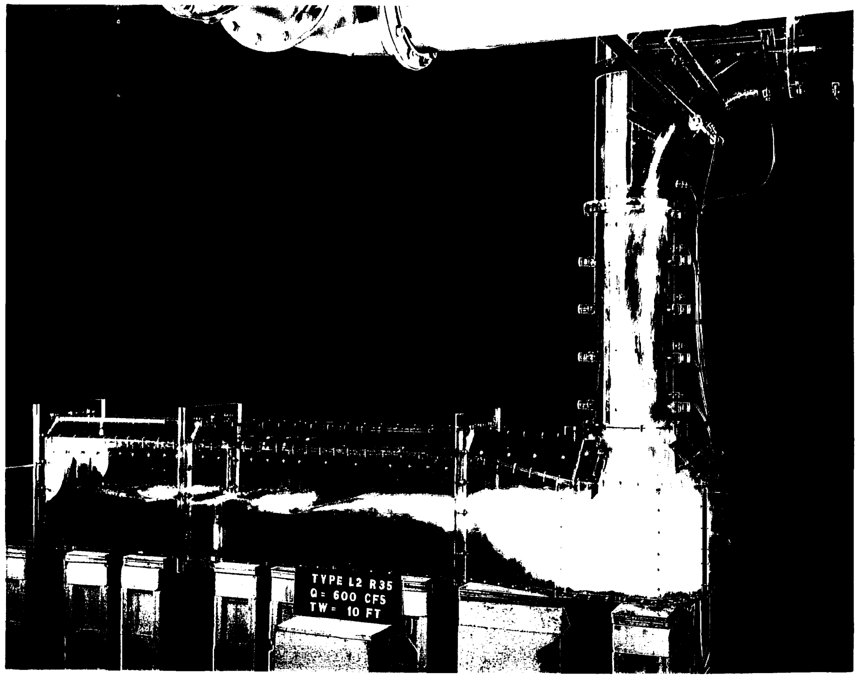

Photo 23. Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 10 ft. The final design.

Photo 24. Type L2 R35 Dropshaft, Q = 600 cfs, T.W. = 22 ft. The final design.

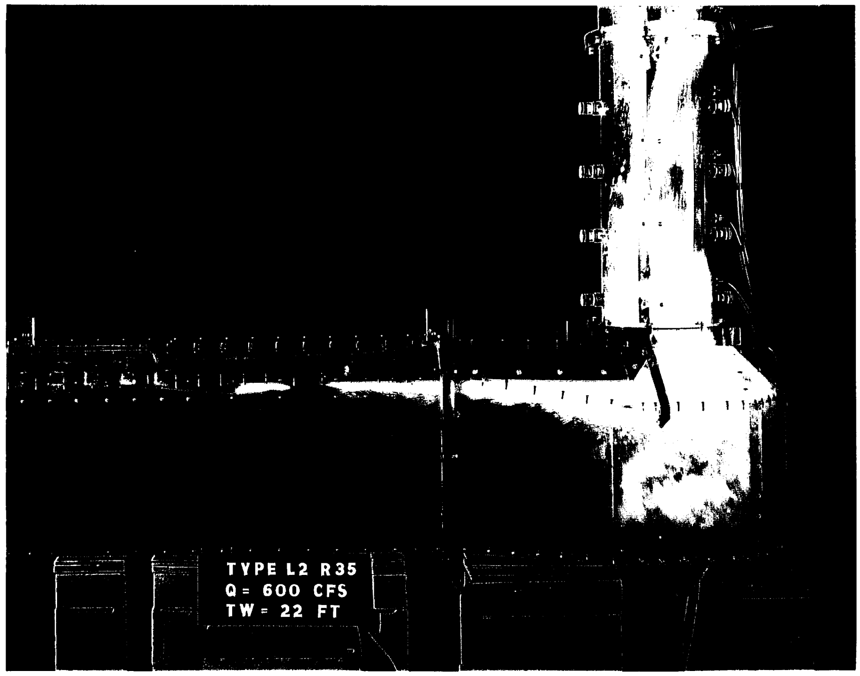

Photo 25. Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 22 ft. The sump and deaeration chamber.

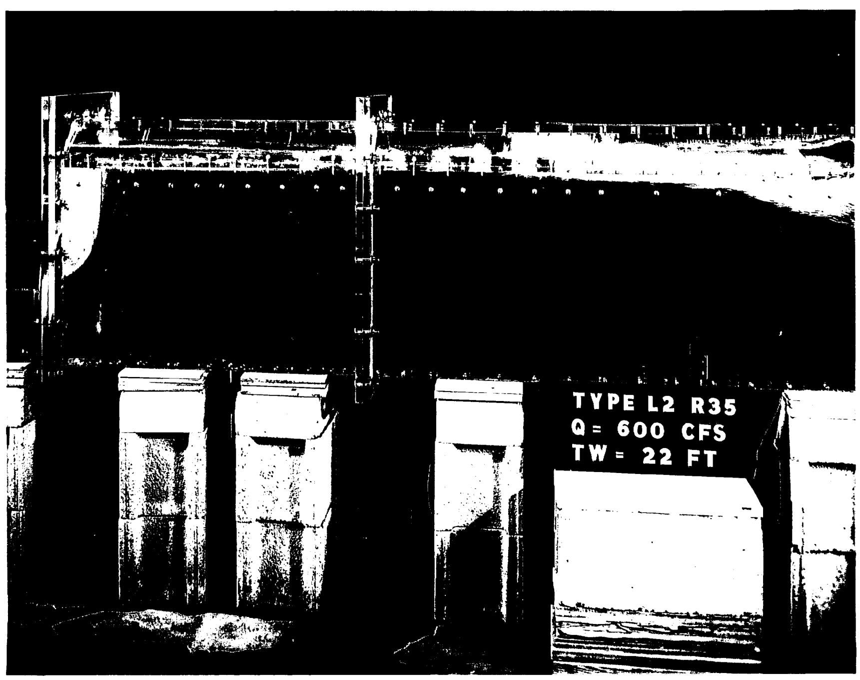

Photo 26. Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 22 ft. The deaeration chamber.

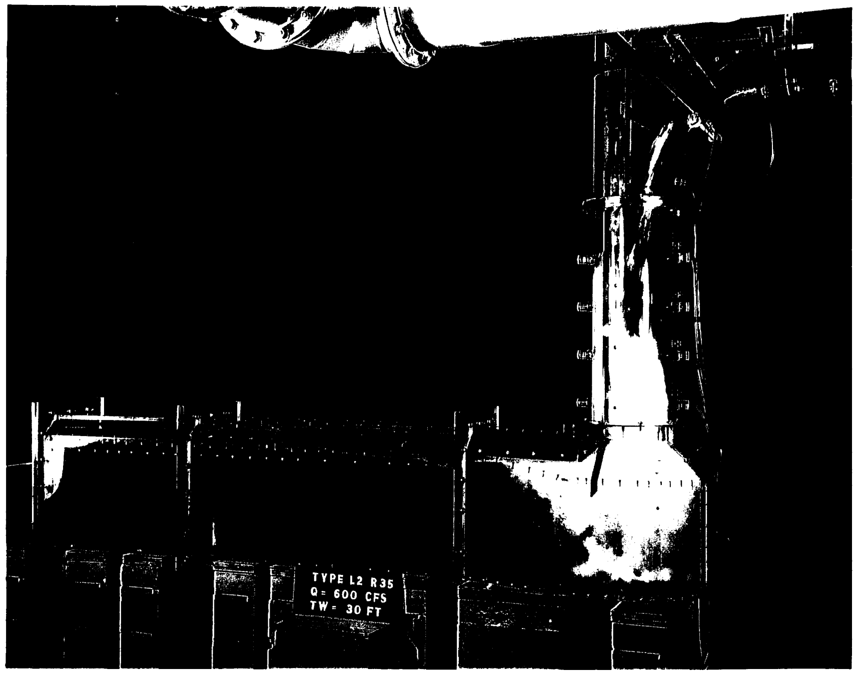

Photo 27. Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 30 ft. The final design.

Photo 28. Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 45 ft. The final design.

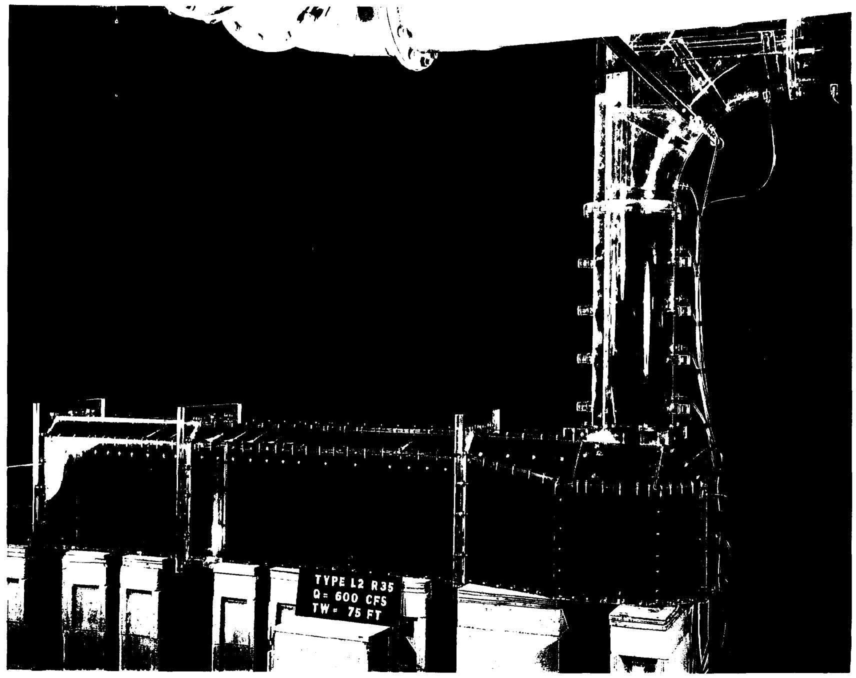

Photo 29. Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 75 ft.
The final design.

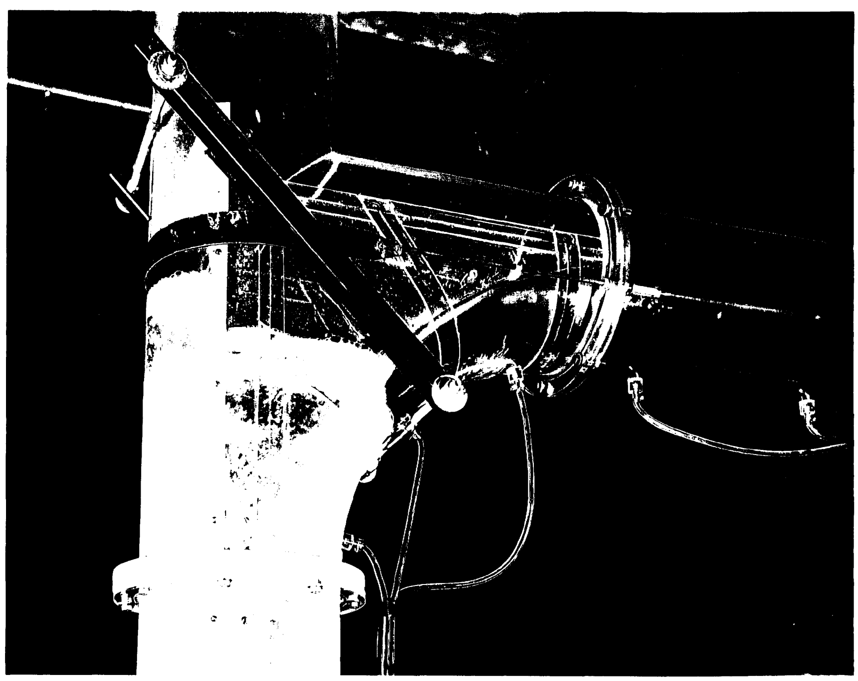

Photo 30. Type L2 R35 dropshaft, Q = 600 cfs, T.W. = 75 ft.
The pipe elbow inlet.

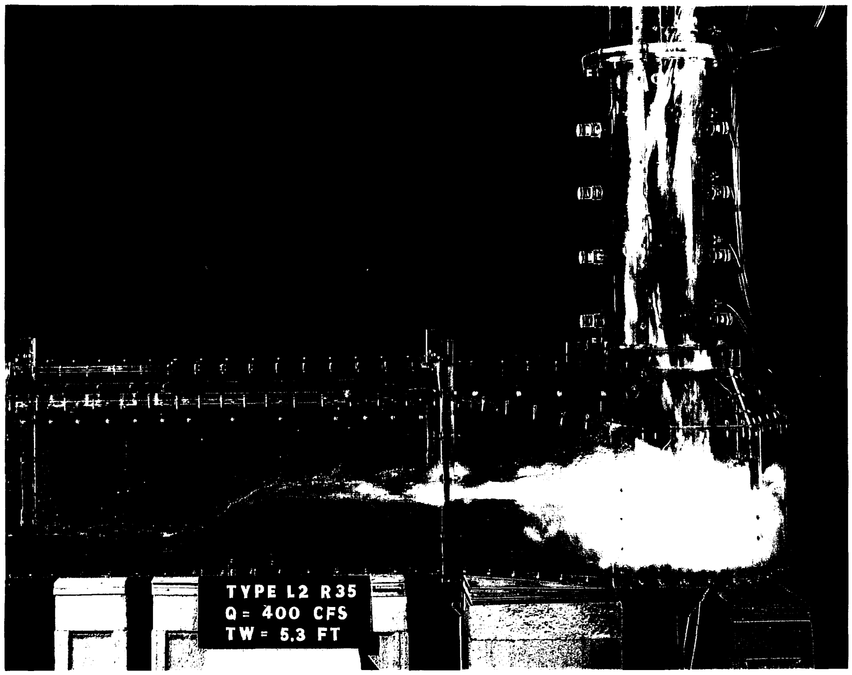

Photo 31. Type L2 R35 dropshaft, Q = 400 cfs, T.W. = 5.3 ft. The sump and deaeration chamber.

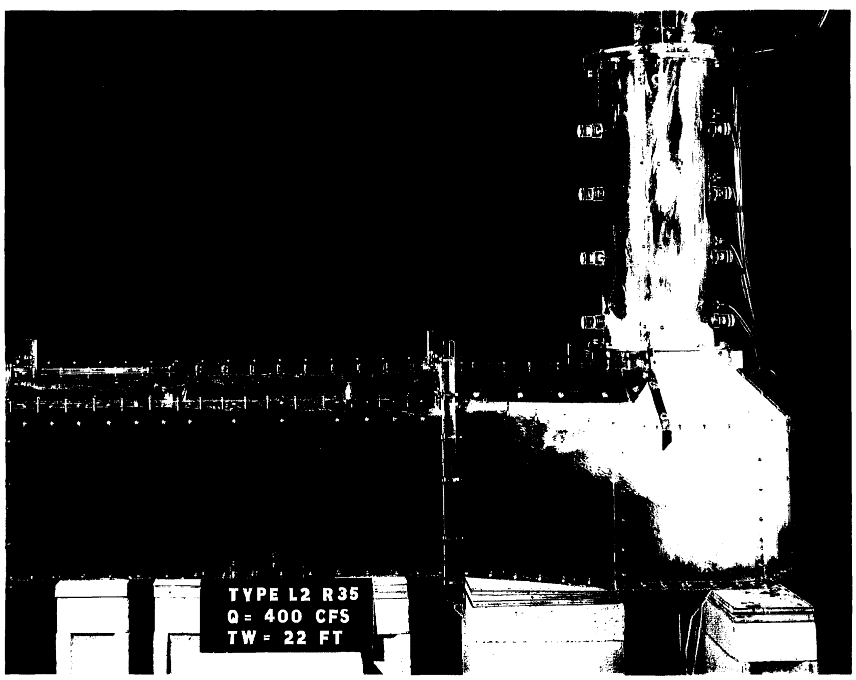

Photo 32. Type L2 R35 dropshaft, Q = 400 cfs, T.W. = 22 ft. The sump and deaeration chamber.

Photo 33. Type L2 R35 dropshaft, Q = 800 cfs, T.W. = 8.5 ft. The final design.

Photo 34. Type L2 R35 dropshaft, Q = 800 cfs, T.W. = 22 ft. The final design.

Photo 35. Type L3 R1 dropshaft, Q = 900 cfs, T.W. = 8.4 ft. The sump and deaeration chamber.

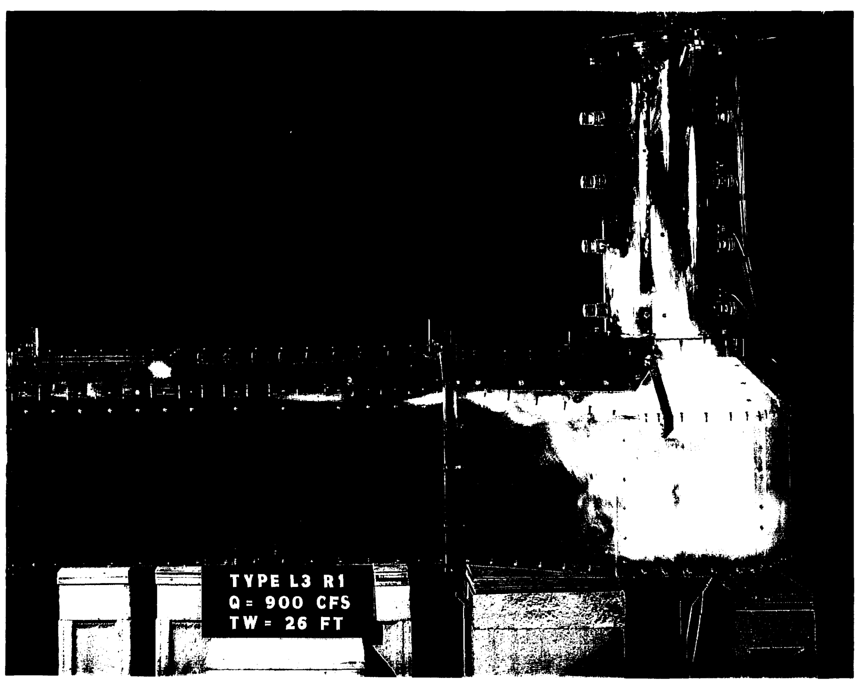

Photo 36. Type L3 R1 dropshaft, Q = 900 cfs, T.W. = 26 ft. The sump and deaeration chamber.

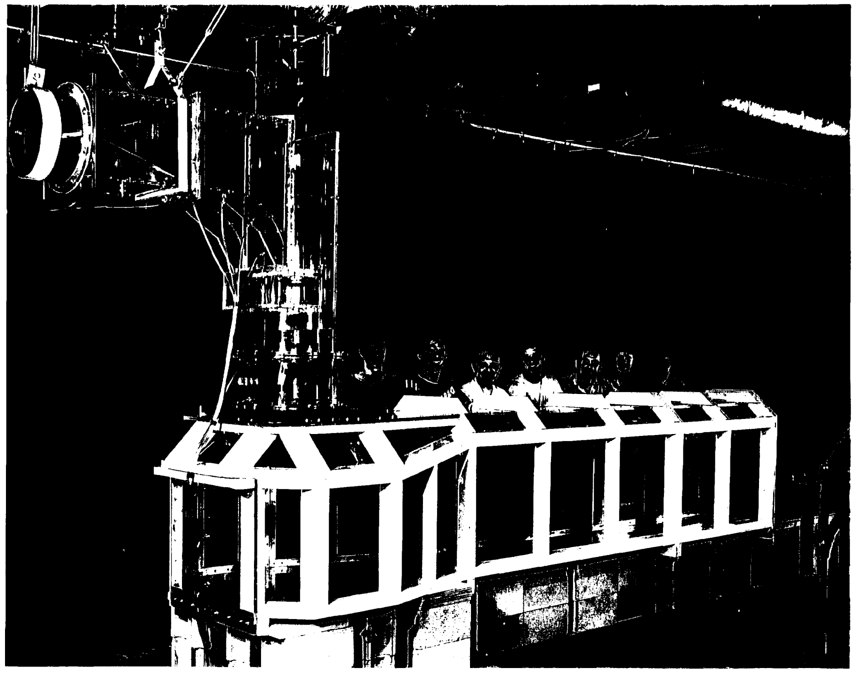

Photo 37. Type L2 R100 dropshaft.
The completed model ready for testing and the personnel responsible for its construction.

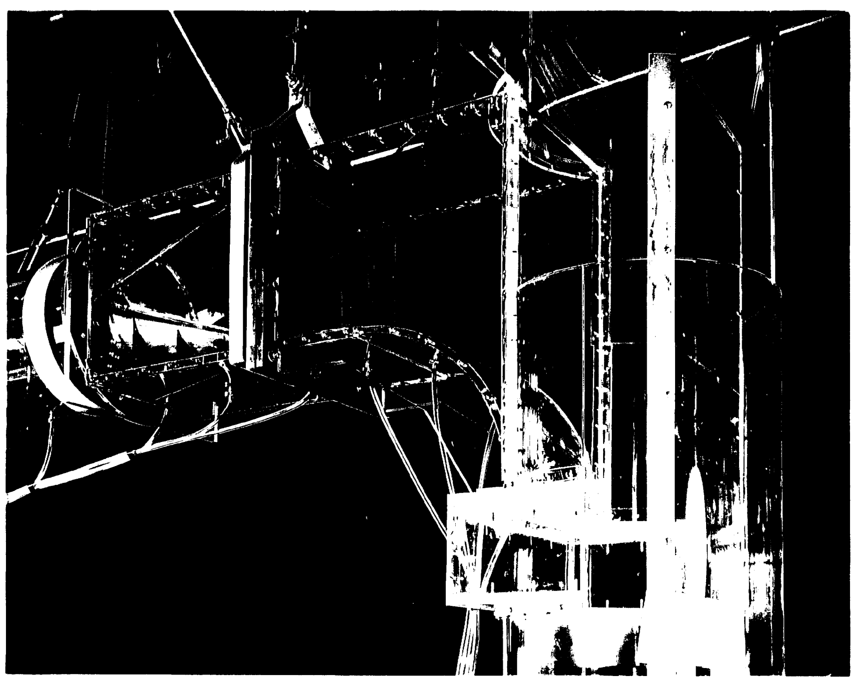

Photo 38. Type L2 R100 dropshaft.
The transition, 1/4 cylinder elbow, and the aeration box.

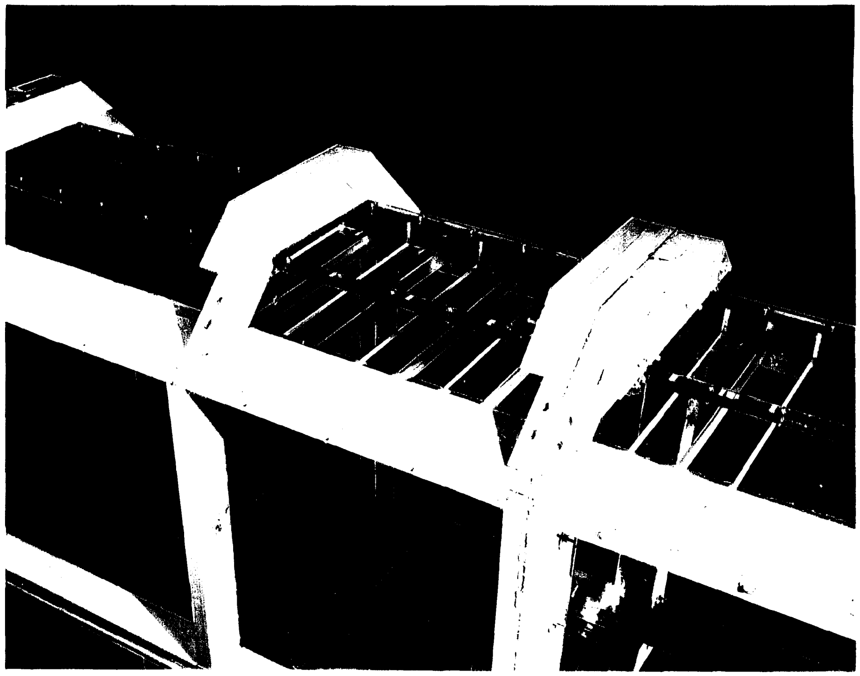

Photo 39. Type L2 R100 dropshaft.
The air slots in the false crown.

Photo 40. Type L2 R100 dropshaft.
The bellmouth.

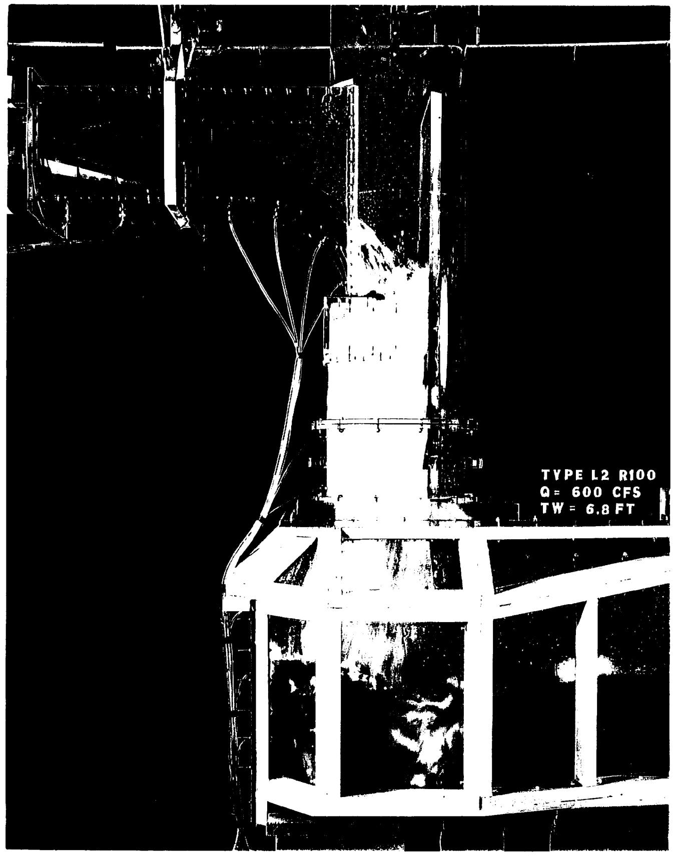

Photo 41. Type L2 R100 dropshaft, Q = 600 cfs, T.W. = 6.8 ft. The inlet, dropshaft, and sump.

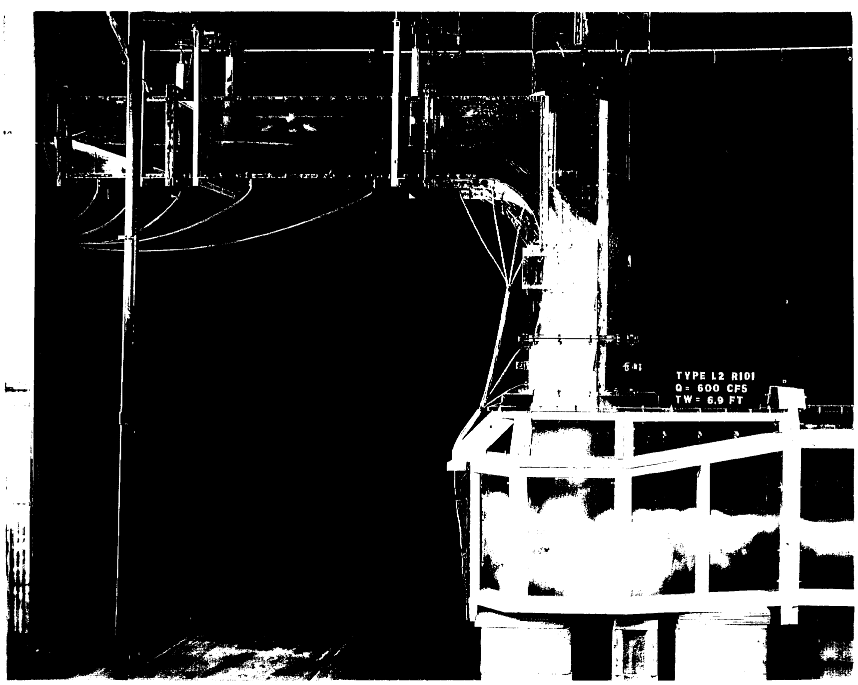

Photo 42. Type L2 R101 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The inlet, dropshaft, and sump with the transition moved upstream.

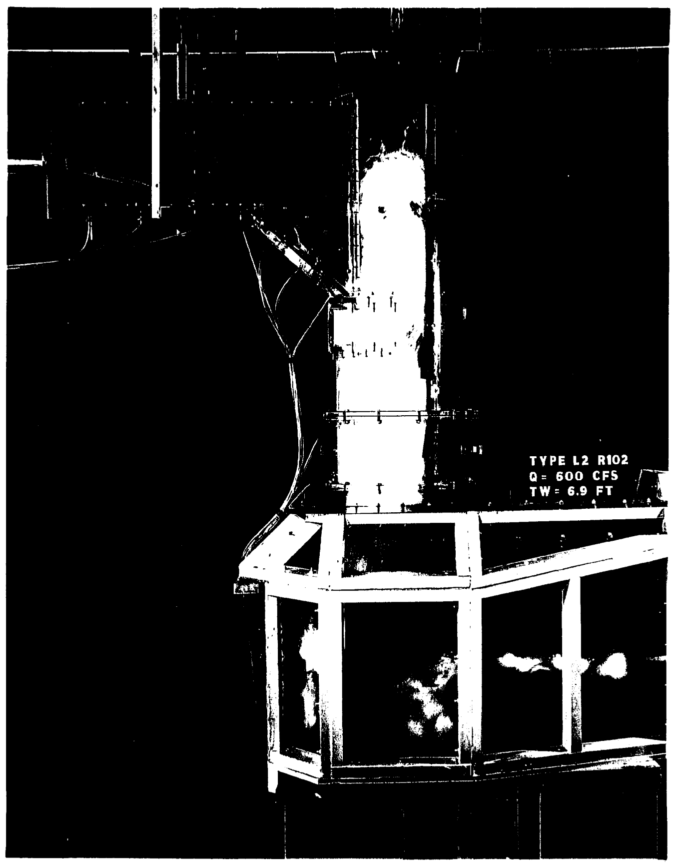

Photo 43. Type L2 R102 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The free trajectory inlet, dropshaft, and sump.

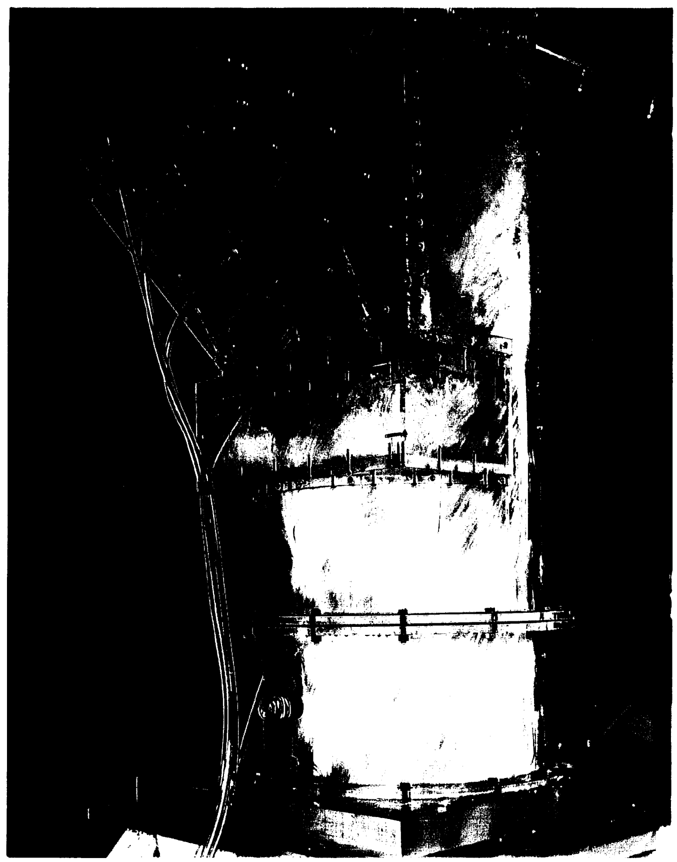

Photo 44. Type L2 R102 dropshaft, Q = 600 cfs, T.W. = 6.9 ft.
The free trajectory inlet and dropshaft.

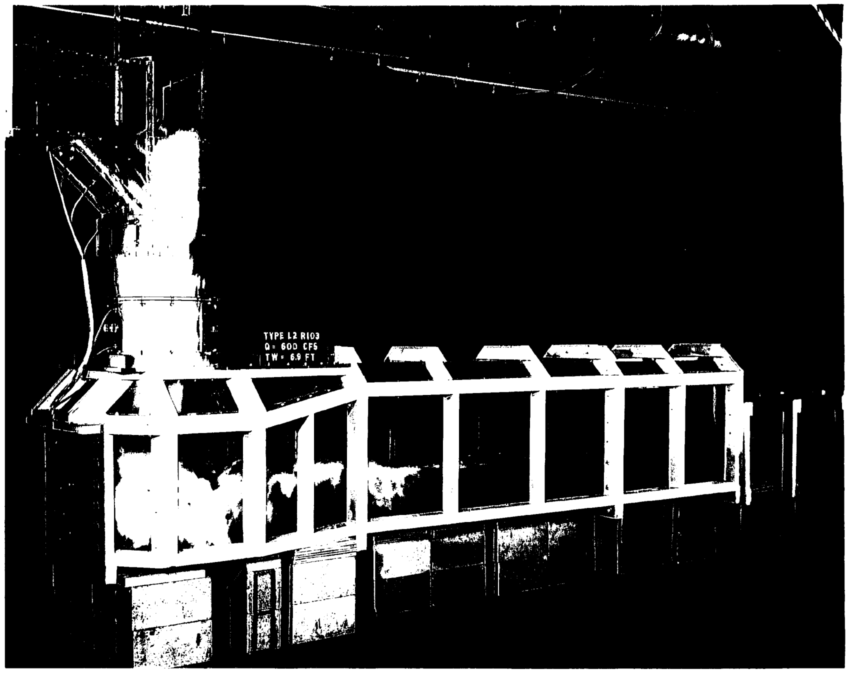

Photo 45. Type L2 R103 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The free trajectory inlet with aeration box blocked off.

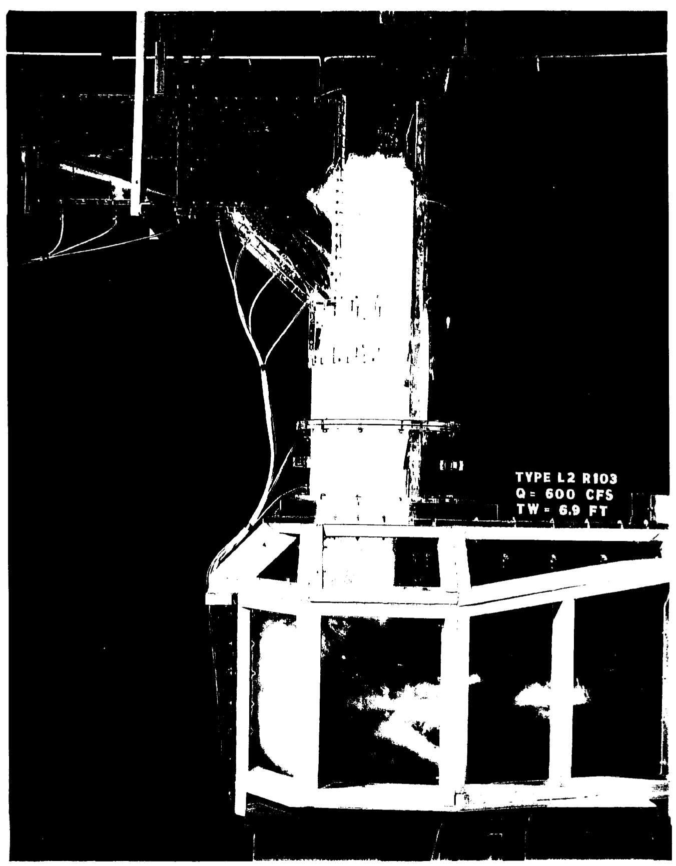

Photo 46. Type L2 R103 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The free trajectory inlet, dropshaft, and sump.

Photo 47. Type L2 R103 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The dropshaft with the aeration box blocked off.

Photo 48. Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 22 ft. The impact area on the divider wall.

Photo 49. Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. The final design.

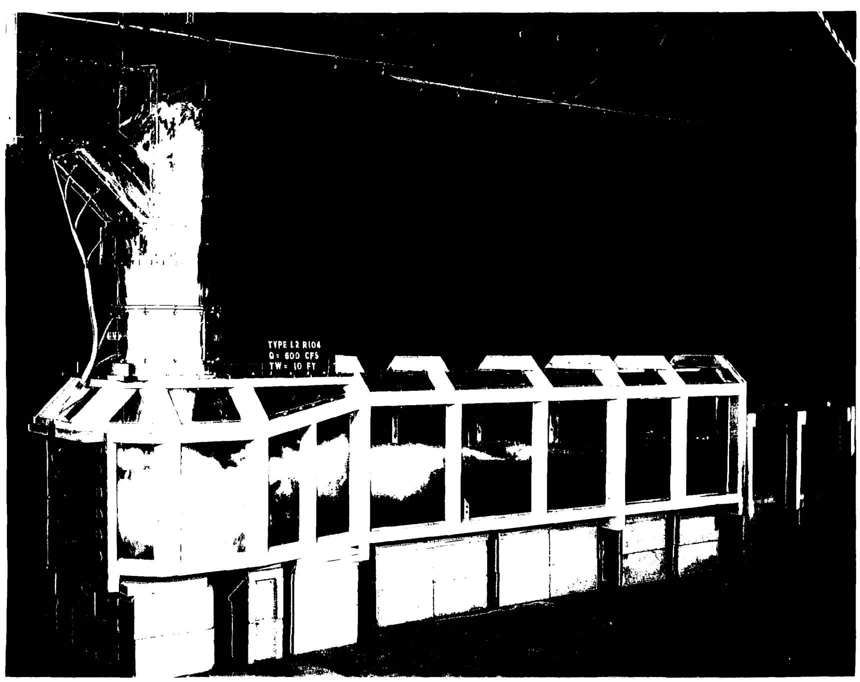

Photo 50. Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 10 ft. The final design.

Photo 51. Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 22 ft. The final design.

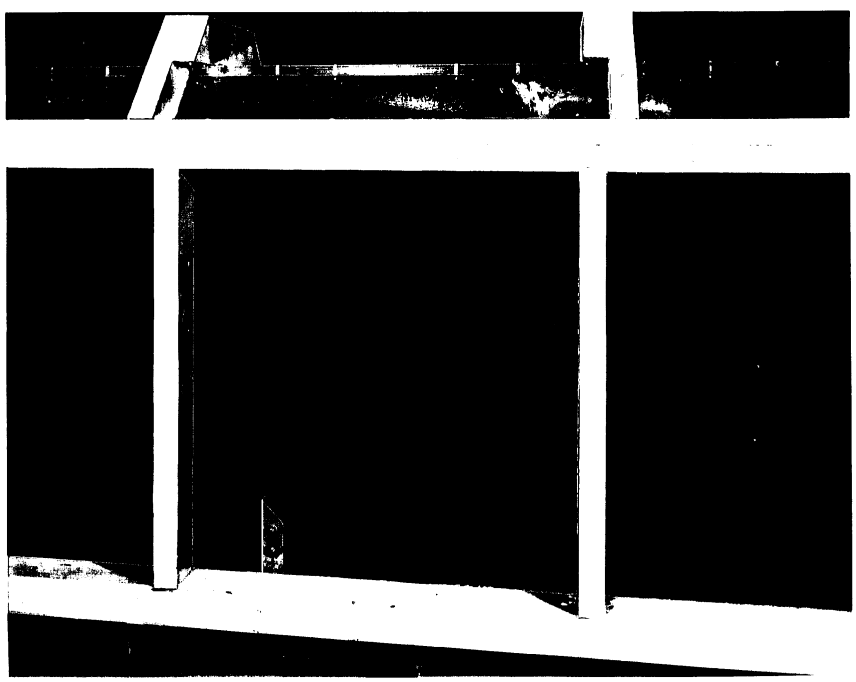

Photo 52. Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 22 ft. The deaeration chamber.

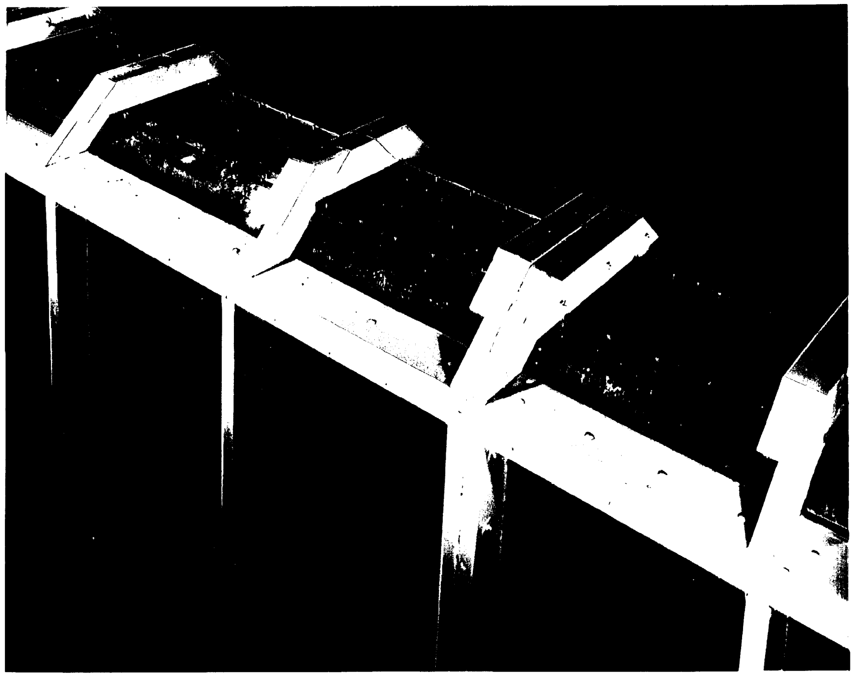

Photo 53. Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 22 ft. The air passing through the slots.

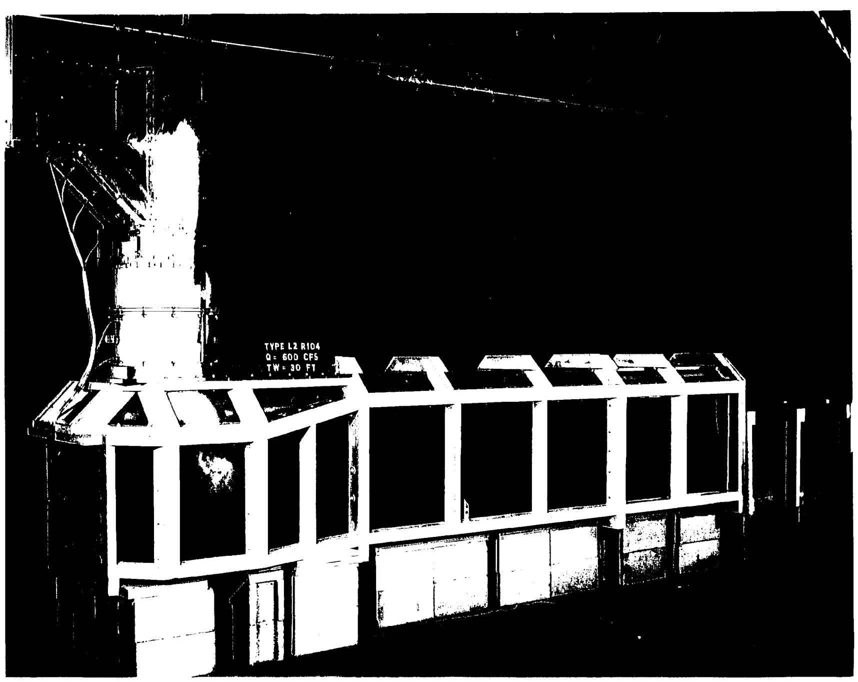

Photo 54. Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 30 ft. The final design.

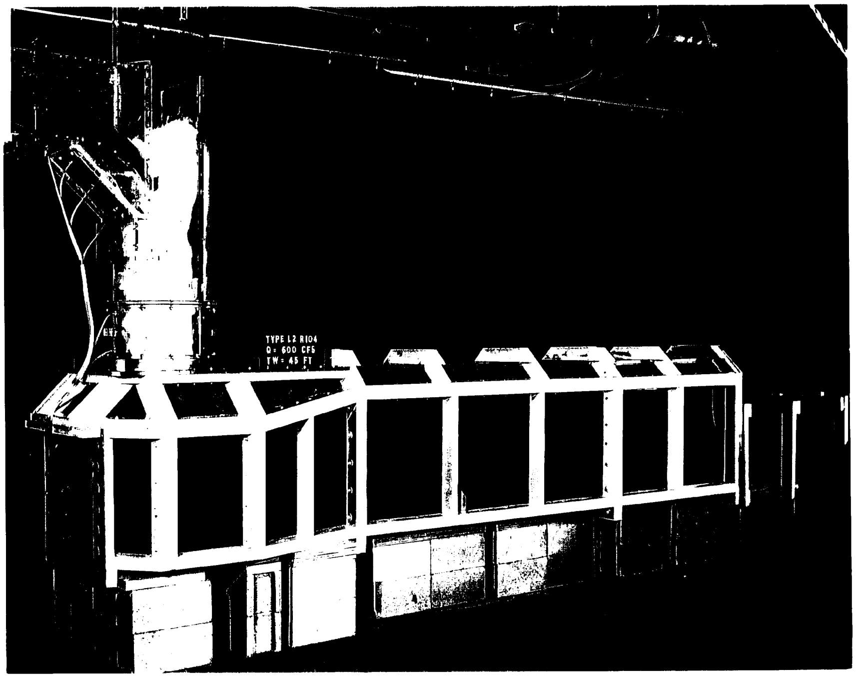

Photo 55. Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 45 ft. The final design.

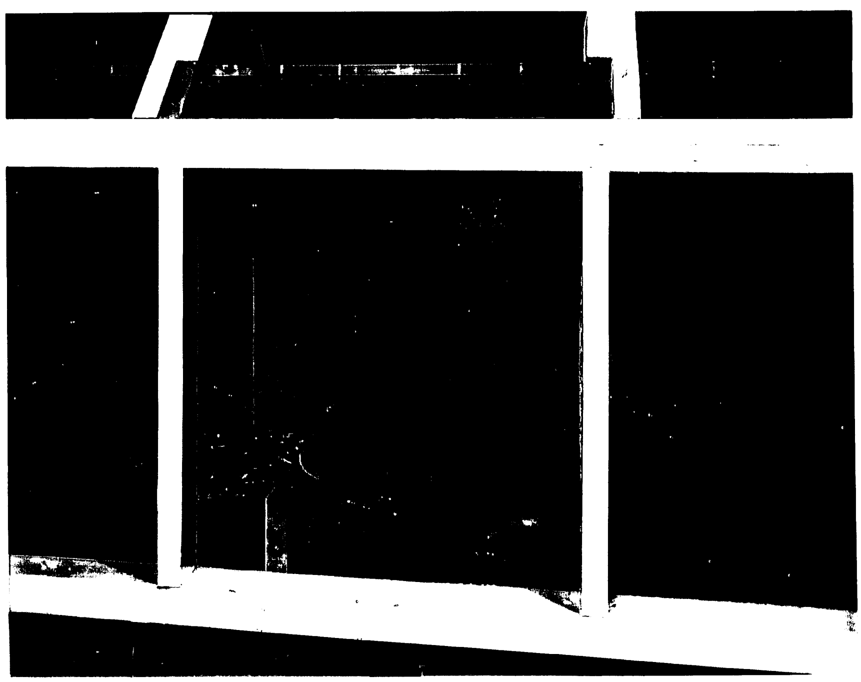

Photo 56. Type L2 R104 dropshaft, Q = 28 cfs. The flow through the slotted weir.

Photo 57. Type L2 R104 dropshaft, Q = 400 cfs, T.W. = 5.8 ft. The final design.

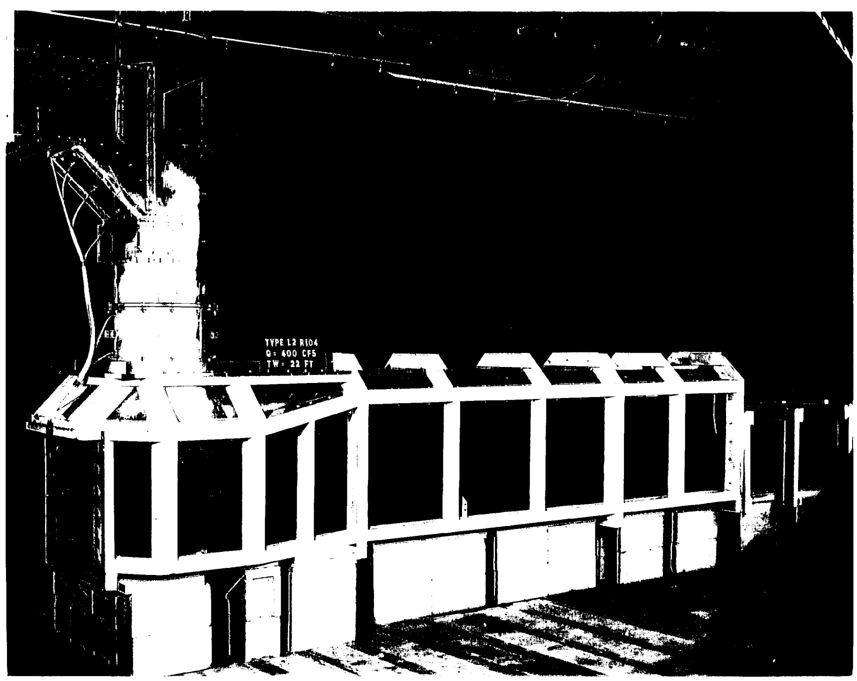

Photo 58. Type L2 R104 dropshaft, Q = 400 cfs, T.W. = 22 ft. The final design.

Photo 59. Type L2 R104 dropshaft, Q = 800 cfs, T.W. = 7.5 ft. The final design.

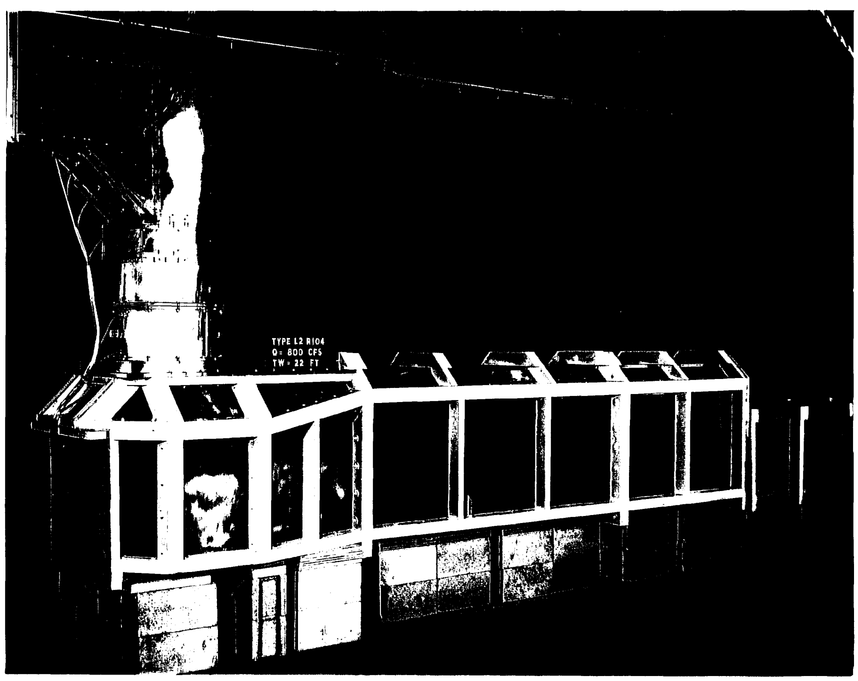

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CHART 112 (302A2321-15) type L2 R100 dropshaft, Q = 400 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 113 (302A2321-102) Type L2 R100 dropshaft, flow conditions varied. Typical pressure fluctuations at tap 21.

CHART 114 (302A2321-13) Type L2 R100 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 115 (302A2321-16) Type L2 R100 dropshaft, Q = 800 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 116 (302A2321-101) Type L2 R100 dropshaft, flow conditions varied. Typical pressure fluctuations at tap 21.

CHART 117 (302A2321-17) Type L2 R100 dropshaft, flow conditions varied. Typical pressure fluctuations at tap 22.

CHART 118 (302A2321-103) Type L2 R100 dropshaft, flow conditions varied. Typical pressure fluctuations at tap 22.

CHART 119 (302A2321-18) Type L2 R100 dropshaft, flow conditions varied. Typical pressure fluctuations at tap 22.

CHART 120 (302A2321-104) Type L2 R100 dropshaft, flow conditions varied. Typical pressure fluctuations at tap 22.

CHART 121 (302A2321-234) Type L2 R100 dropshaft, flow conditions varied. Summary of typical pressure fluctuations at taps 21 and 22.

CHART 122 (302A2321-31) Type L2 R101 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 123 (302A2321-32) Type L2 R101 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 124 (302A2321-123) Type L2 R101 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 125 (302A2321-39) Type L2 R101 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 22.

CHART 126 (302A2321-40) Type L2 R101 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 22.

CHART 127 (302A2321-109) Type L2 R101 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 22.

CHART 128 (302A2321-235) Type L2 R101 dropshaft, flow conditions varied. Summary of typical pressure fluctuations at taps 21 and 22.

CHART 129 (302A2321-70) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 18.

CHART 130 (302A2321-88) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 18.

CHART 131 (302A2321-71) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 20.

CHART 132 (302A2321-89) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 20.

CHART 133 (302A2321-66) Type L2 R104 dropshaft, Q = 200 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 134 (302A2321-92) Type L2 R104 dropshaft, Q = 200 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 135 (302A2321-67) Type L2 R104 dropshaft, Q = 400 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 136 (302A2321-93) Type L2 R104 dropshaft, Q = 400 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 137 (302A2321-68) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 138 (302A2321-94) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 139 (302A2321-69) Type L2 R104 dropshaft, Q = 800 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 140 (302A2321-95) Type L2 R104 dropshaft, Q = 800 cfs, tailwater varied. Typical pressure fluctuations at tap 21.

CHART 141 (302A2321-72) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 22.

CHART 142 (302A2321-90) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at tap 22.

CHART 143 (302A2321-236) Type L2 R104 dropshaft, flow conditions varied. Summary of typical pressure fluctuations at taps 18, 20-22.

CHART 144 (302A2321-59) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at taps 10 and 11.

CHART 145 (302A2321-60) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at taps 13 and 14.

CHART 146 (302A2321-61) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at taps 15 and 16.

CHART 147 (302A2321-62) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at taps 17 and 18.

CHART 148 (302A2321-63) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at taps 19 and 23.

CHART 149 (302A2321-64) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at taps 24 and 26.

CHART 150 (302A2321-65) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Typical pressure fluctuations at taps 30 and 35.

CHART 151 (302A2321-237) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Summary of typical pressure fluctuations at various taps.

CHART 152 (302A2321-96) Type L2 R104 dropshaft, Q = 200 cfs, tailwater varied. Air concentrations in dropshaft.

CHART 153 (302A2321-97) Type L2 R104 dropshaft, Q = 400 cfs, tailwater varied. Air concentrations in dropshaft.

CHART 154 (302A2321-98) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Air concentrations in dropshaft.

CHART 155 (302A2321-99) Type L2 R104 dropshaft, Q = 800 cfs, tailwater varied. Air concentrations in dropshaft.

CHART 156 (302A2321-238) Single spectrum display.

CHART 157 (302A2321-212) Type L2 R100 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. Spectrum displays at tap 39.

CHART 158 (302A2321-213) Type L2 R100 dropshaft, Q = 600 cfs, tailwater varied. Spectrum displays at tap 39.

CHART 159 (302A2321-216) Type L2 R101 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. Spectrum displays at tap 39.

CHART 160 (302A2321-217) Type L2 R101 dropshaft, Q = 600 cfs, tailwater varied. Spectrum displays at tap 39.

CHART 161 (302A2321-220) Type L2 R104 dropshaft, Q = 330 cfs, tailwater varied. Spectrum displays at tap 39.

CHART 162 (302A2321-219) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Spectrum displays at tap 39.

CHART 163 (302A2321-222) Type L2 R104 dropshaft, Q = 400 cfs, tailwater varied. Spectrum displays at tap 40.

CHART 164 (302A2321-221) Type L2 R104 dropshaft, = 600 cfs, tailwater varied. Spectrum displays at tap 40.

CHART 165 (302A2321-215) Type L2 R100 dropshaft, flow conditions varied. Spectrum displays at tap 21.

CHART 166 (302A2321-214) Type L2 R100 dropshaft, Q = 600 cfs, tailwater varied. Spectrum displays at tap 21.

CHART 167 (302A2321-218) Type L2 R101 dropshaft, Q = 600 cfs, tailwater varied. Spectrum displays at tap 21.

CHART 168 (302A2321-226) Type L2 R104 dropshaft, Q = 200 cfs, tailwater varied. Spectrum displays at tap 21.

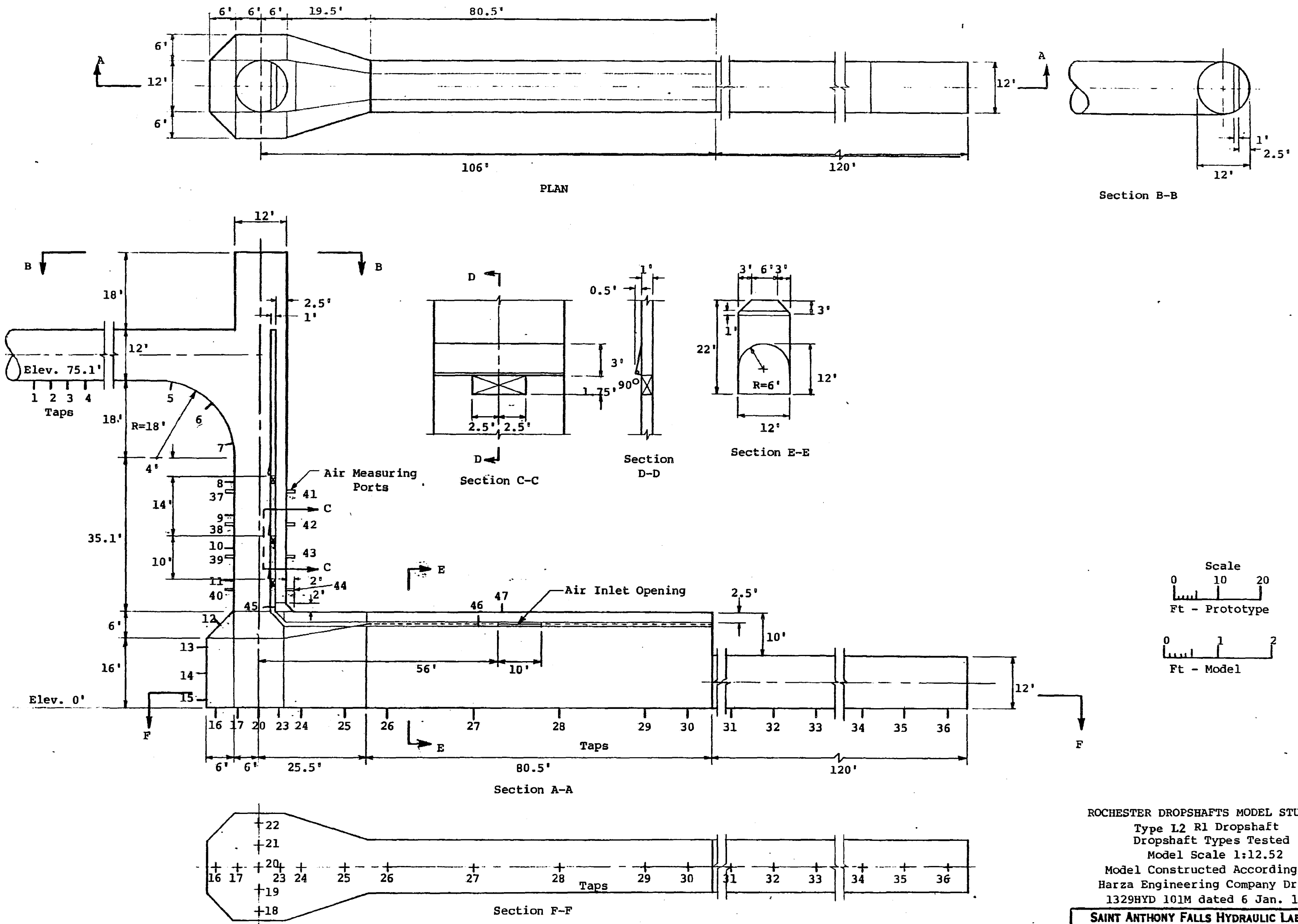
CHART 169 (302A2321-225) Type L2 R104 dropshaft, Q = 400 cfs, tailwater varied. Spectrum displays at tap 21.

CHART 170 (302A2321-223) Type L2 R104 dropshaft, Q = 600 cfs, T.W. = 6.9 ft. Spectrum displays at tap 21.

CHART 171 (302A2321-224) Type L2 R104 dropshaft, Q = 600 cfs, tailwater varied. Spectrum displays at tap 21.

CHART 172 (302A2321-239) Determining spectrum values.

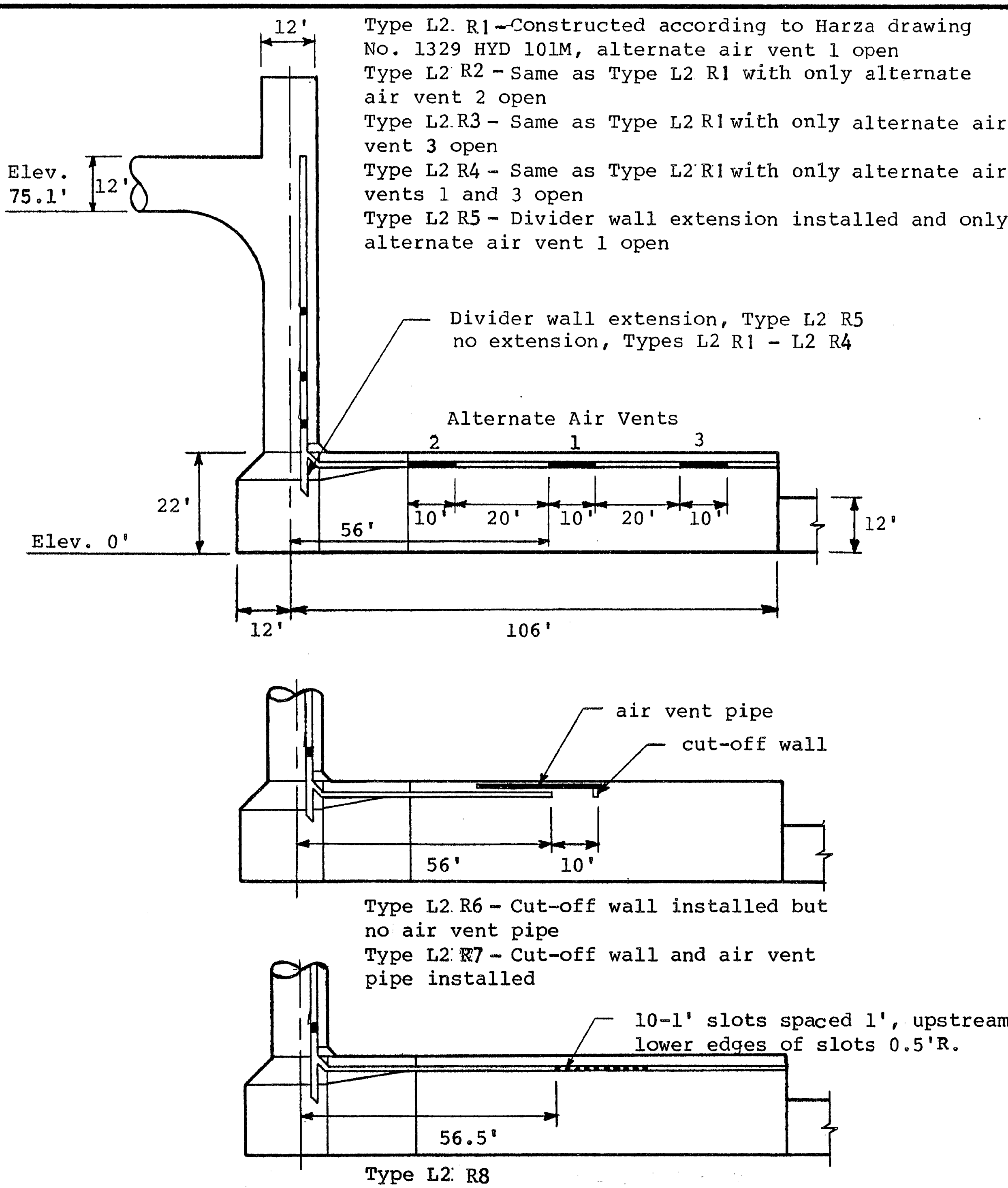
CHART 173 (302B511-12) Type L3 R100 dropshaft, dropshaft types tested.



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R1 Dropshaft
Dropshaft Types Tested
Model Scale 1:12.52
Model Constructed According to
Harza Engineering Company Drawing
1329HYD 101M dated 6 Jan. 1981

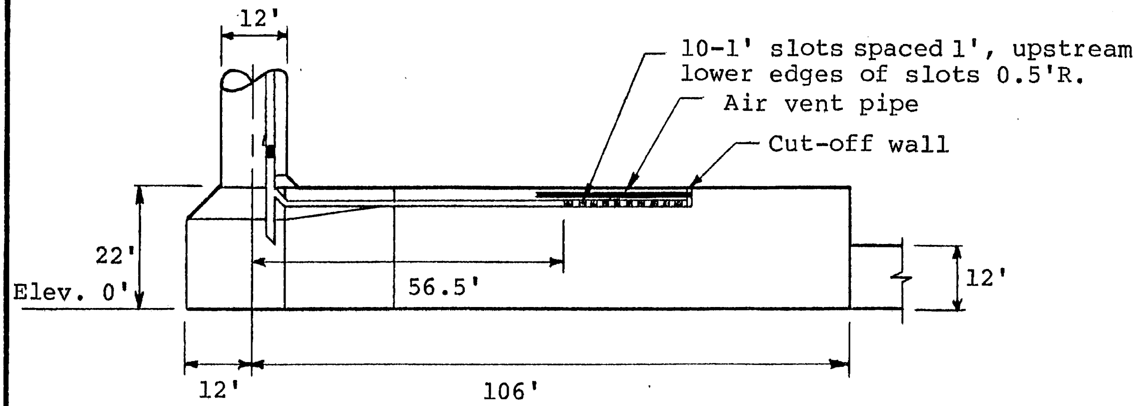
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 4/9/81	NO. 302B511-6

CHART 1

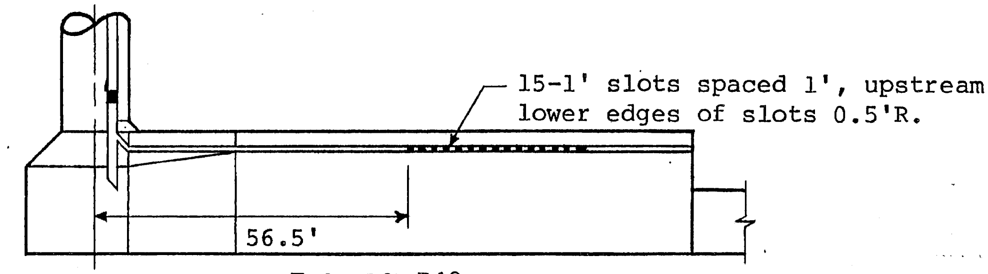


ROCHESTER DROPSHAFTS MODEL STUDIES
Dropshaft Types Tested
Model Scale 1:12.52

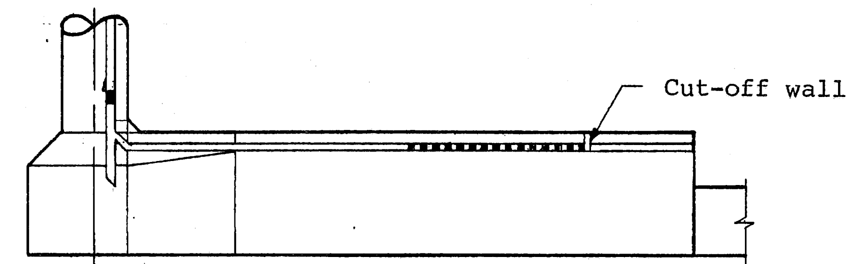
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 2/3/82	NO. 302A2321-167



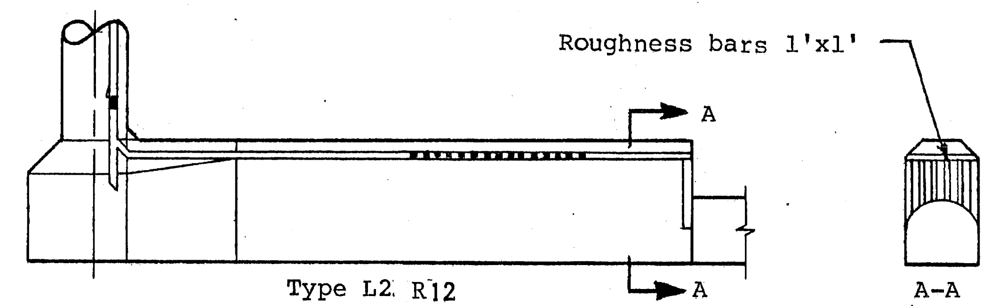
Type L2. R9



Type L2' R10



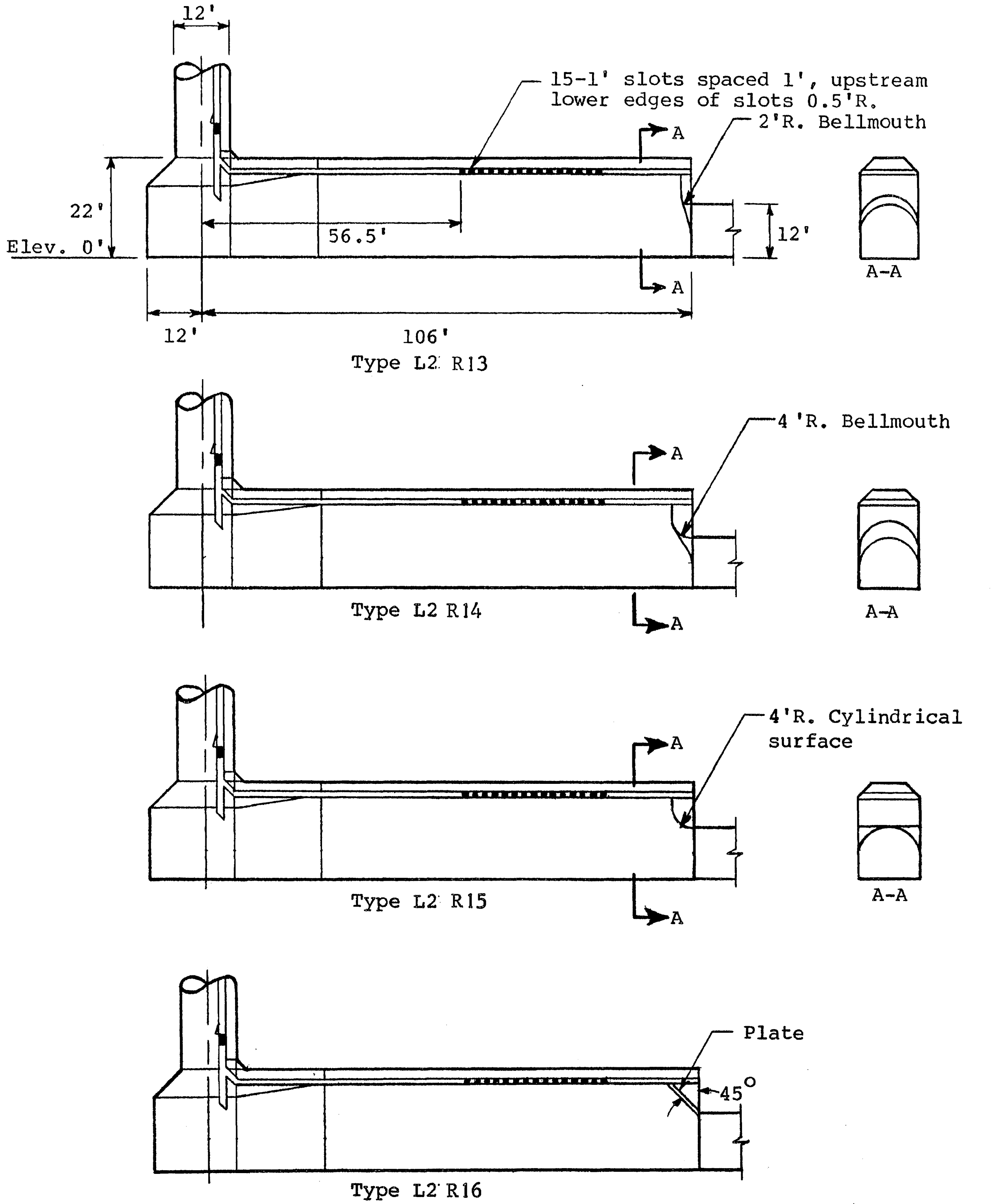
Type L2: R11



Type L2. R12

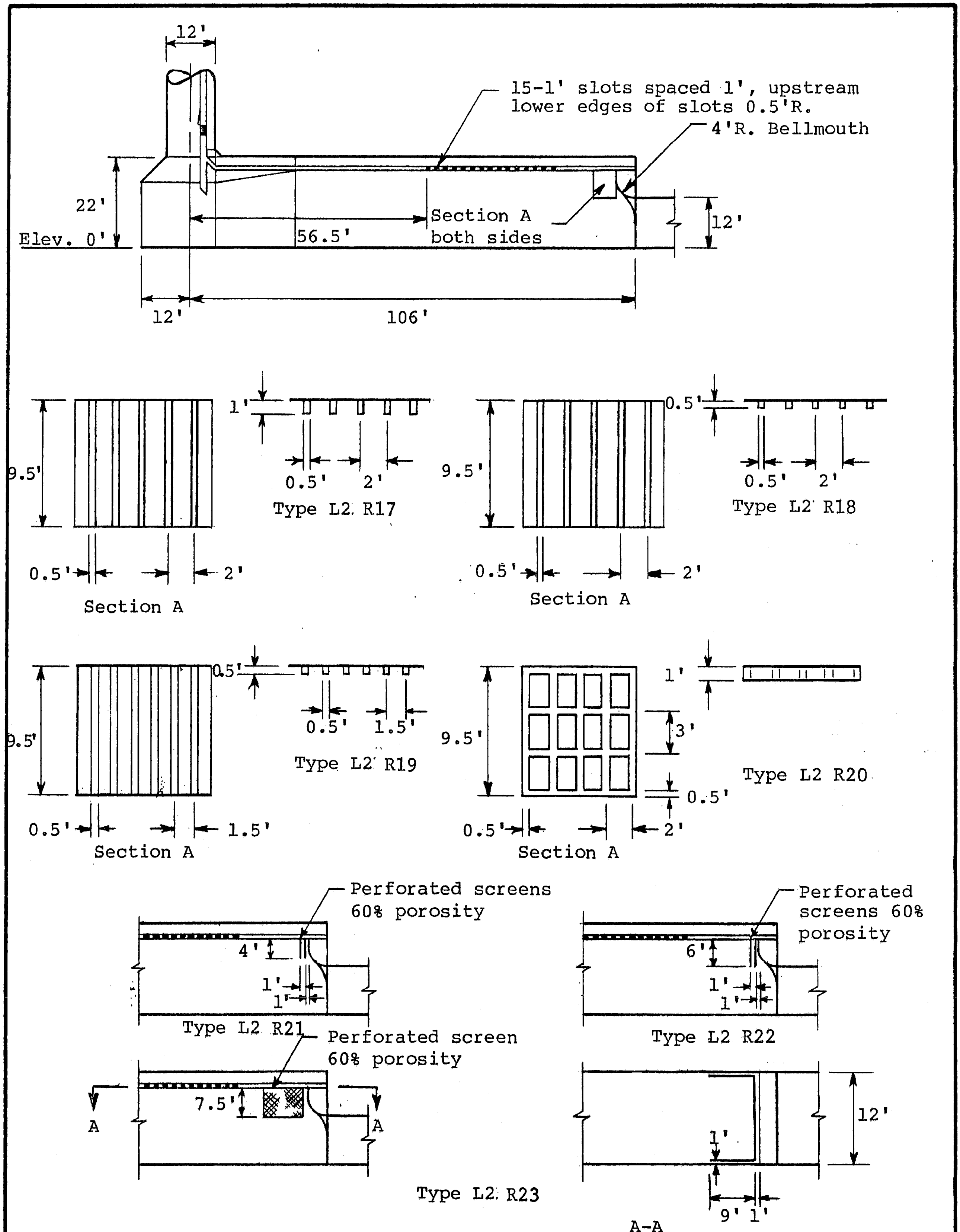
ROCHESTER DROPSHAFTS MODEL STUDIES
Dropshaft Types Tested
Model Scale 1:12.52

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 2/3/82	NO. 302A2321-168



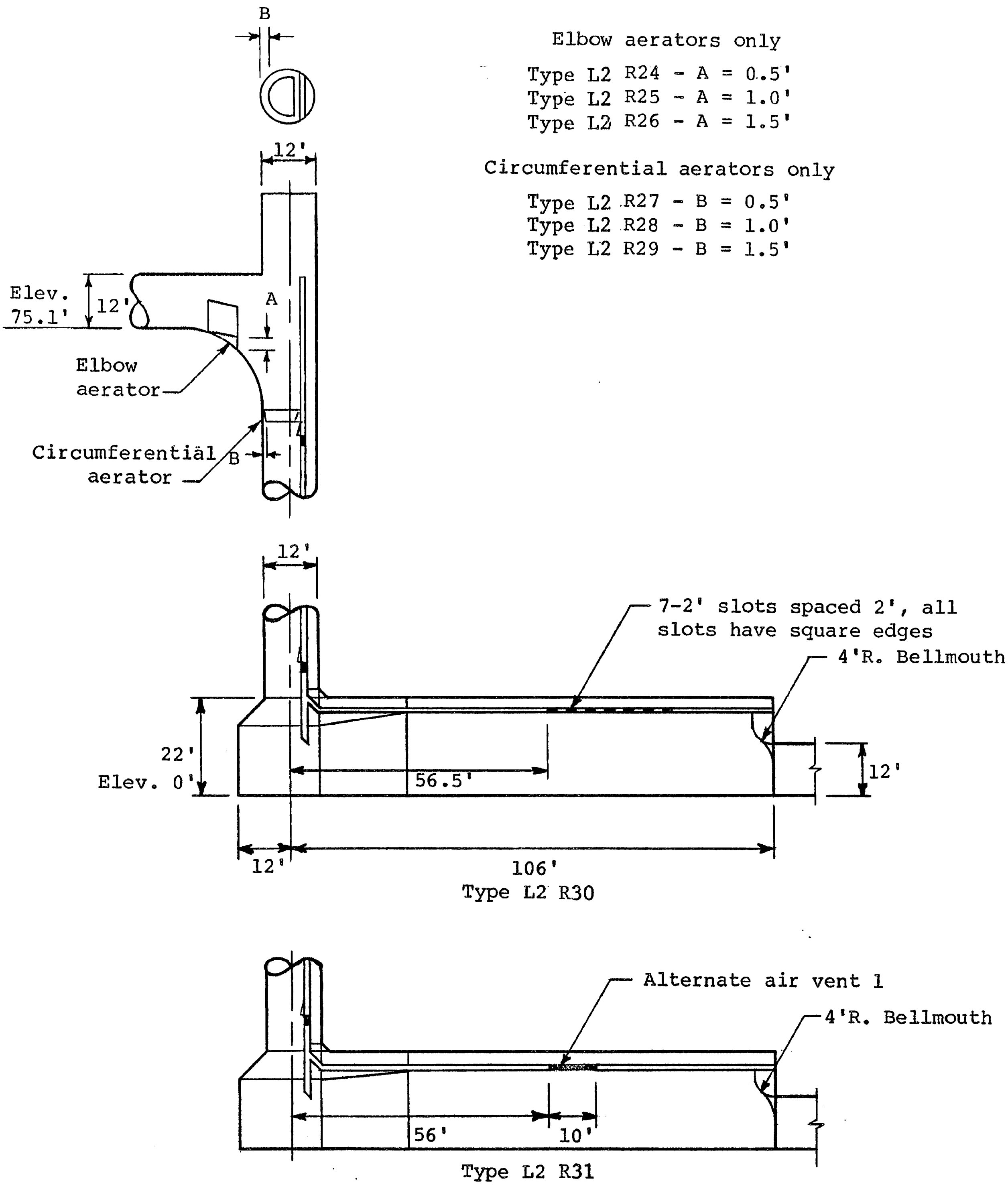
ROCHESTER DROPSHAFTS MODEL STUDIES
Dropshaft Types Tested
Model Scale 1:12.52

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 2/3/82	NO. 302A2321-169



ROCHESTER DROPSHAFTS MODEL STUDIES
Dropshaft Types Tested
Model Scale 1:12.52

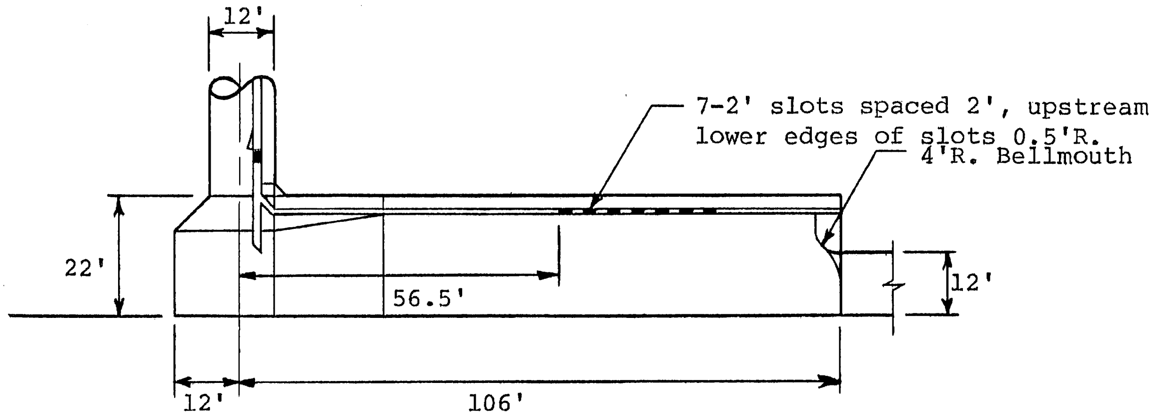
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 2/3/82	NO. 302A2321-170



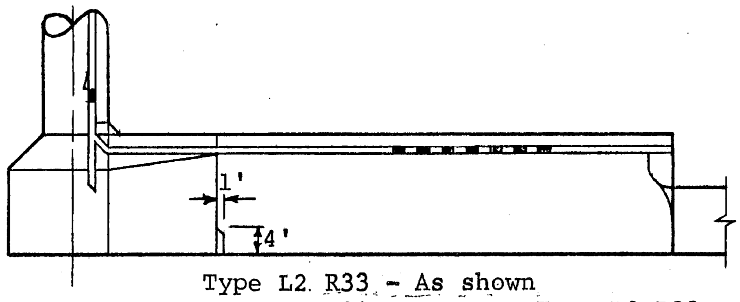
ROCHESTER DROPSHAFTS MODEL STUDIES
Dropshaft Types Tested
Model Scale 1:12.52

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

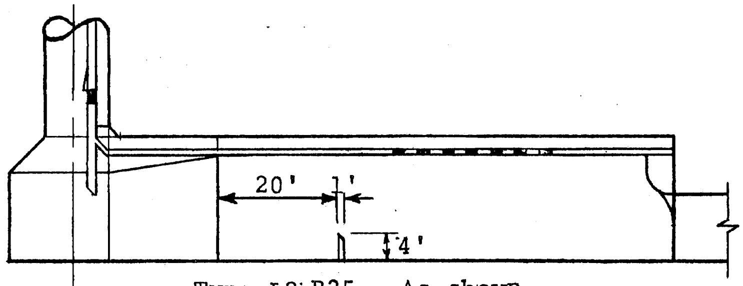
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 2/3/82	NO. 302A2321-171



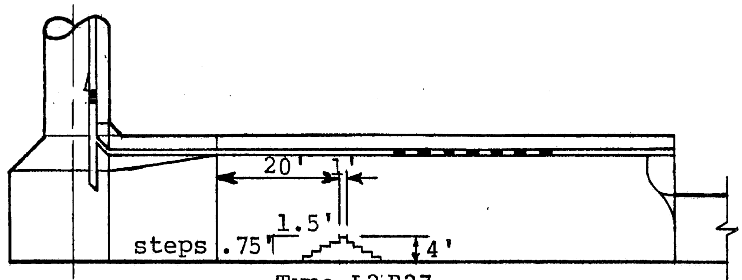
Type L2 R32



Type L2 R33 - As shown
Type L2 R34 - Same as Type L2 R33
with weir height of 8'



Type L2 R35 - As shown
Type L2 R36 - Same as Type L2 R35
with weir height of 8'

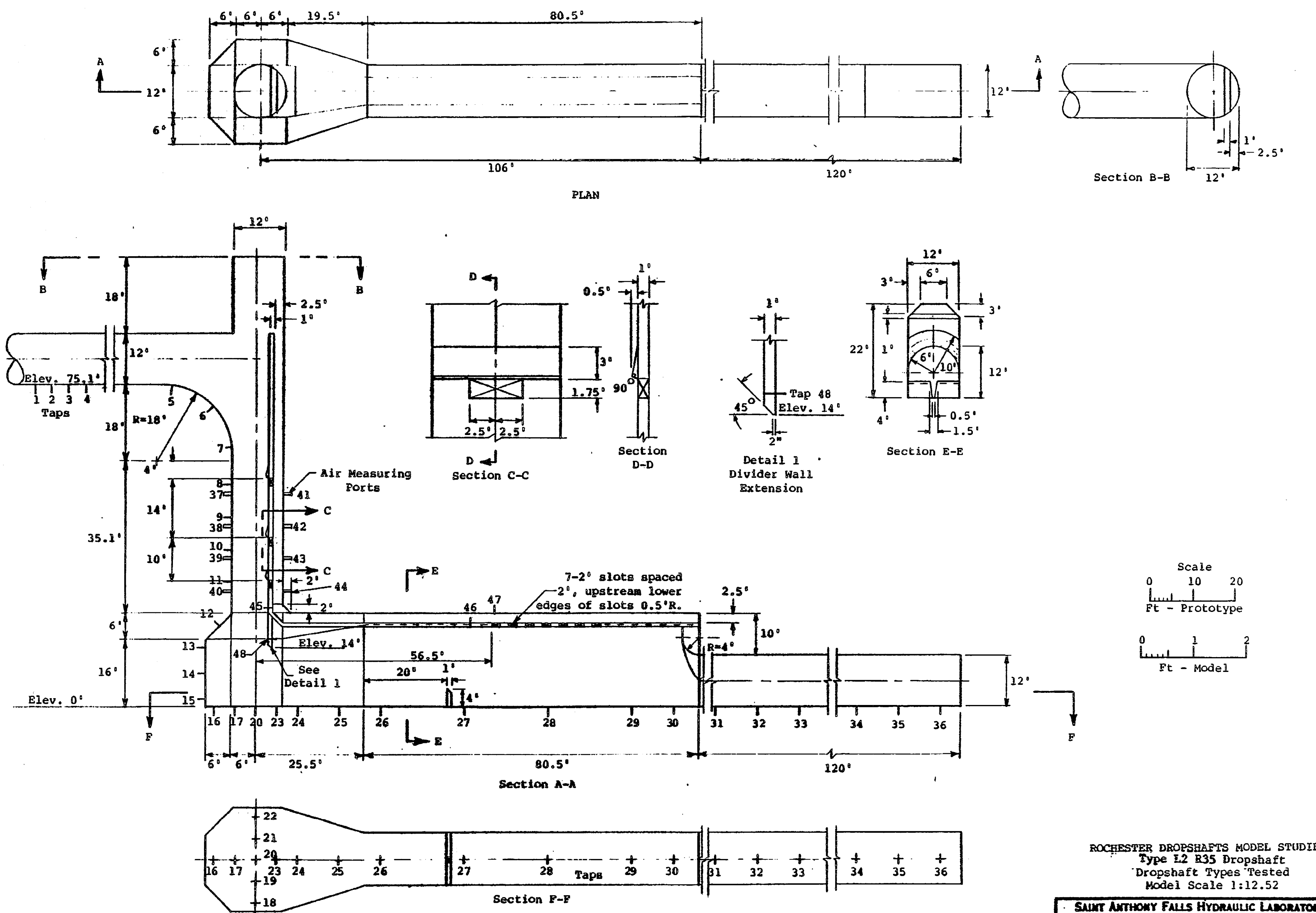


Type L2 R37

ROCHESTER DROPSHAFTS MODEL STUDIES
Dropshaft Types Tested
Model Scale 1:12.52

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

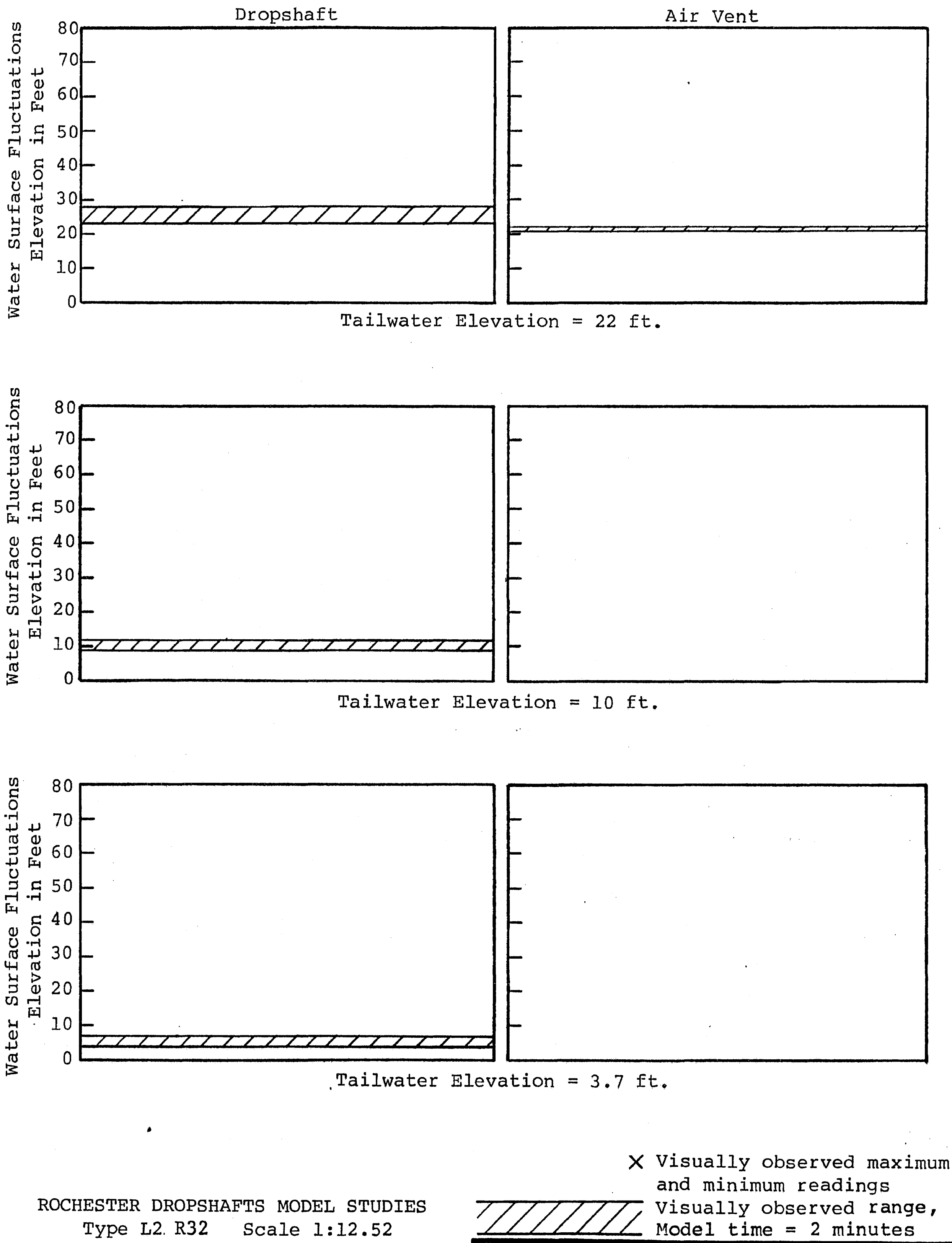
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 2/3/82	NO. 302A2321-172



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Dropshaft
Dropshaft Types Tested
Model Scale 1:12.52

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 1/6/82	NO. 302B511-7

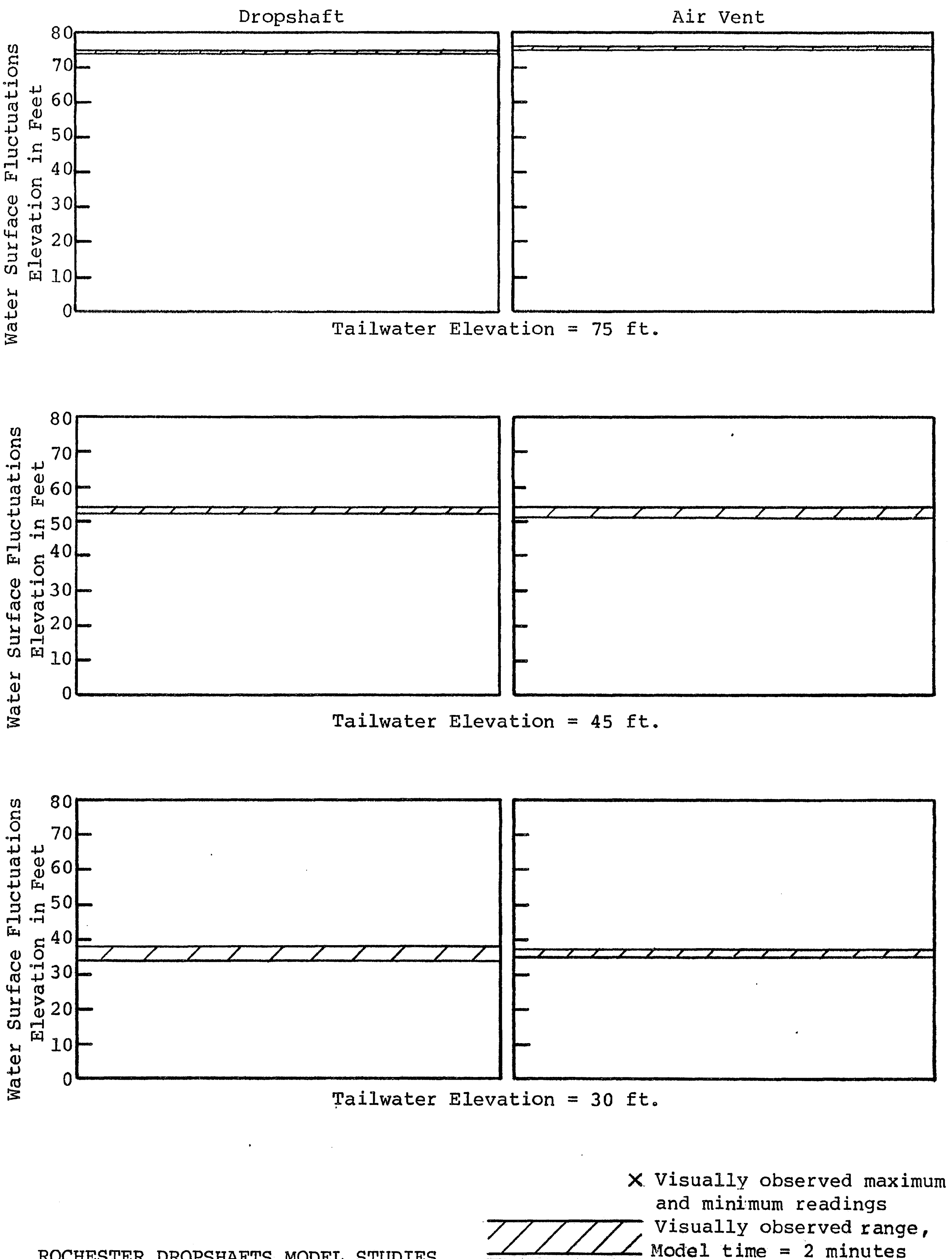
CHART 8



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Water Surface Fluctuations
Q = 200 cfs

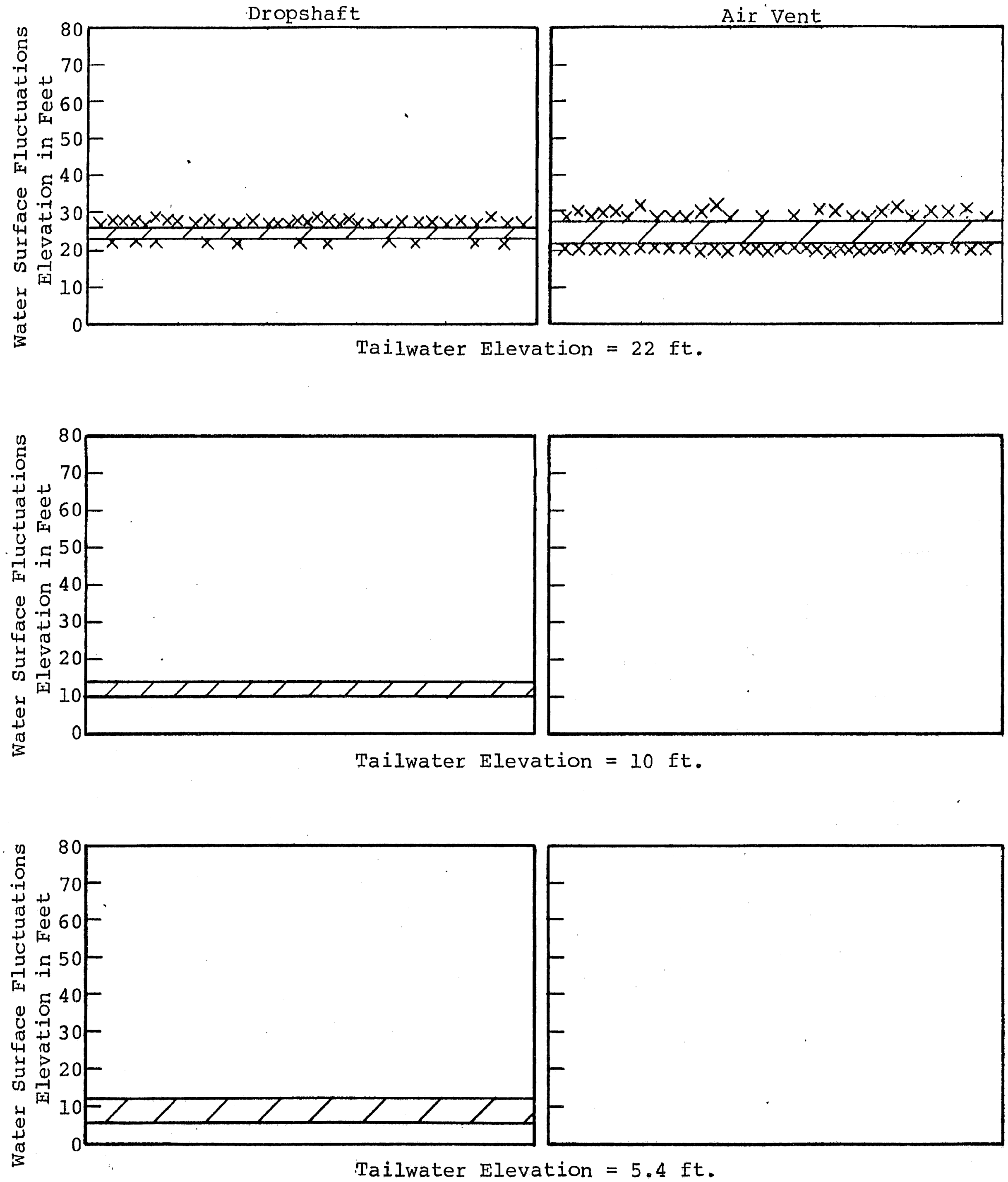
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 2/1/82	NO. 302A2321-159



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Water Surface Fluctuations
Q = 200 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED MD[illegible]	APPROVED
SCALE	DATE 2/1/82	NO.302A2321-160



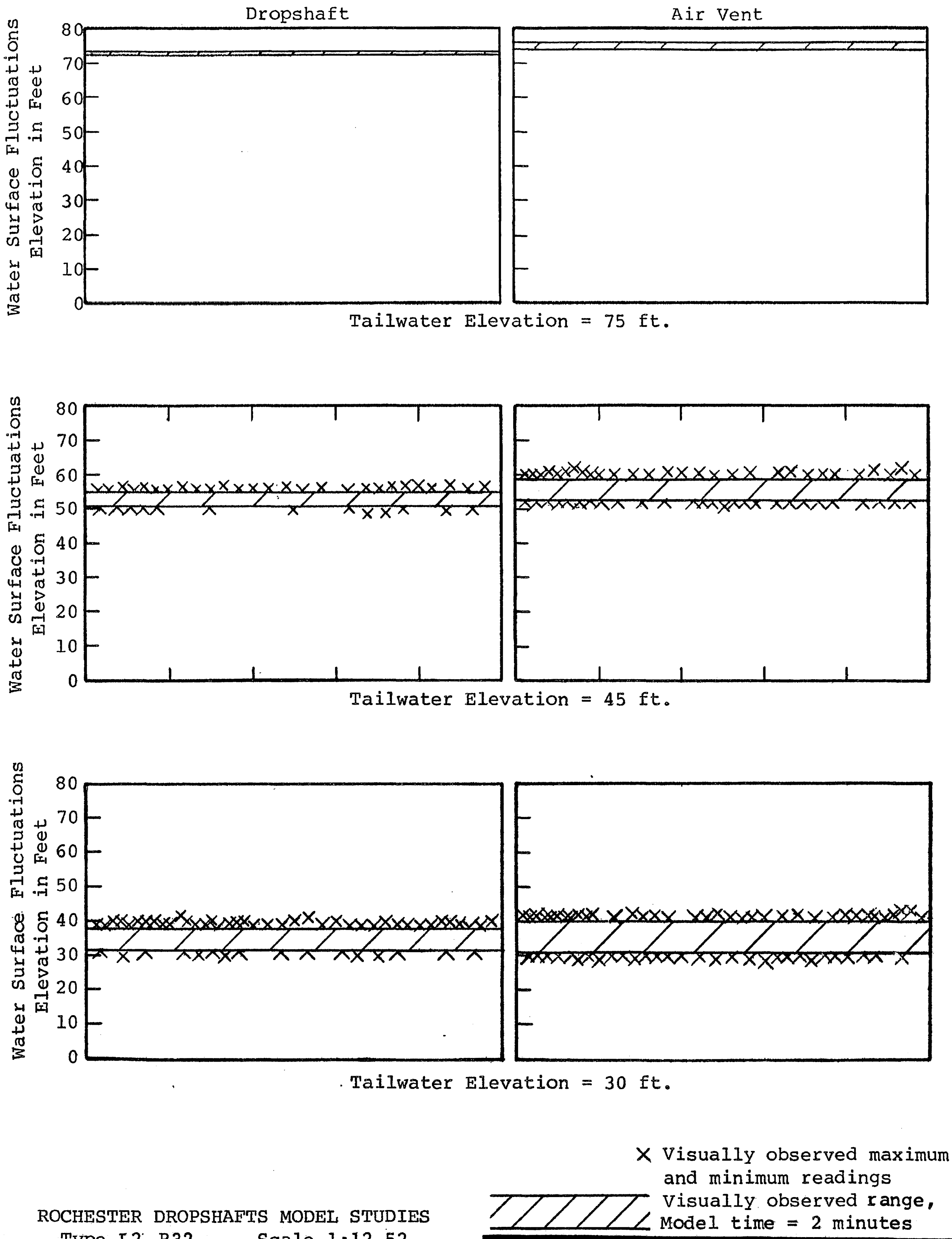
× Visually observed maximum and minimum readings

▨ Visually observed range, Model time = 2 minutes

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Water Surface Fluctuations
Q = 400 cfs

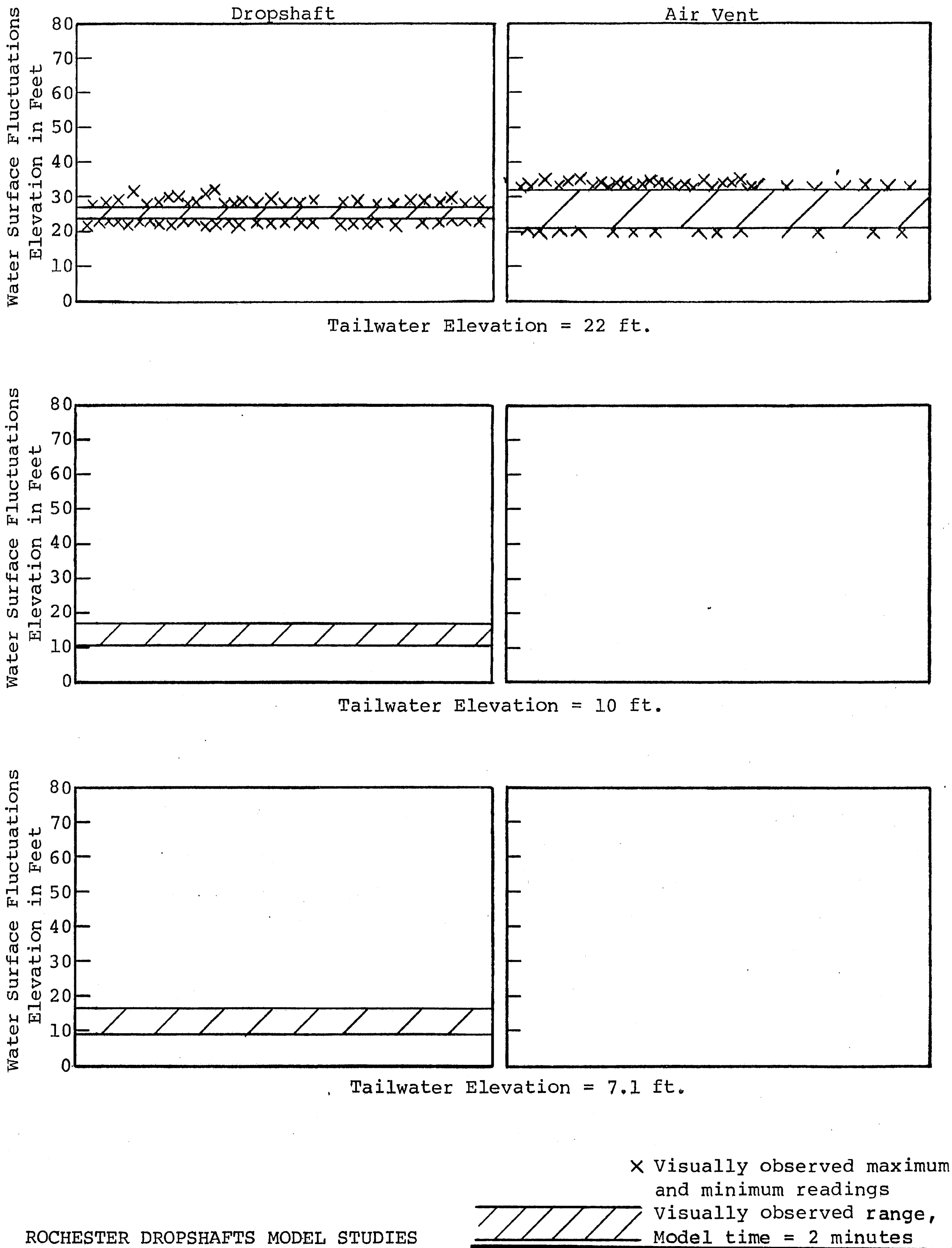
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 2/1/82	NO. 302A2321-161



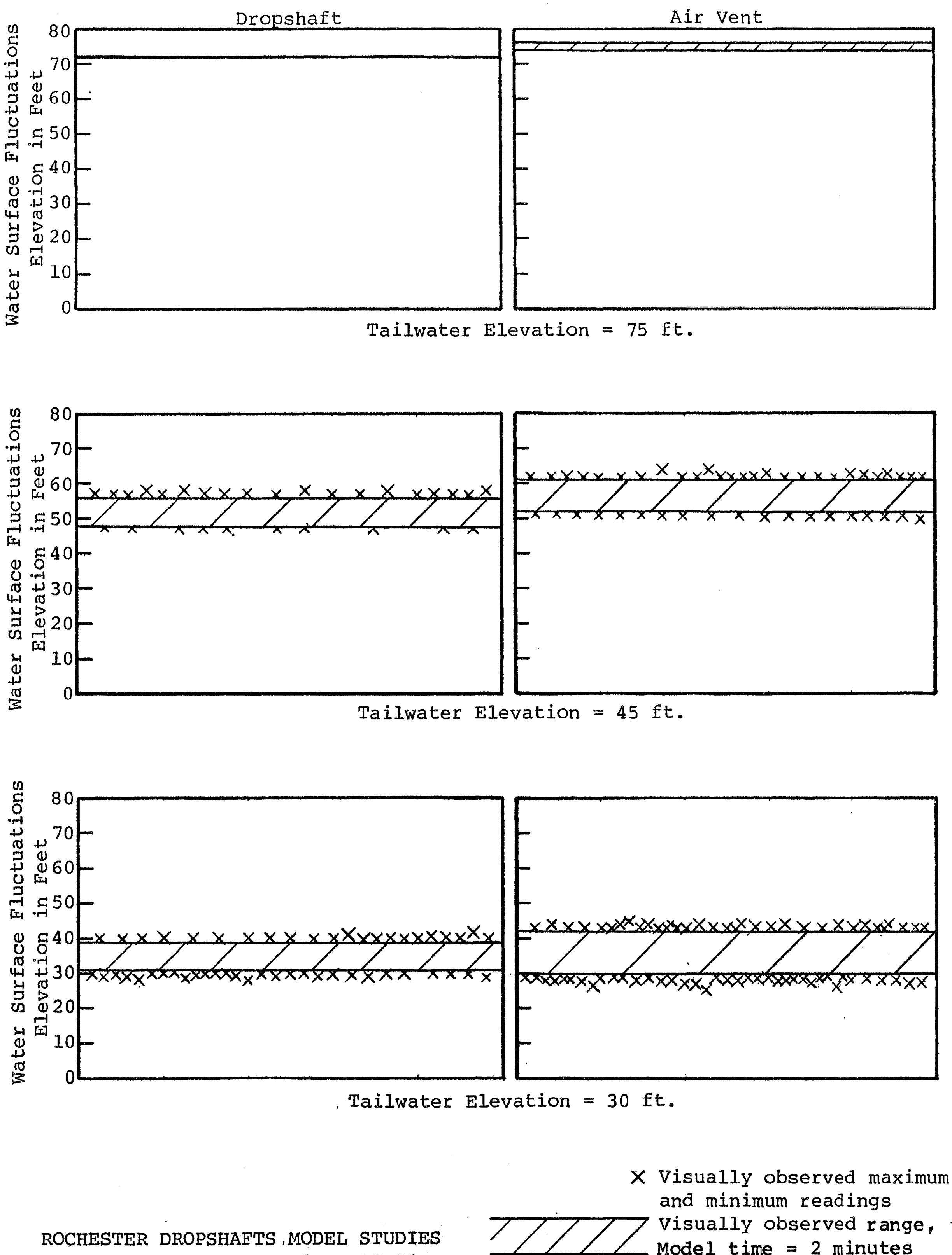
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Water Surface Fluctuations
Q = 400 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED MQD	APPROVED
SCALE	DATE 2/1/82	NO. 302A2321-162



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2. R32 Scale 1:12.52
Water Surface Fluctuations
Q = 600 cfs

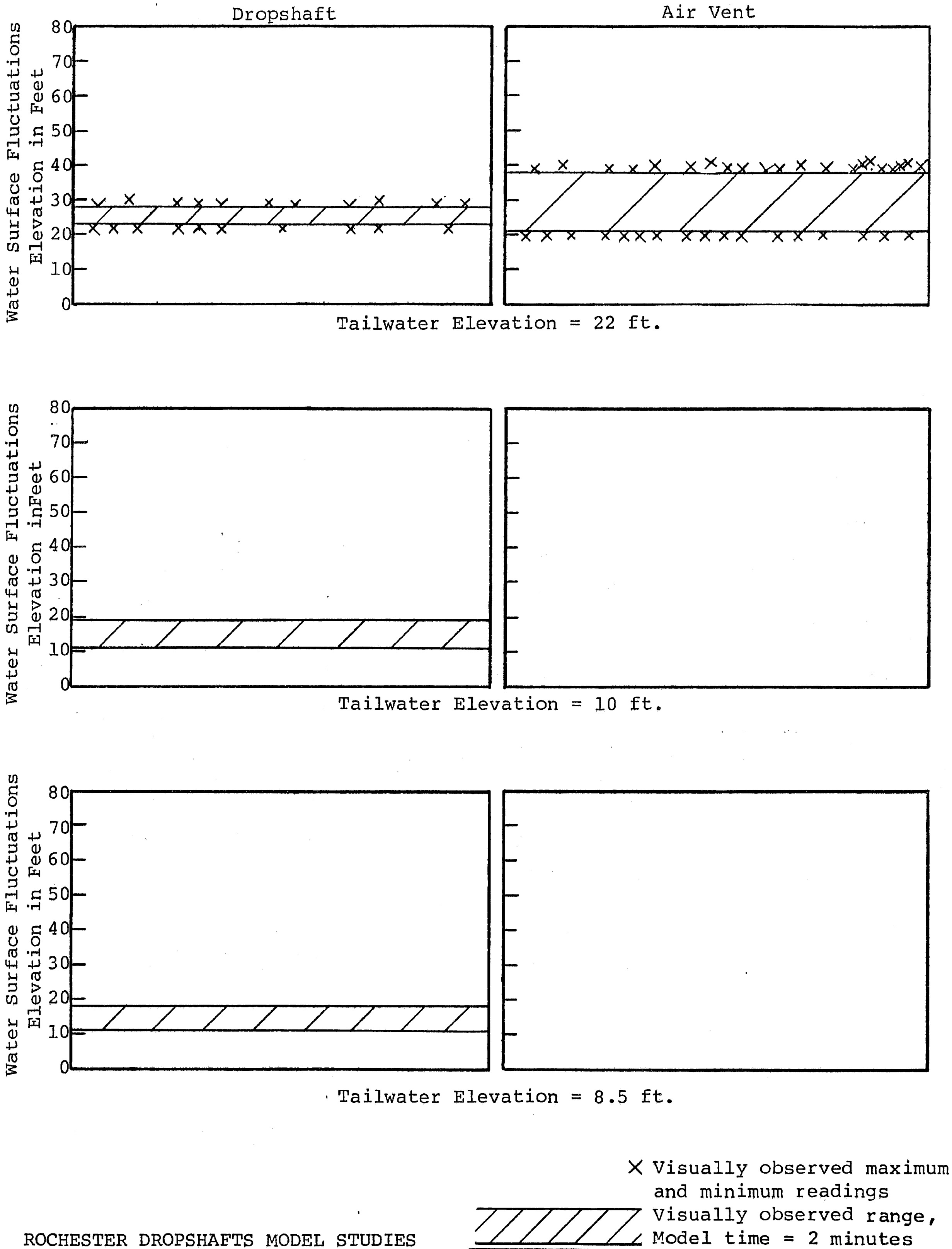
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 2/1/82	NO. 302A2321-163



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Water Surface Fluctuations
Q = 600 cfs

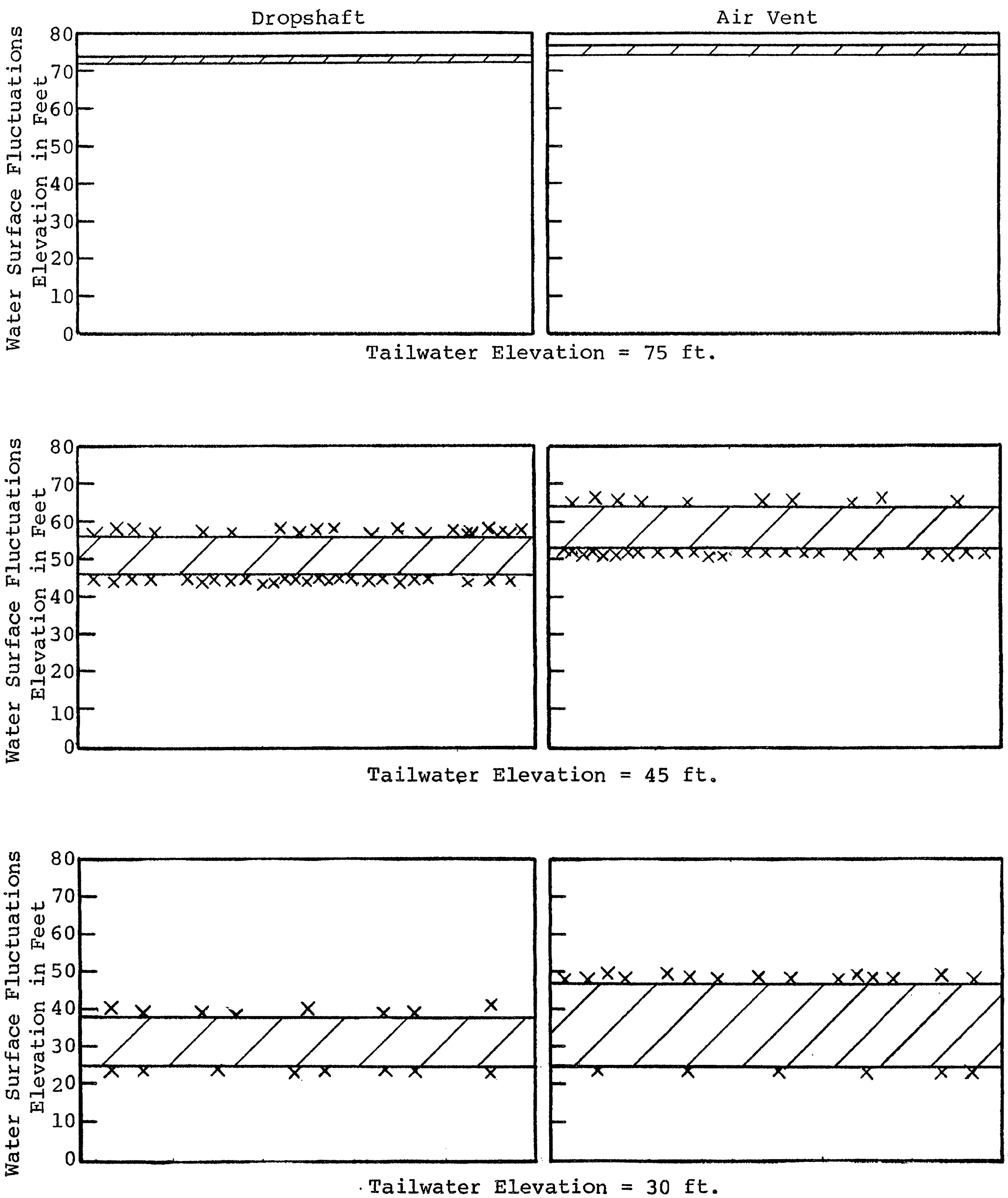
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 2/1/82	NO. 302A2321-164



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Water Surface Fluctuations
Q = 800 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 2/1/82	NO. 302A2321-165

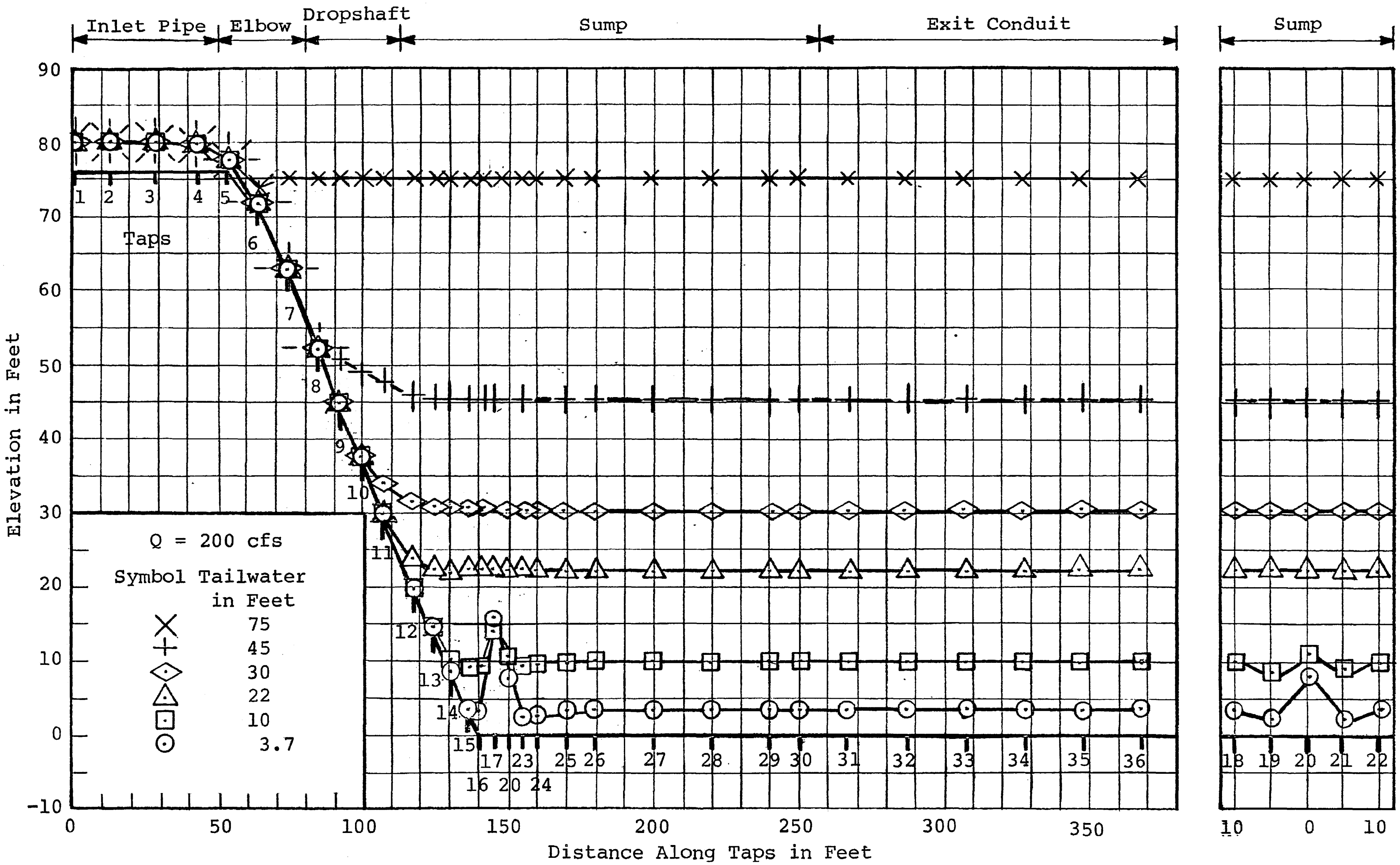


X Visually observed maximum and minimum readings

Visually observed range, Model time = 2 minutes

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Water Surface Fluctuations
Q = 800 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED MOD	APPROVED
SCALE	DATE 2/1/82	NO. 302A2321-166

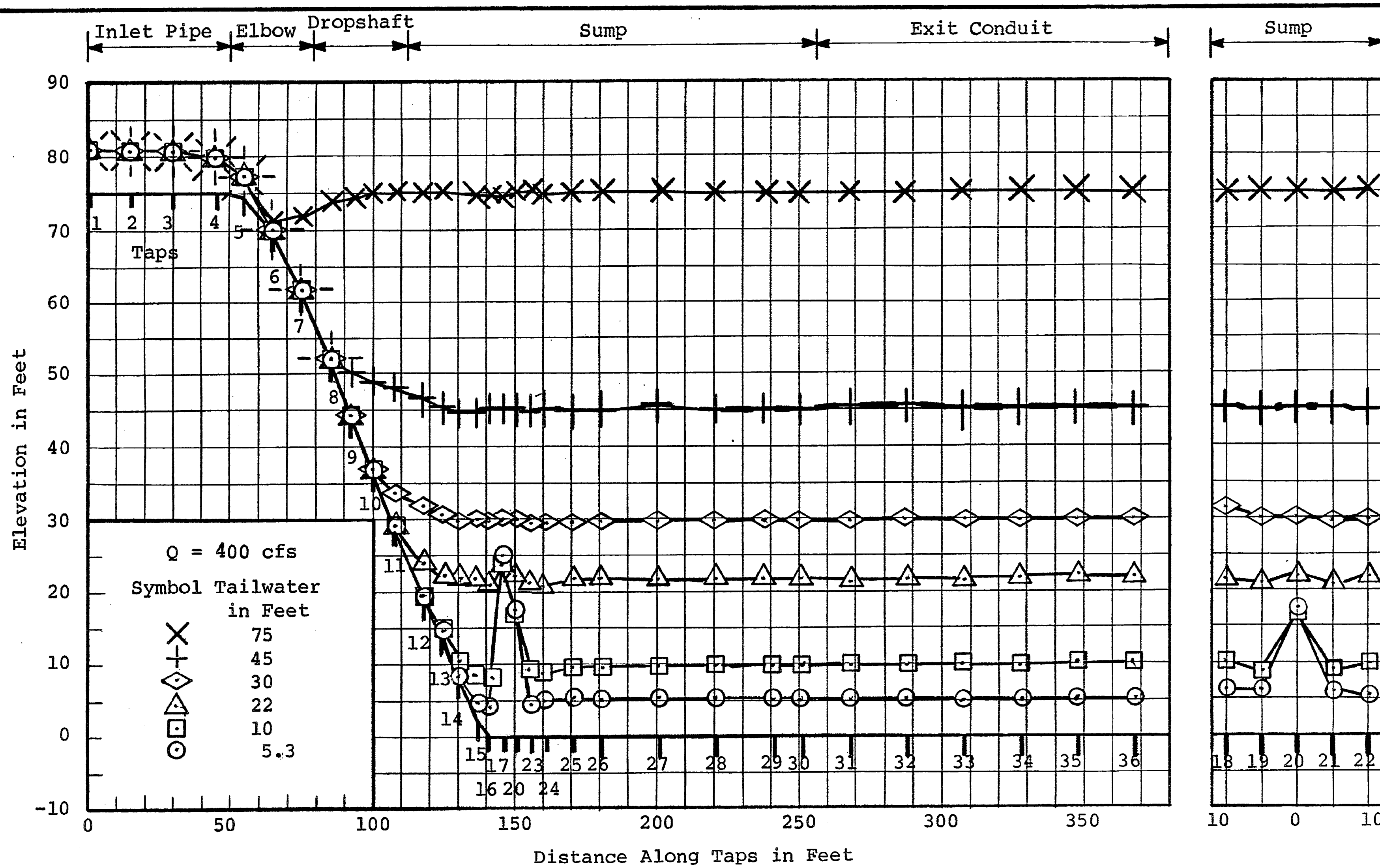


ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 10/28/81	NO. 302A2321-2

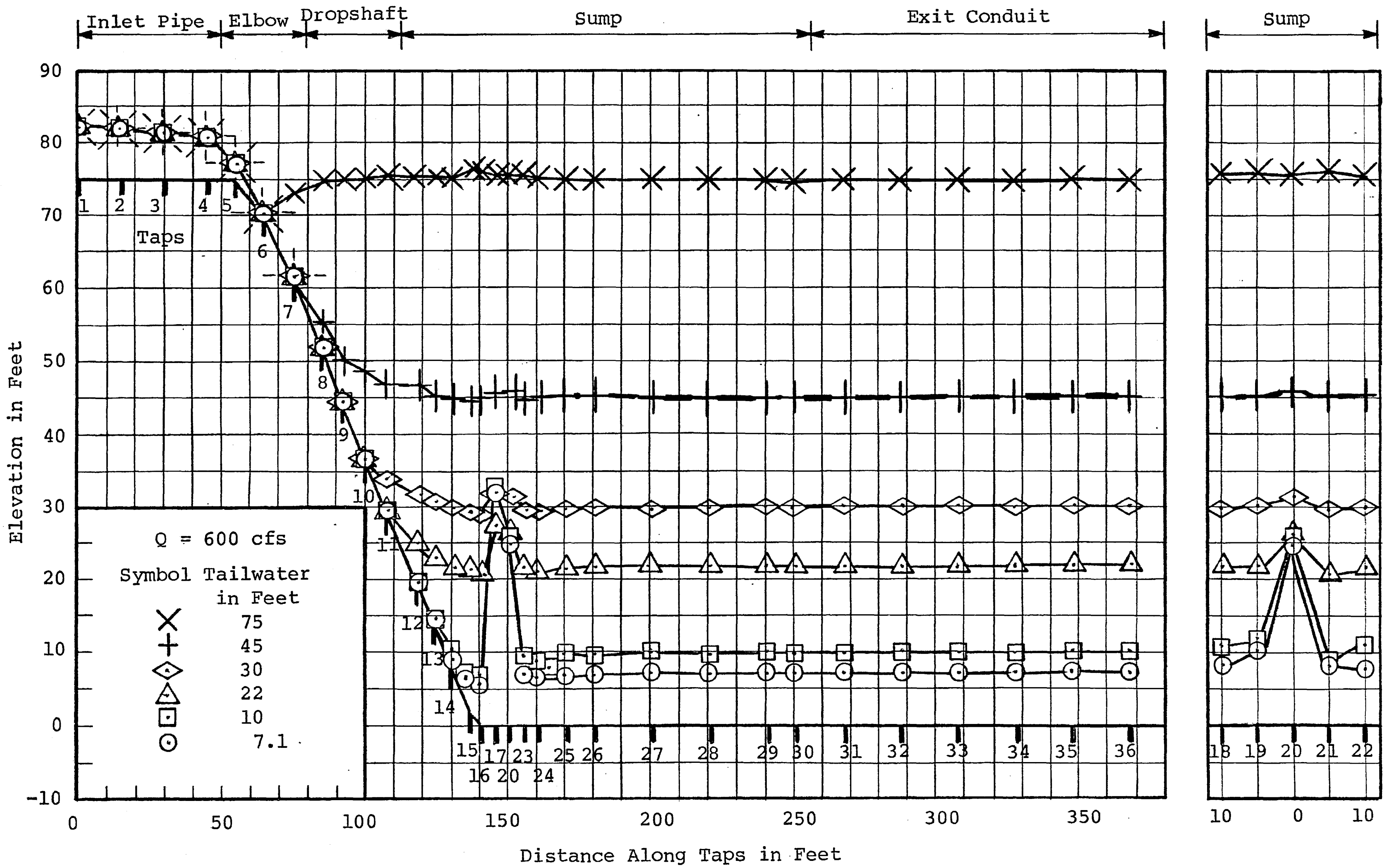
CHART 17



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 10/28/81	NO. 302A2321-3

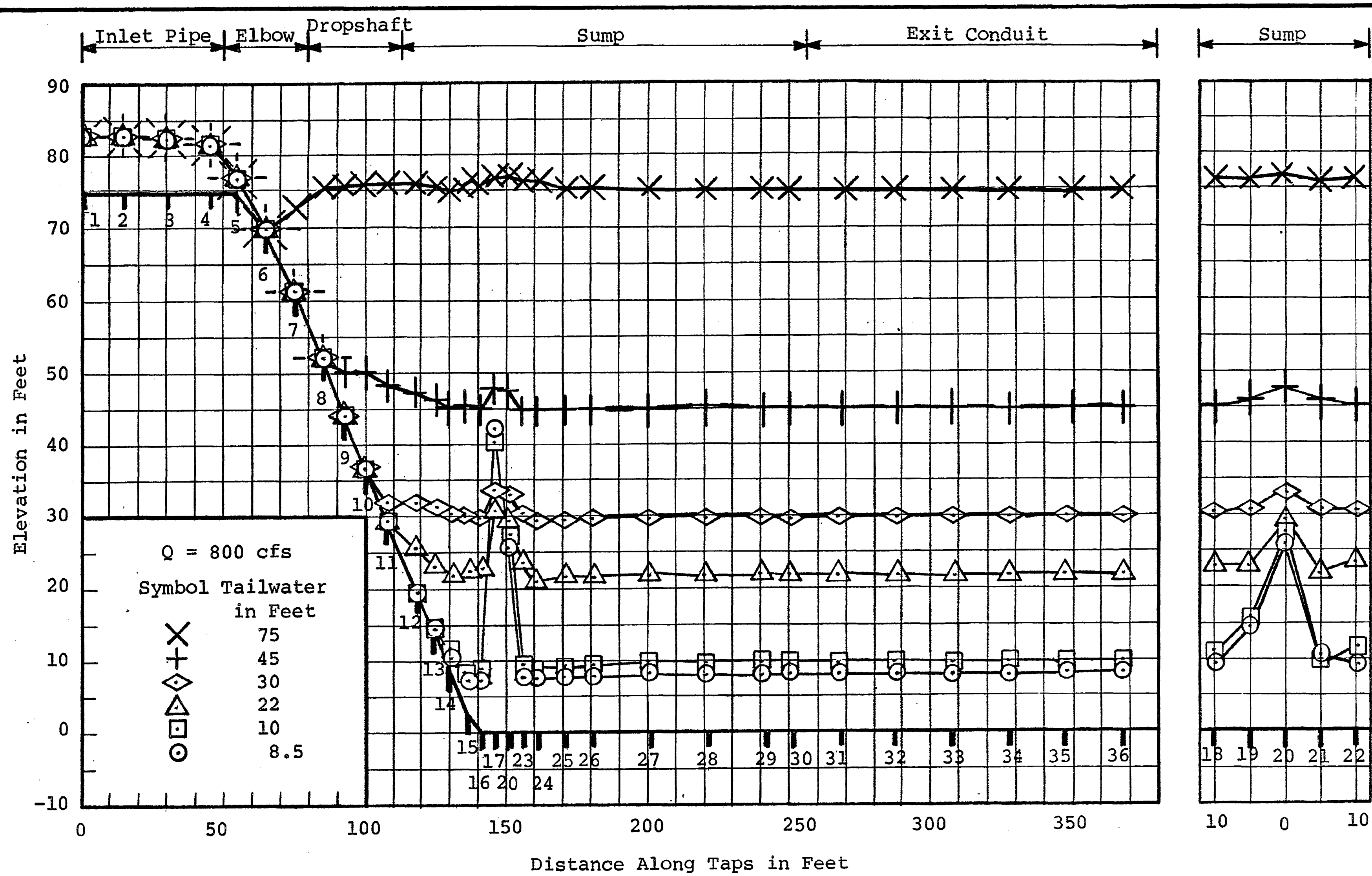
CHART 18



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2:R32 Scale 1:12.52
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 10/28/81	NO. 302A2321-4

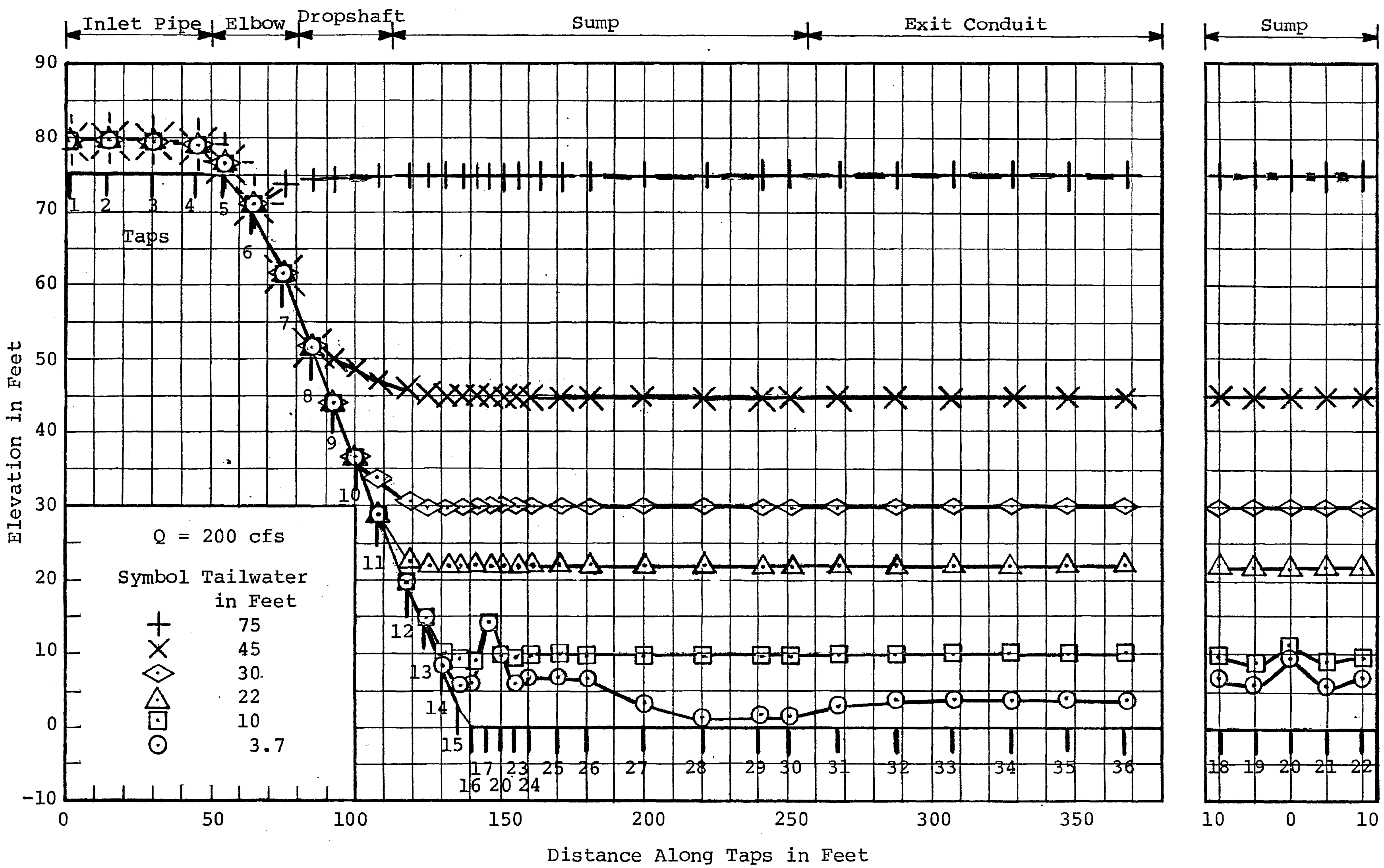
CHART 19



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 10/28/81	NO. 302A2321-5

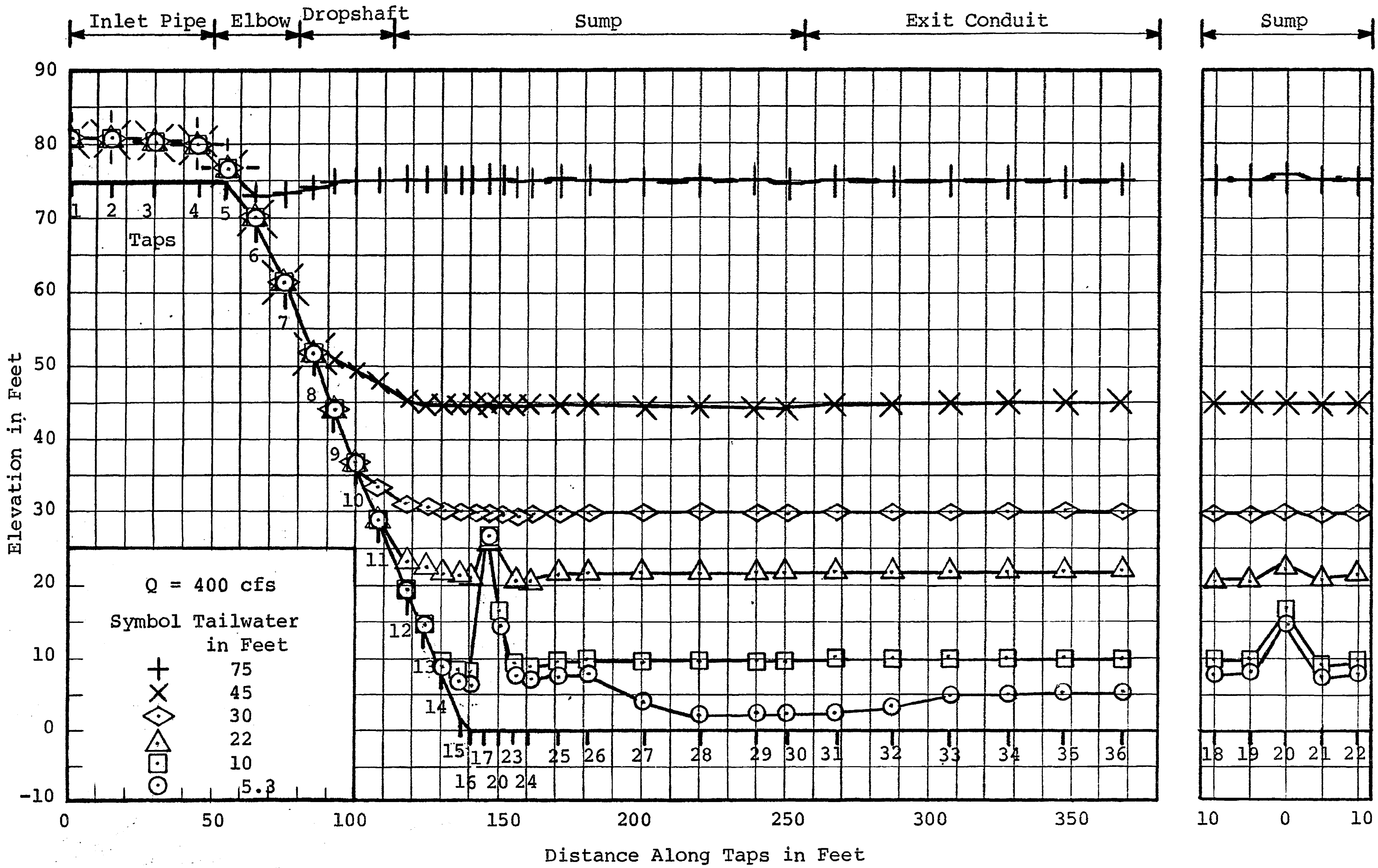
CHART 20



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 10/28/81	NO. 302A2321-7

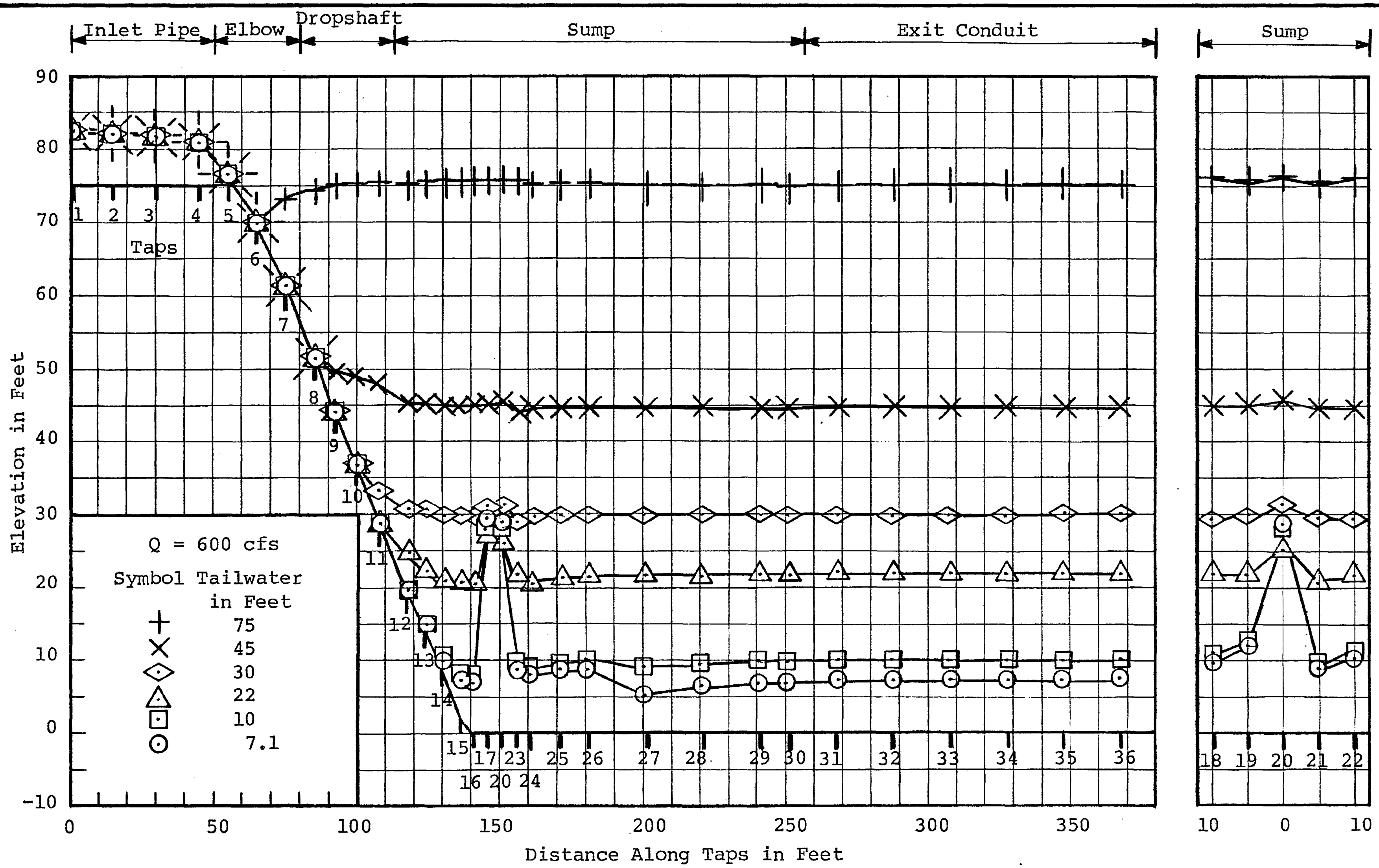
CHART 21



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED WQH	APPROVED
SCALE	DATE 10/28/81	NO. 302A2321-8

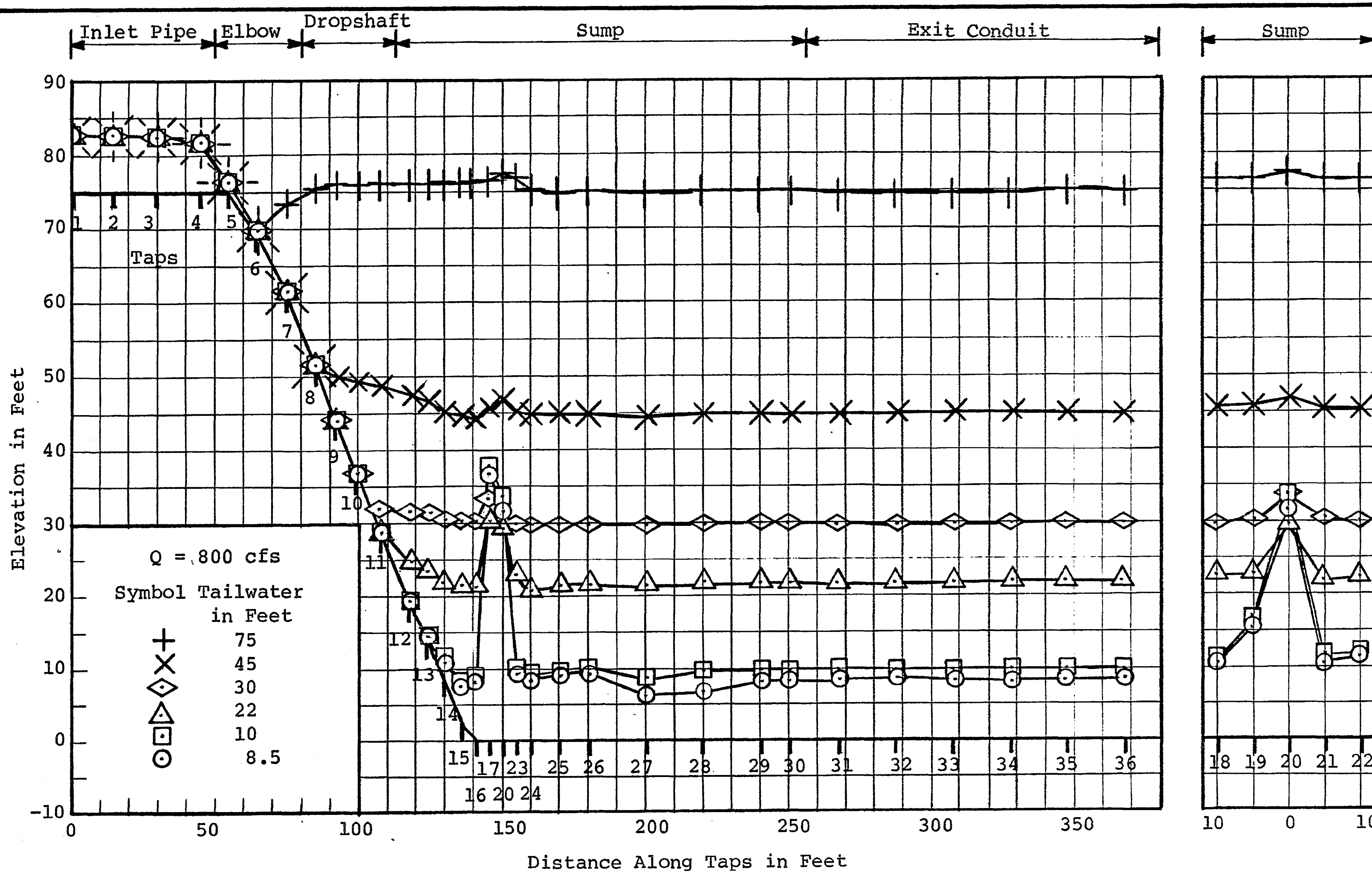
CHART 22



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED WQF	APPROVED
SCALE	DATE 10/28/81	NO. 302A2321-9

CHART 23

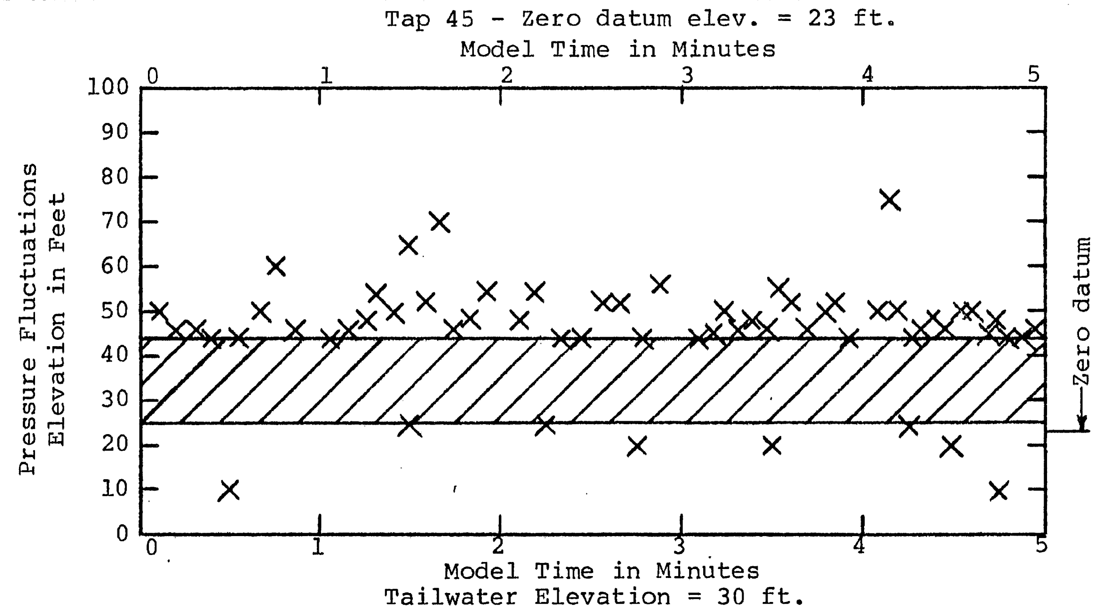


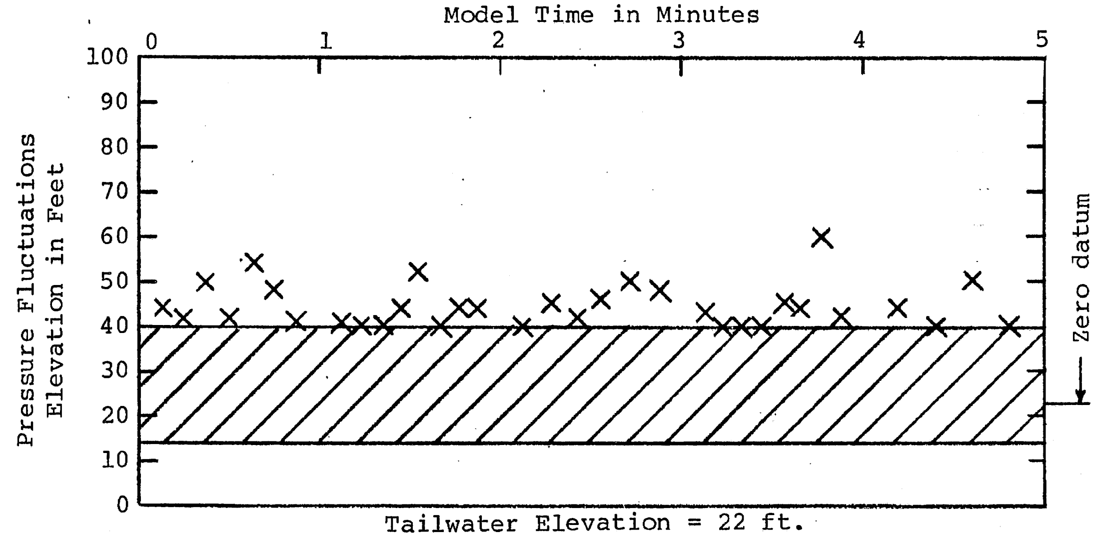
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 10/28/81	NO. 302A2321-10

CHART 24





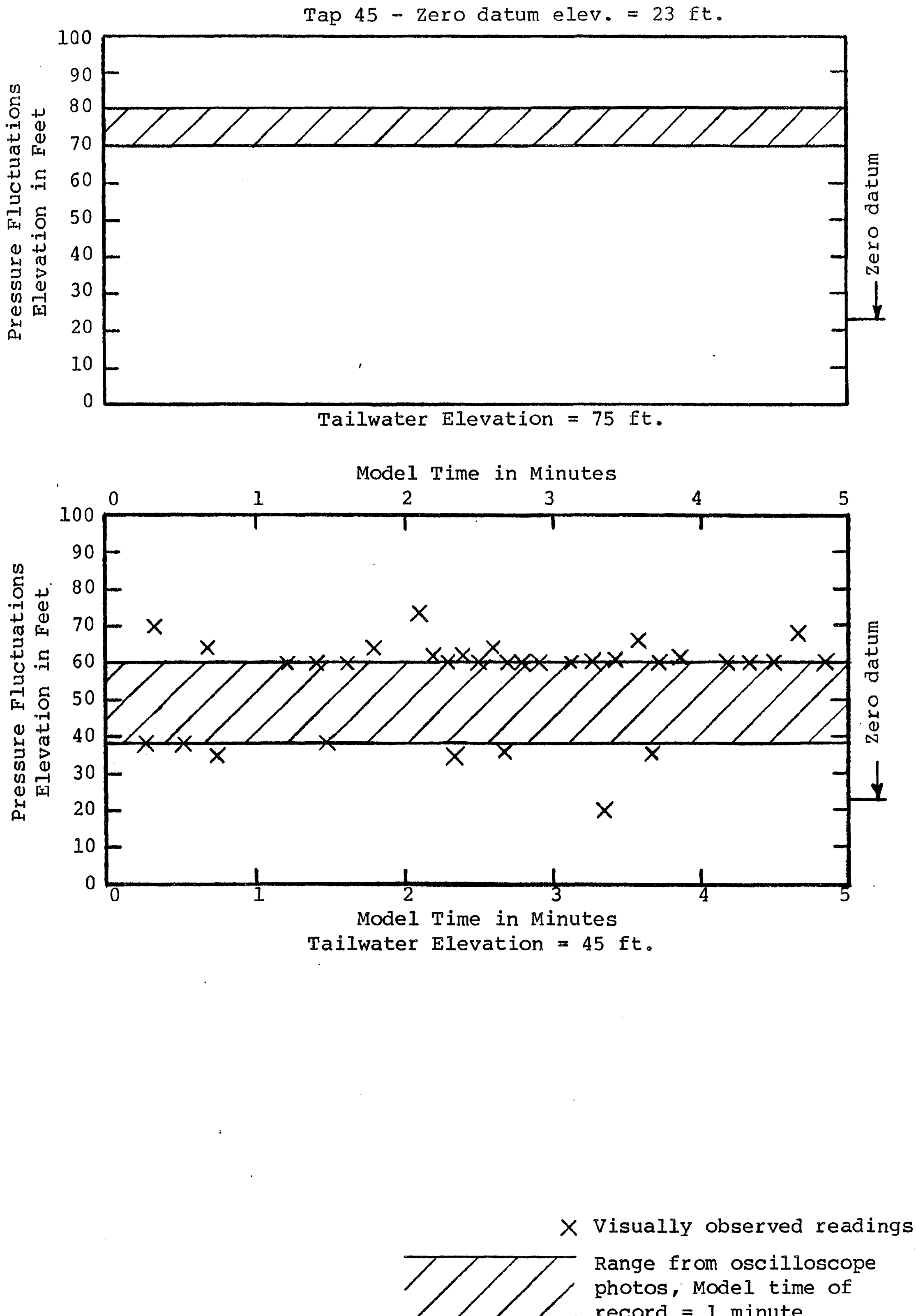
× Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R14 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

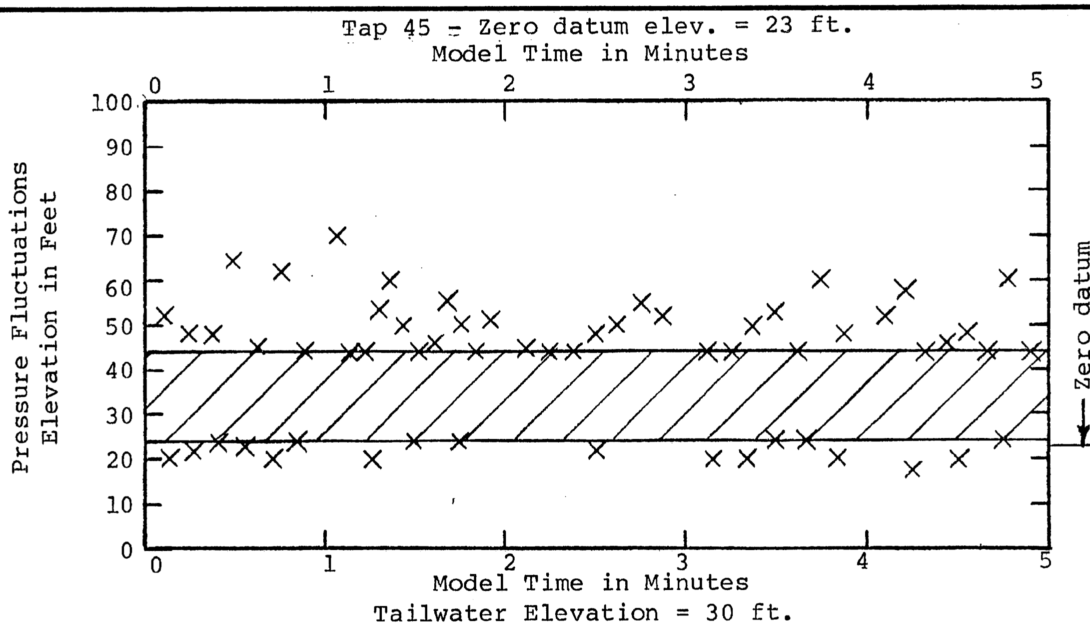
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

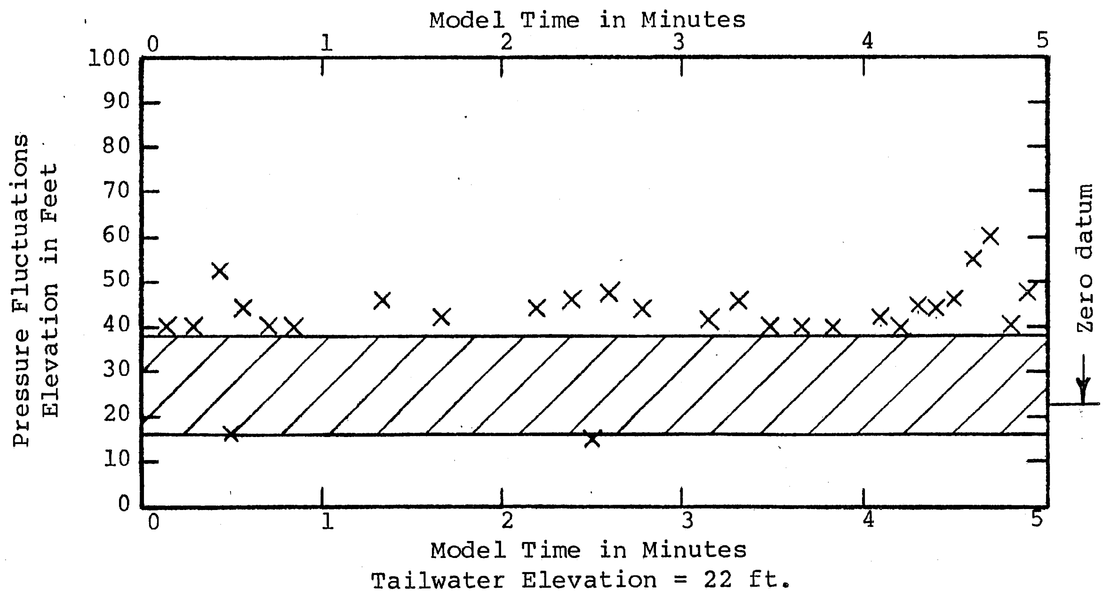
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-189

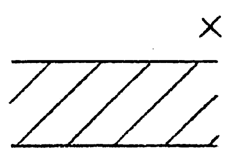


ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R14 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED MD	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-190

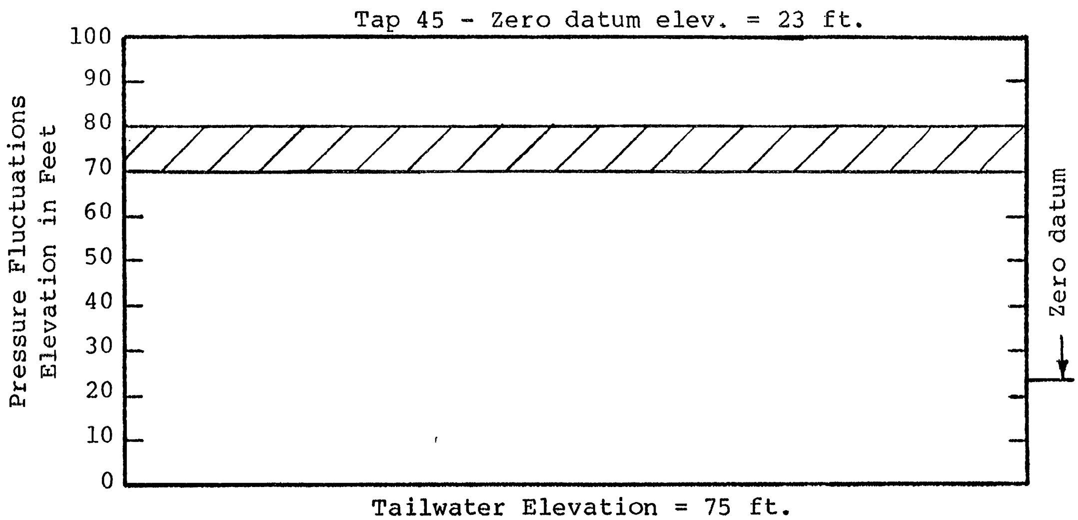


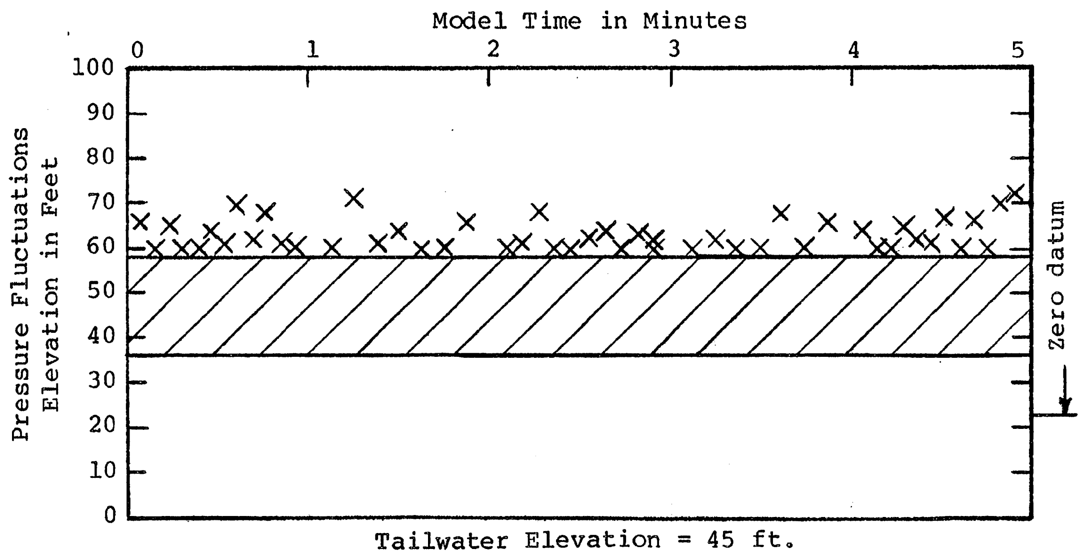


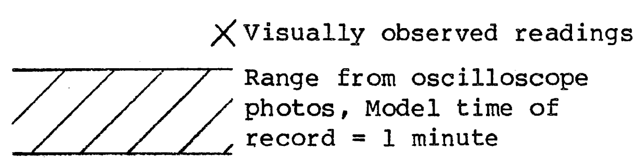


ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED WQh	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-191







ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2. R32 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

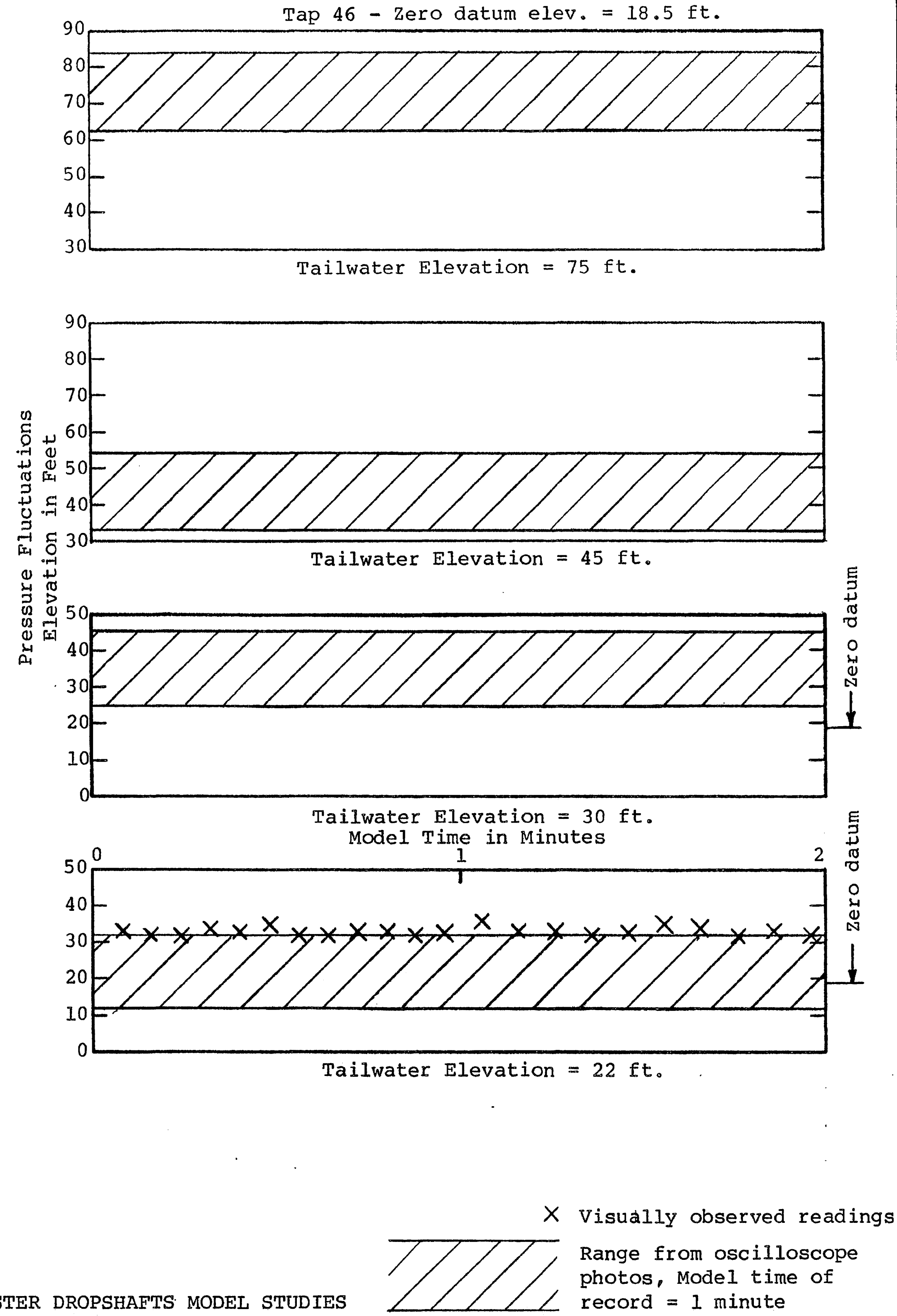
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-192

Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Range from Photos Max.-ft	Range from Photos Min.-ft	Observed Readings Max.-ft	Observed Readings Min.-ft
		Type L2 R14 - Tap 45 Elevation = 23 ft				
600	22	22	40	14	60	14
600	30	30	44	25	75	10
600	45	45	60	38	72	20
600	75	75	80	70		
		Type L2 R32 - Tap 45 Elevation = 23 ft				
600	22	22	38	16	60	16
600	30	30	44	24	70	18
600	45	45	58	36	72	36
600	75	75	80	70		

ROCHESTER DROPSHAFTS MODEL STUDIES
Model Scale 1:12.52
Summary of Typical
Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

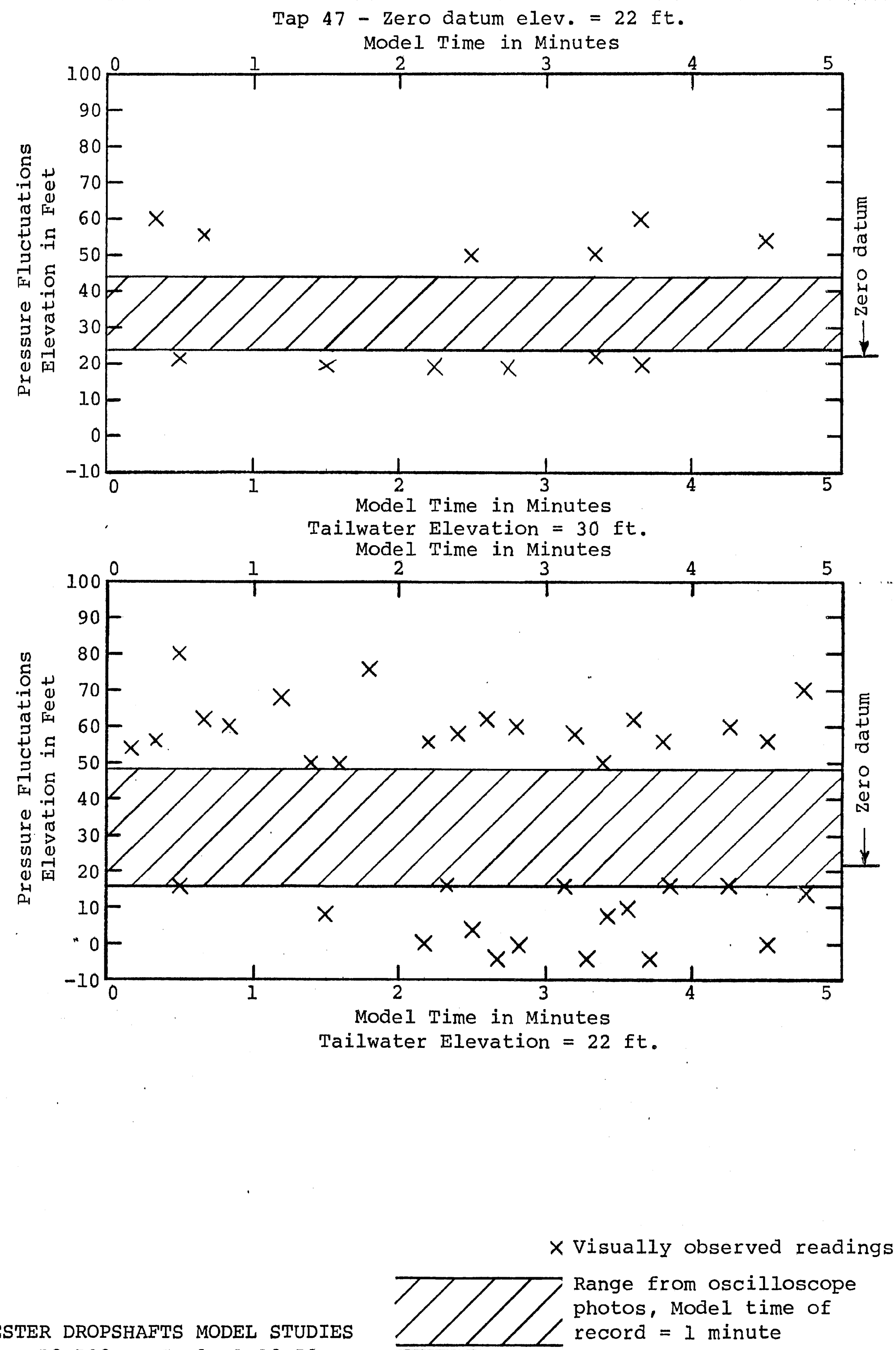
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 2/3/82	NO. 302A2321-227



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2: R14 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

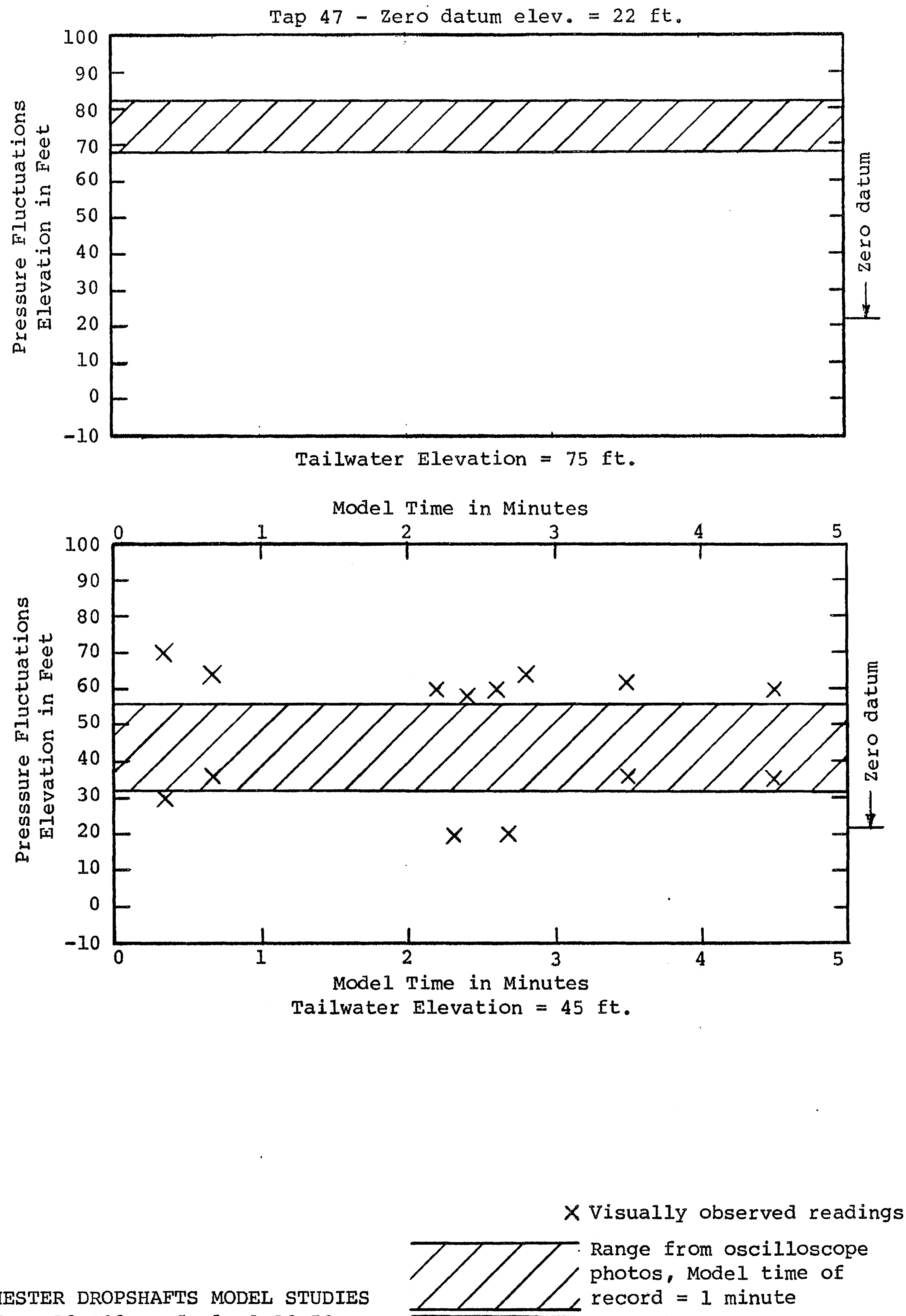
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-188



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Typical Pressure Fluctuations
Q = 400 cfs

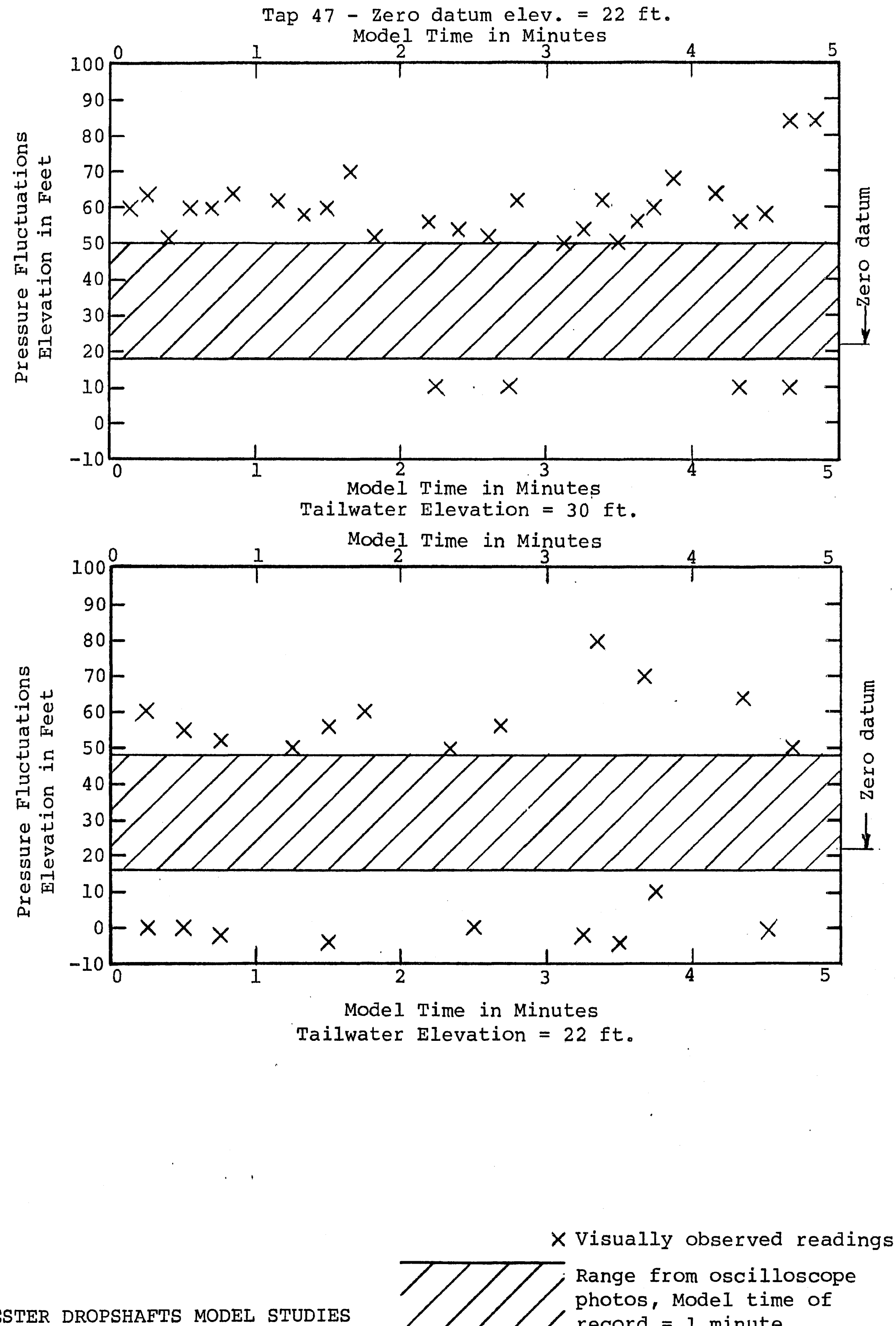
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 1/21/82	NO. 302A2321-145



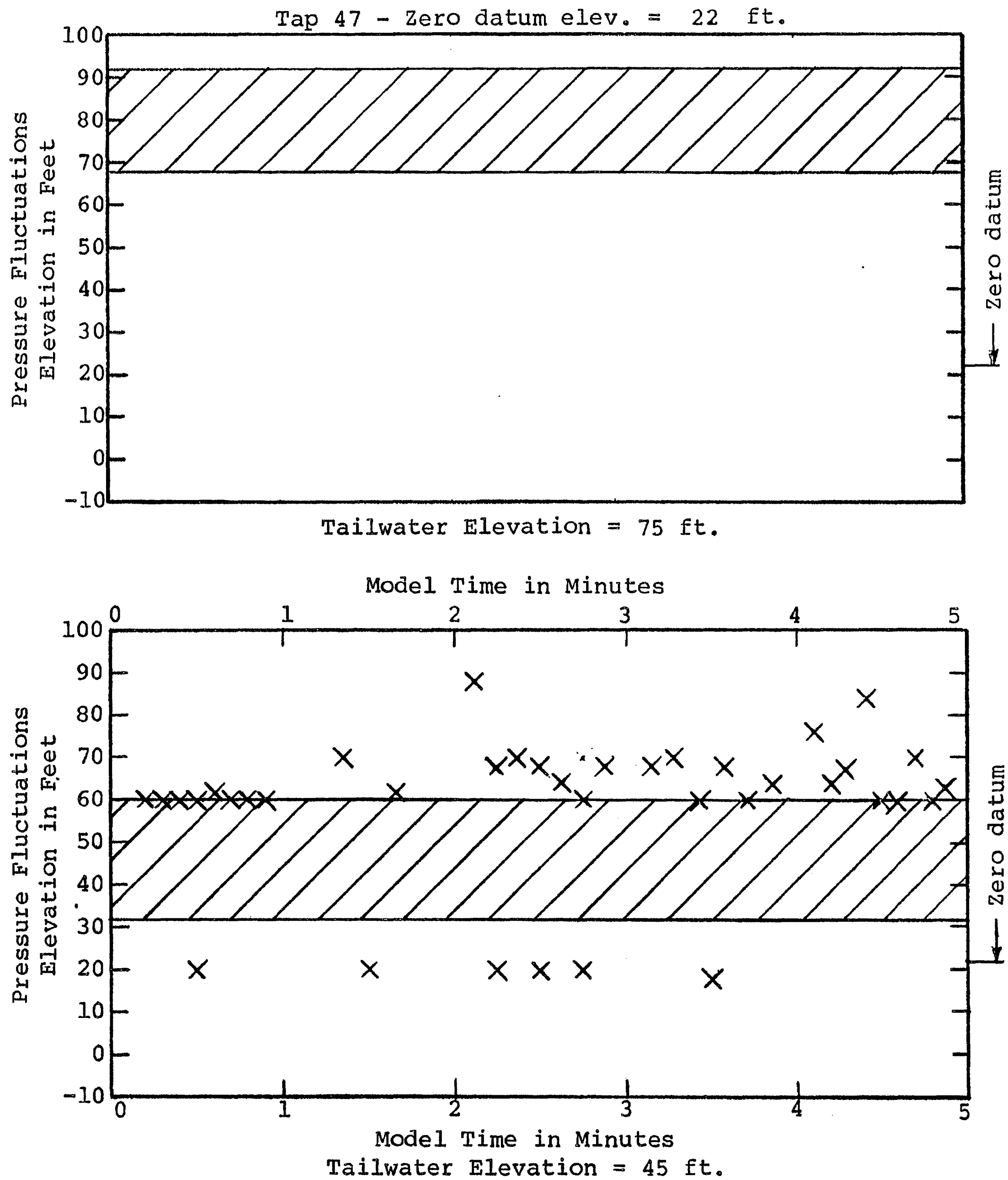
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Typical Pressure Fluctuations
Q = 400 cfs

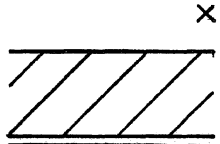
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 1/21/82	NO. 302A2321-146



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 1/21/82	NO. 302A2321-143





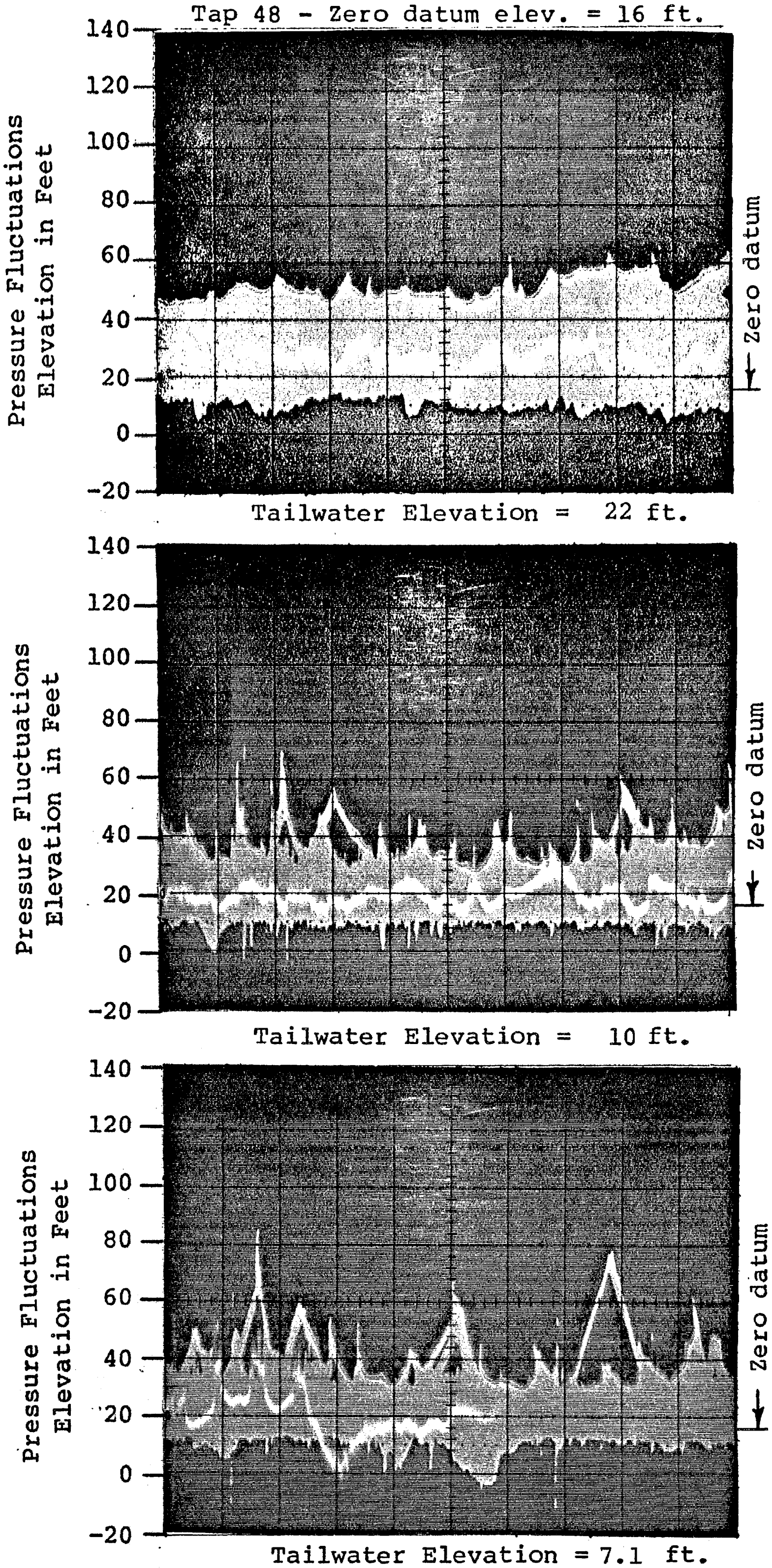
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/21/82	NO. 302A2321-144

Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Range from Photos Max.-ft	Range from Photos Min.-ft	Observed Readings Max.-ft	Observed Readings Min.-ft
		Type L2 R32 - Tap 47 Elevation = 22 ft				
400	22	22	48	16	80	-4
400	30	30	44	24	60	20
400	45	45	56	32	70	20
400	75	75	82	68		
600	22	22	48	16	80	-4
600	30	30	50	18	84	10
600	45	45	60	32	88	18
600	75	75	92	68		

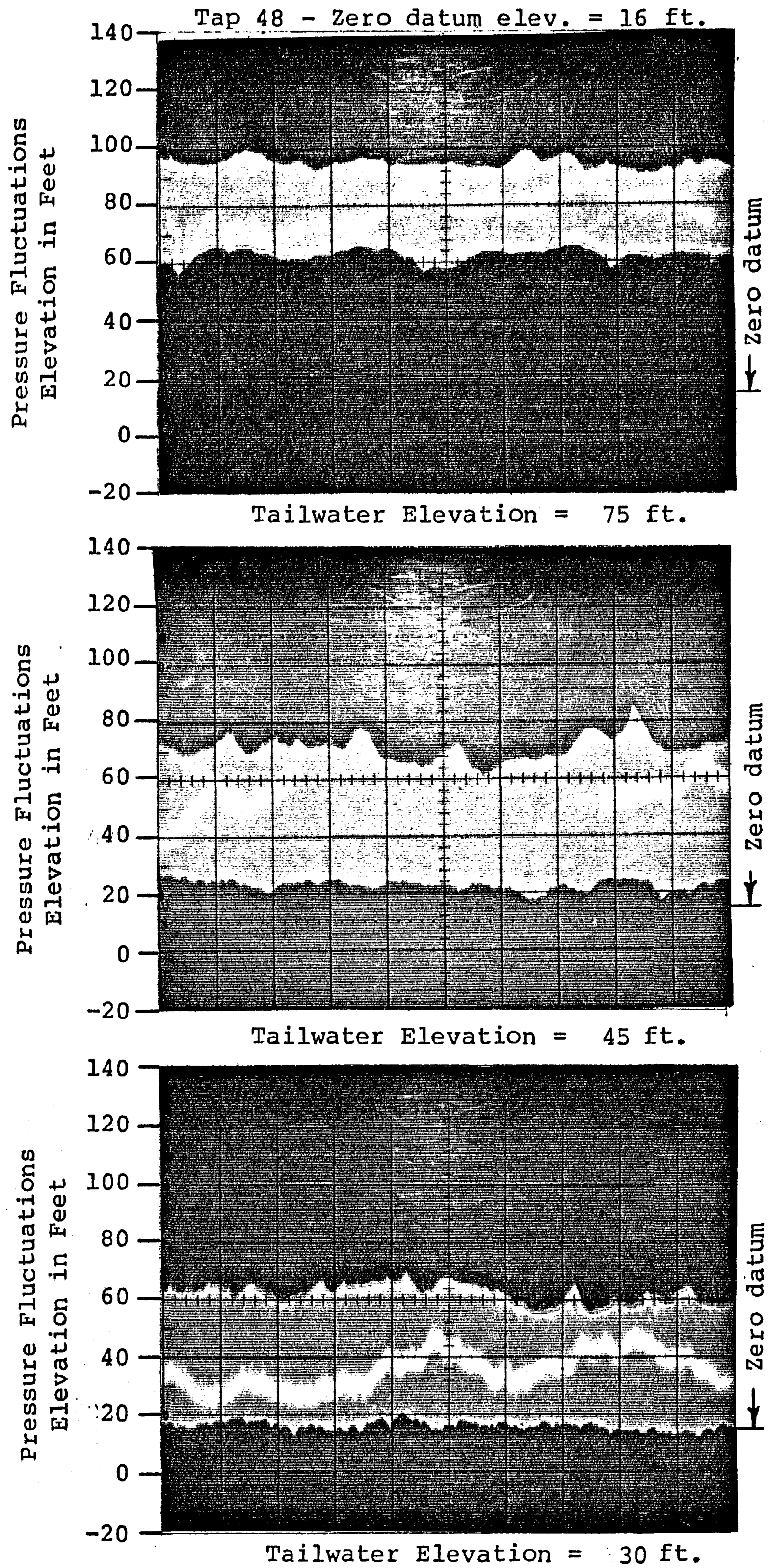
ROCHESTER DROPSHAFTS MODEL STUDIES
Model Scale 1:12.52
Summary of Typical
Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BD	APPROVED
SCALE	DATE 7/28/81	NO. 302A2321-228



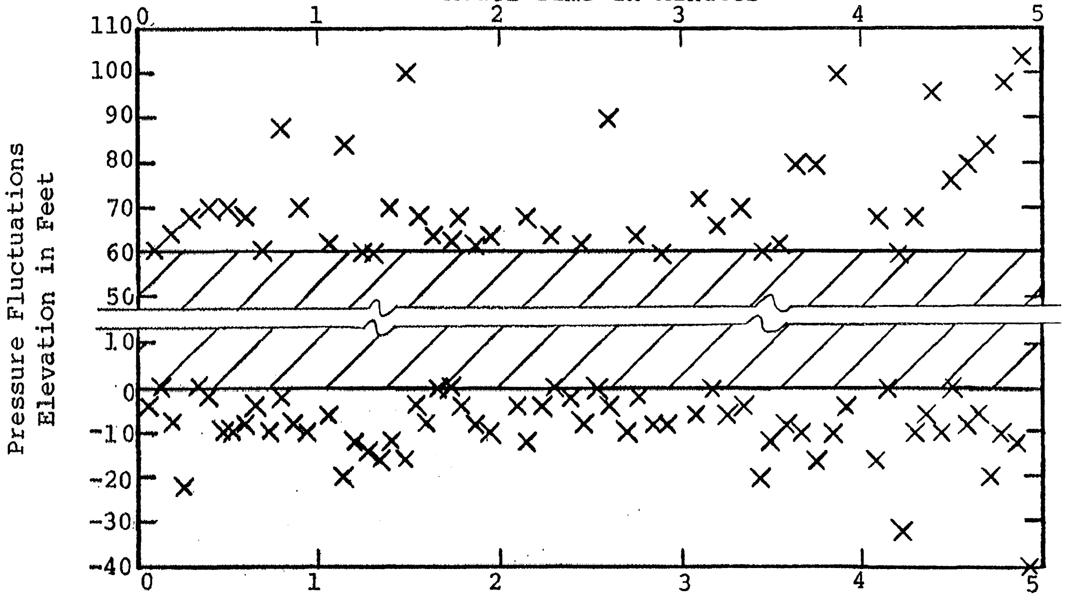
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2. R35 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 1/18/82	NO. 302A2321-110

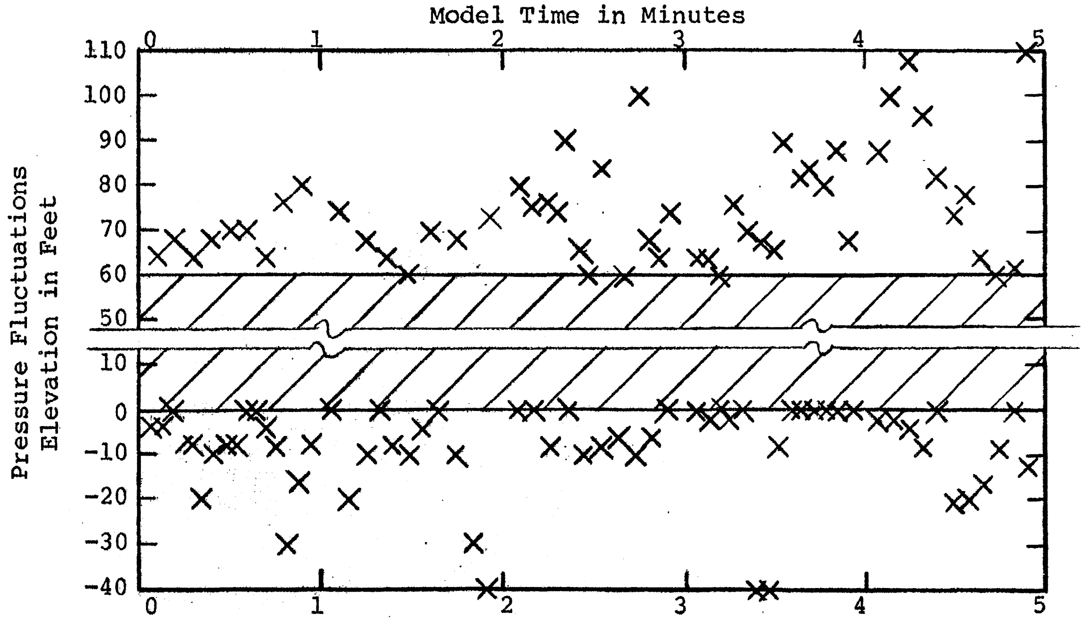


ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 1/18/82	NO. 302A2321-111



Tailwater Elevation = 10 ft.



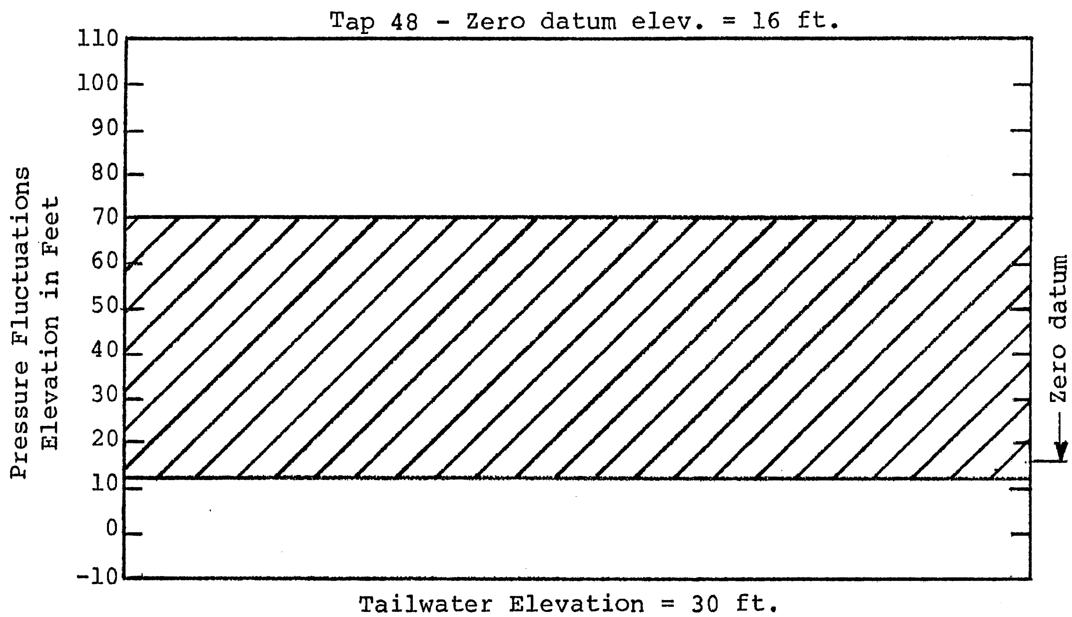
Tailwater Elevation = 7.1 ft.

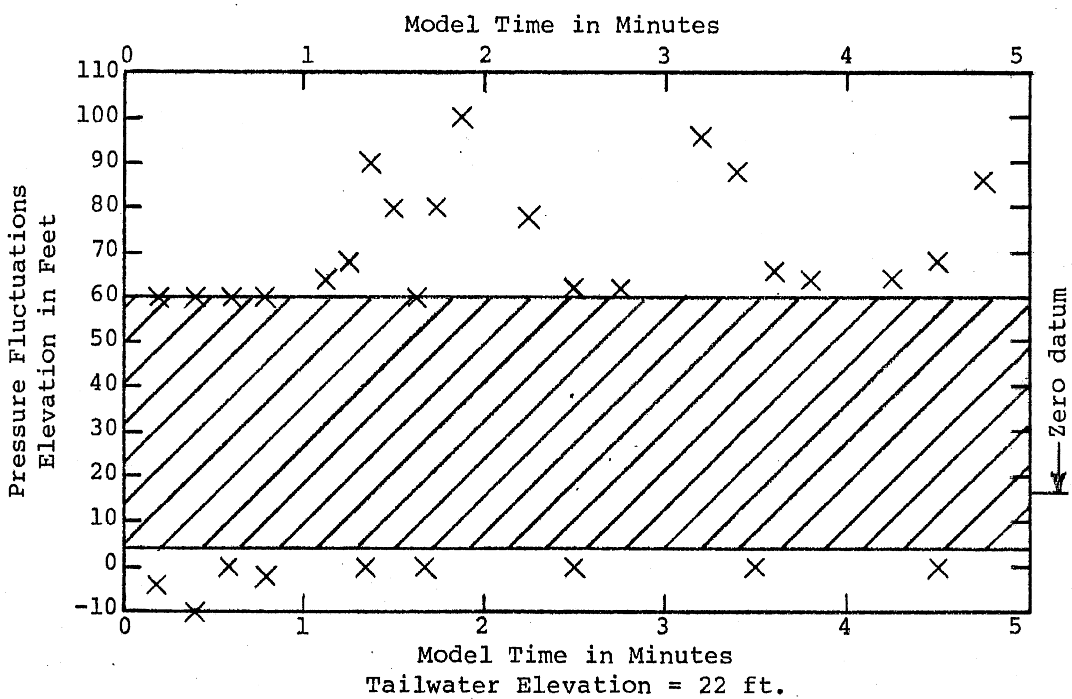
× Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 1/25/82	NO. 302A2321-151



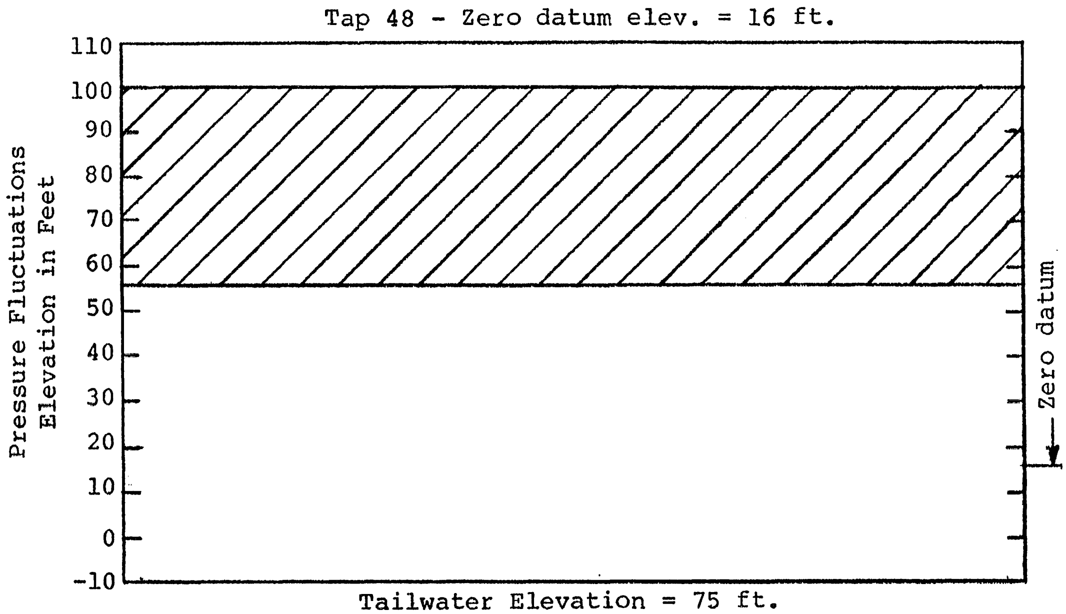


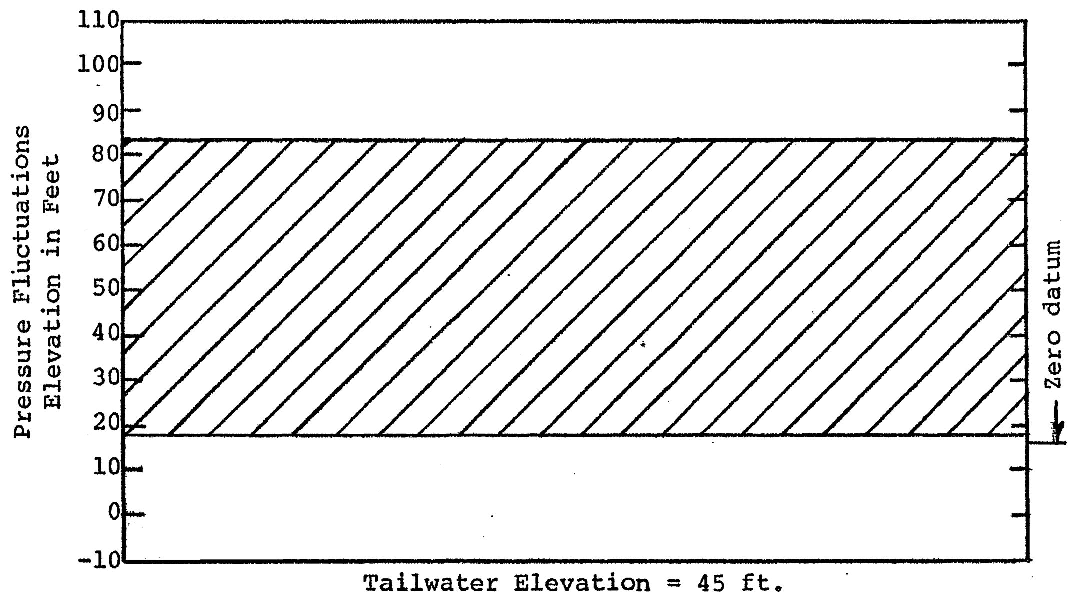
× Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 1/25/82	NO. 302A2321-152



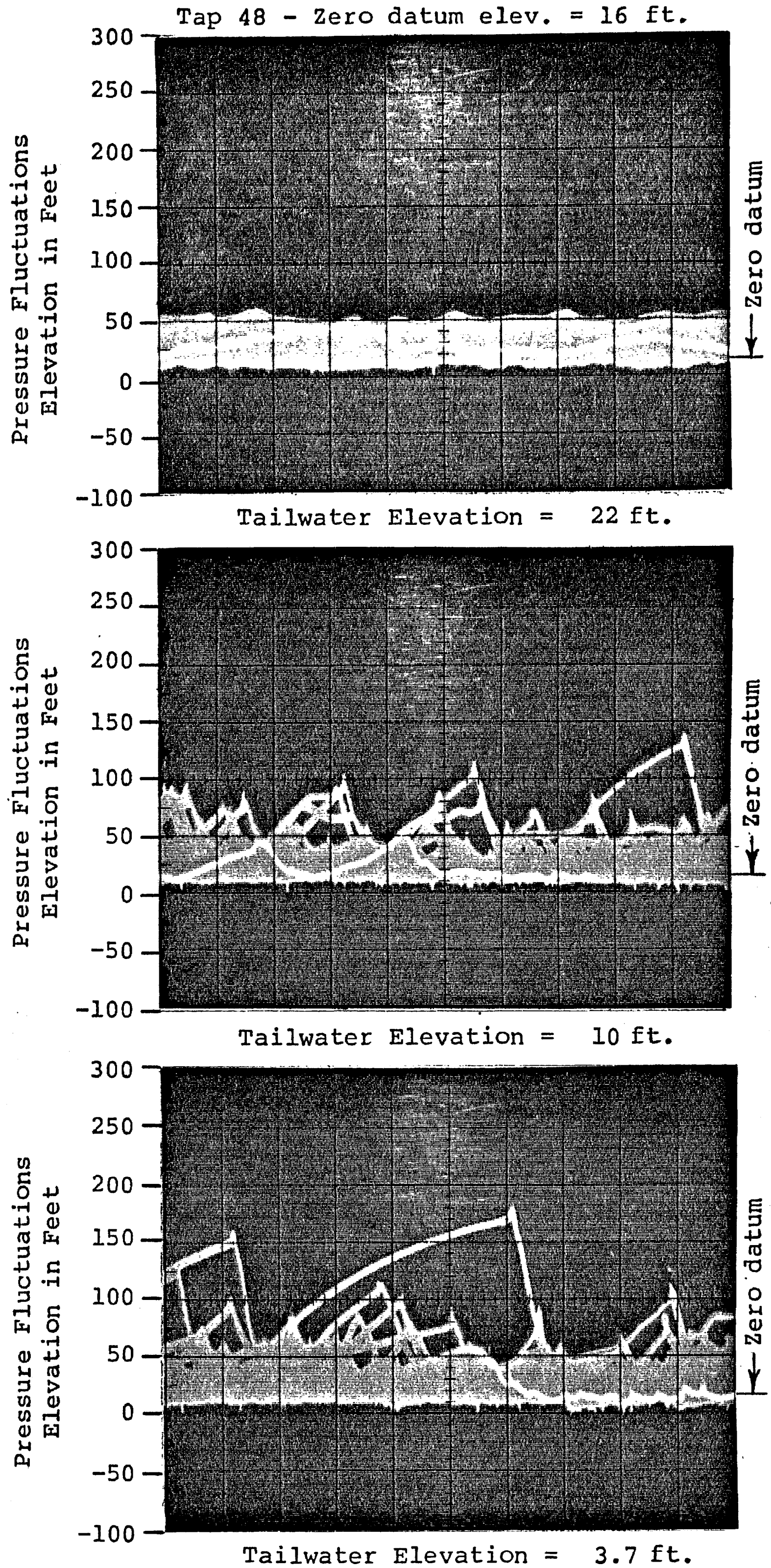


X Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

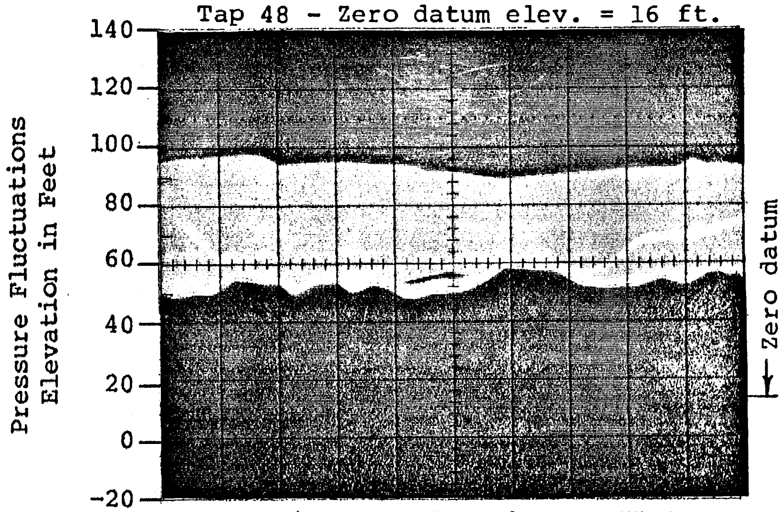
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 1/25/82	NO. 302A2321-153



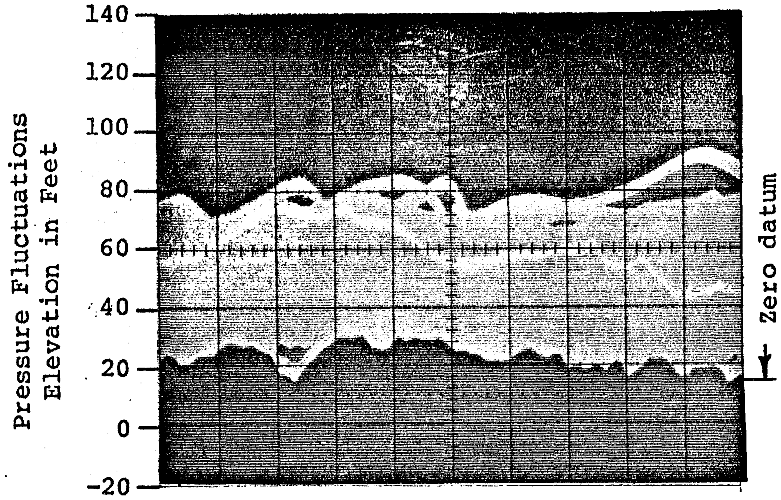
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 200 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 1/18/82	NO. 302A2321-112

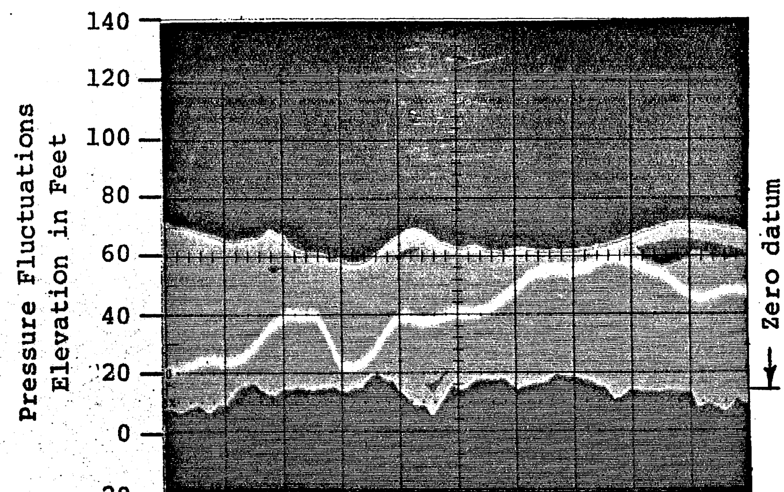
Tap 48 - Zero datum elev. = 16 ft.



Tailwater Elevation = 75 ft.



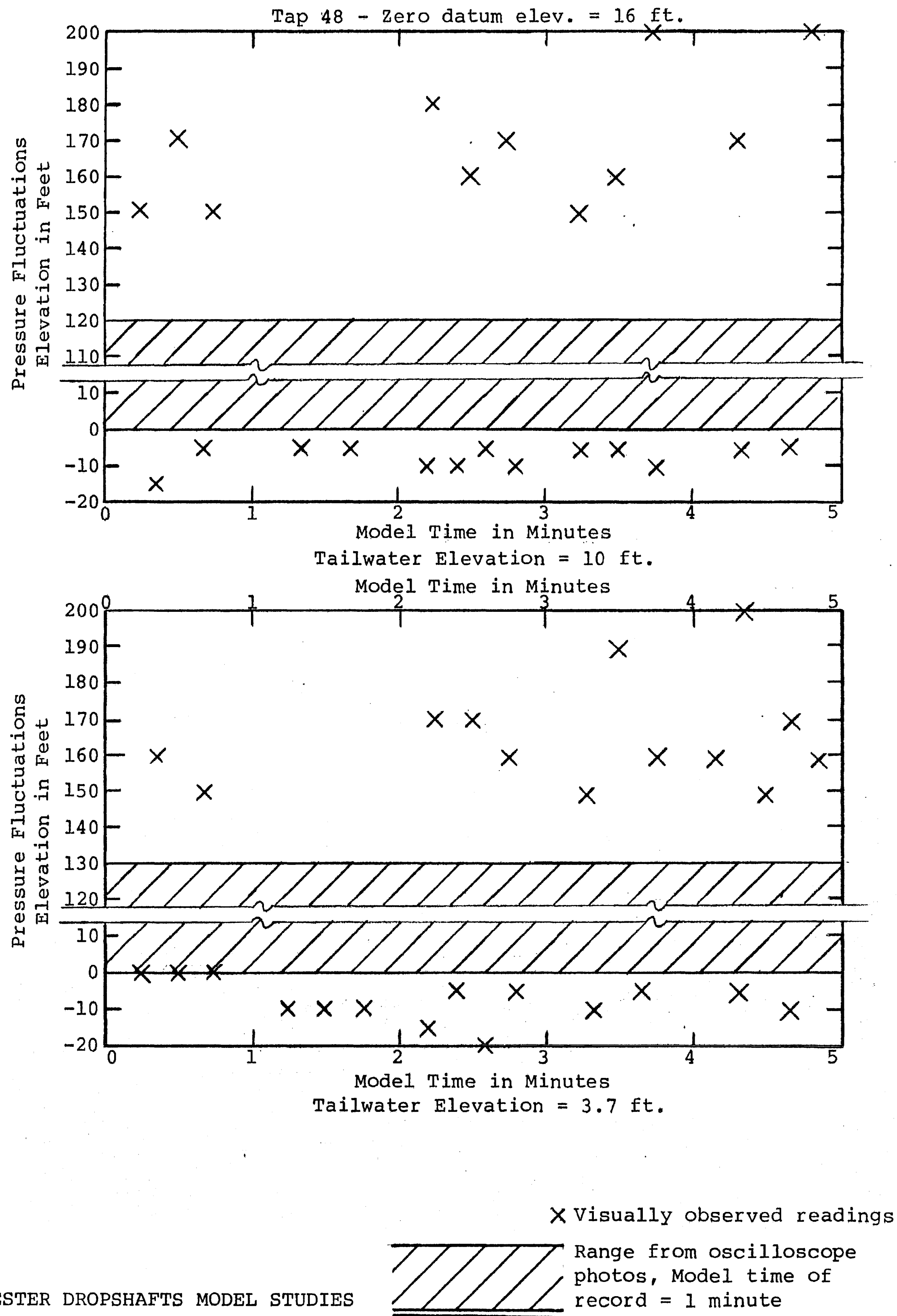
Tailwater Elevation = 45 ft.



Tailwater Elevation = 30 ft.

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 200 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 1/18/82	NO. 302A2321-113



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 200 cfs

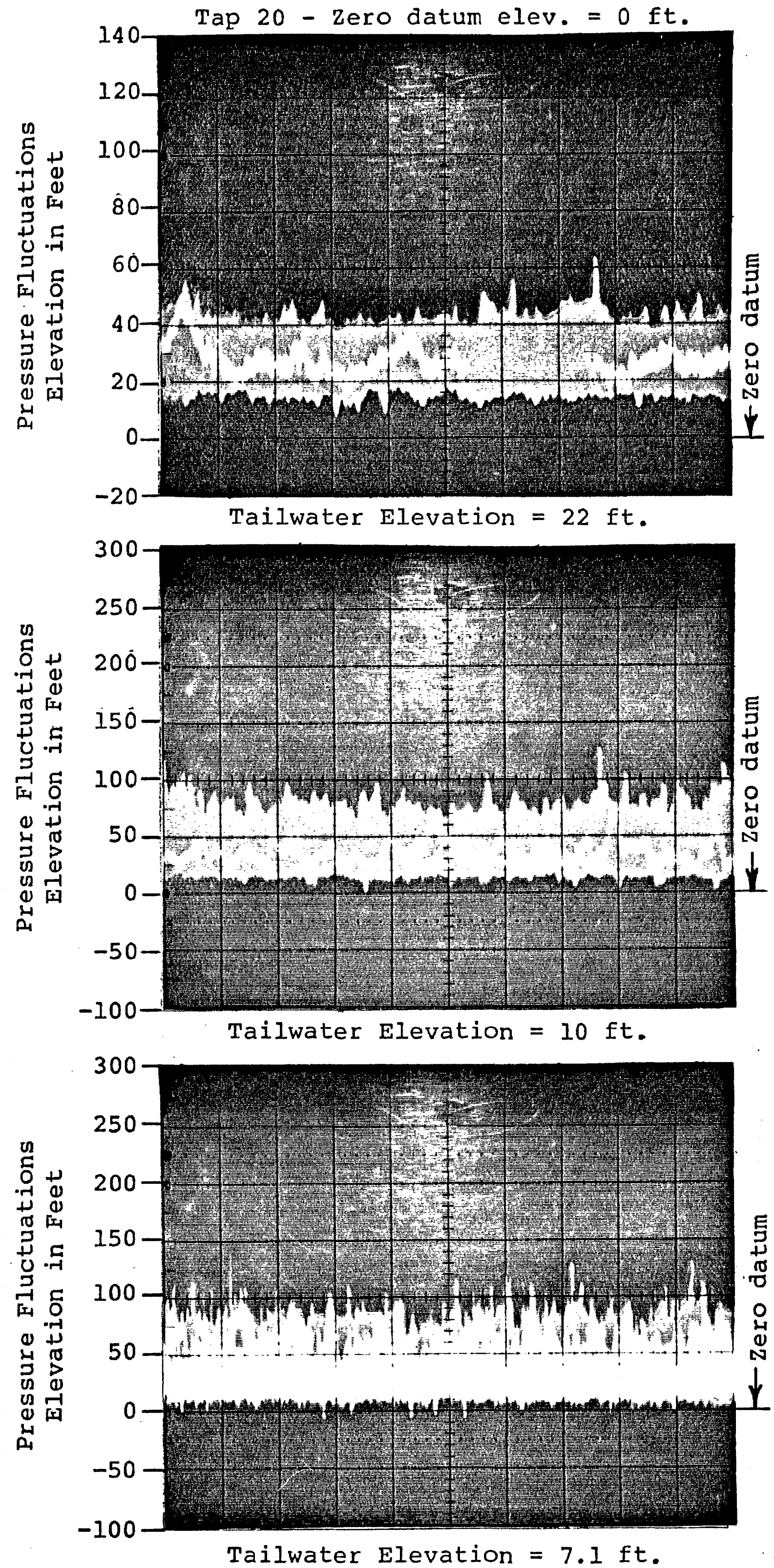
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 1/25/82	NO. 302A 2321-154

Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Range from Photos Max.-ft	Range from Photos Min.-ft	Observed Readings Max.-ft	Observed Readings Min.-ft
		Type L2 R35 - Tap 48 Elevation = 16 ft				
200	3.7	16.9	130	0	200	-20
200	10	16.9	120	0	200	-15
200	22	22.7	60	5		
200	30	31.4	72	6		
200	45	45.2	94	14		
200	75	75.1	98	48		
400	5.3	16.8	40	6	80	-10
400	10	17.0	50	6	100	-20
400	22	23.1	56	10	64	6
400	30	30.6	66	6		
400	45	45.4	80	26		
400	75	75.1	104	54		
600	7.1	17.2	60	0	110	-40
600	10	17.2	60	0	114	-40
600	22	24.4	60	4	100	-10
600	30	31.3	70	12		
600	45	46.2	84	18		
600	75	75.3	100	56		
800	8.5	17.2	90	4	128	-20
800	10	17.3	60	4	120	-40
800	22	24.9	64	8	114	-16
800	30	31.7	70	10		
800	45	46.8	78	26		
800	75	76.2	98	60		

ROCHESTER DROPSHAFTS MODEL STUDIES
Model Scale 1:12.52
Summary of Typical
Pressure Fluctuations

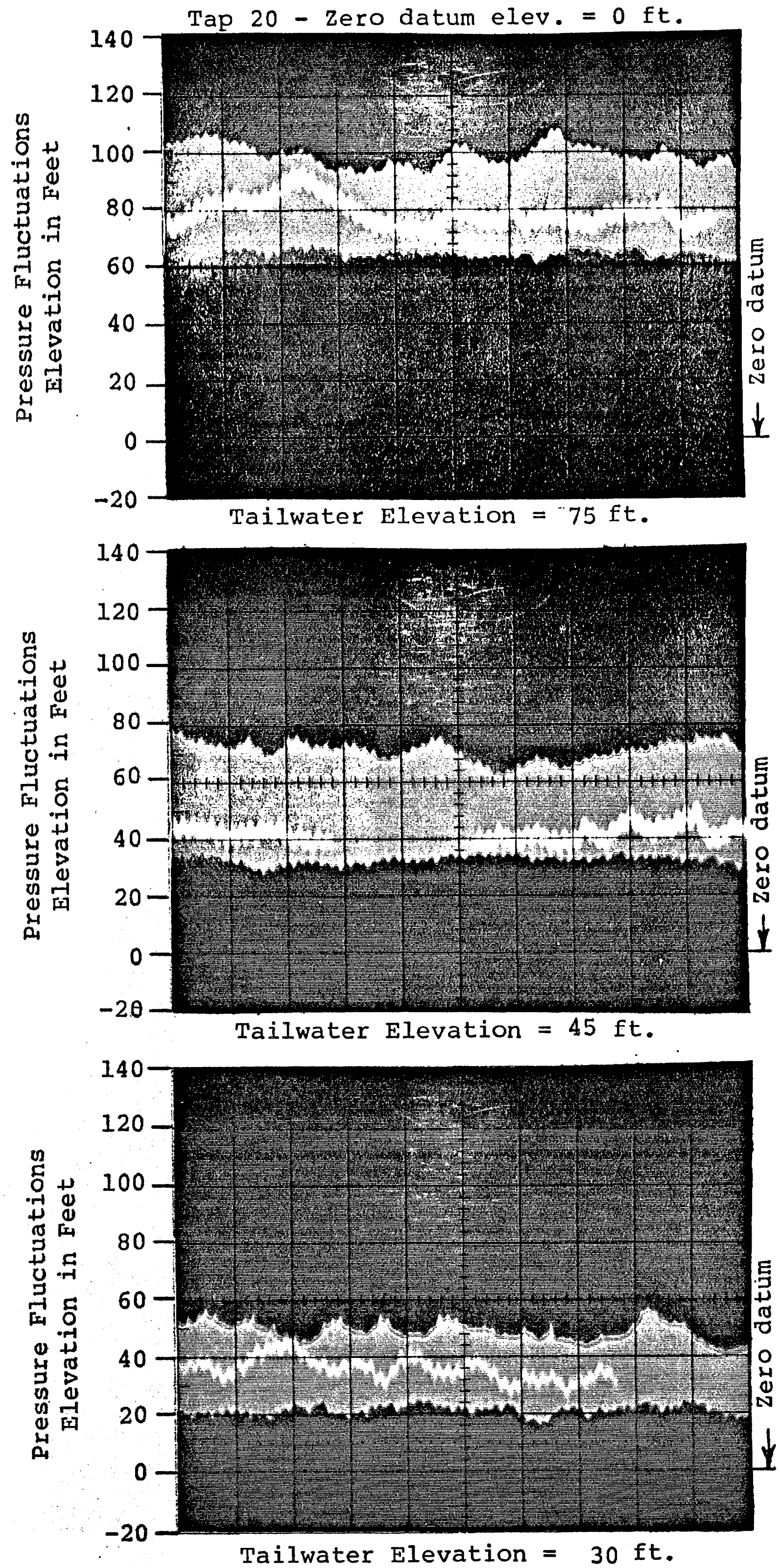
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 9/2/81	NO. 302A2321-229



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

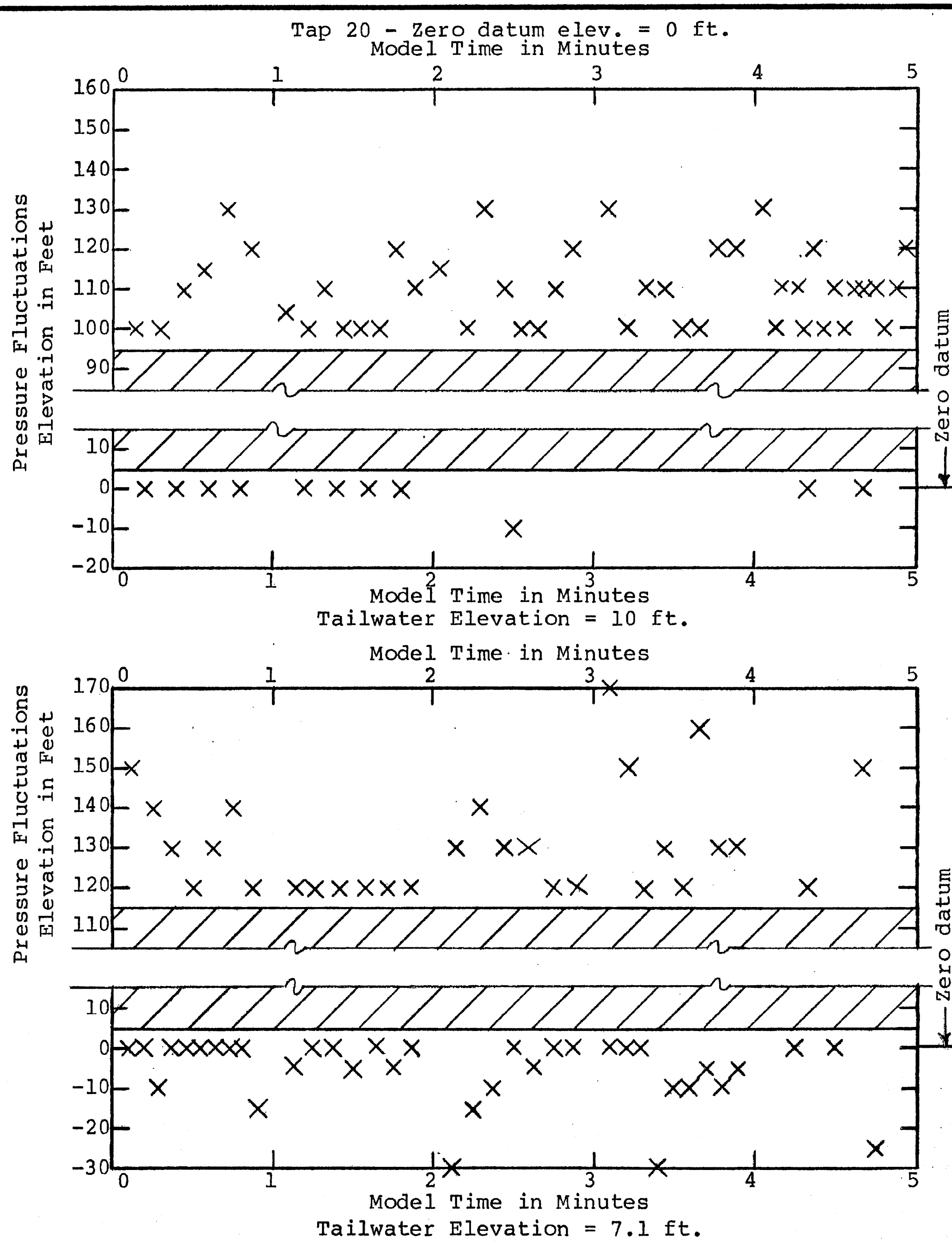
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 1/18/82	NO.302A2321-136



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 1/18/82	NO. 302A2321-137

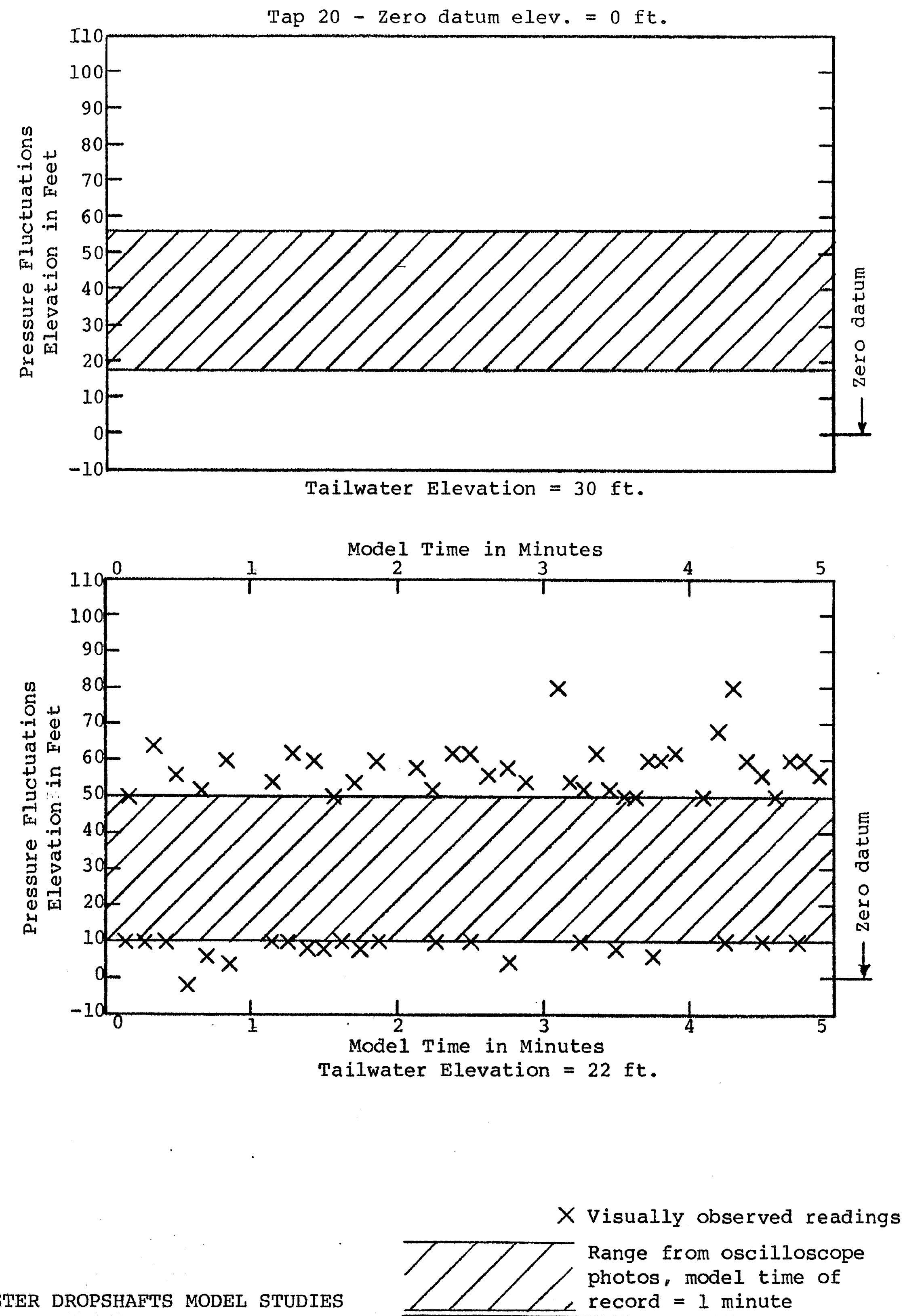


× Visually observed readings

Range from oscilloscope photos, model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 2/17/82	NO. 302A2321-179

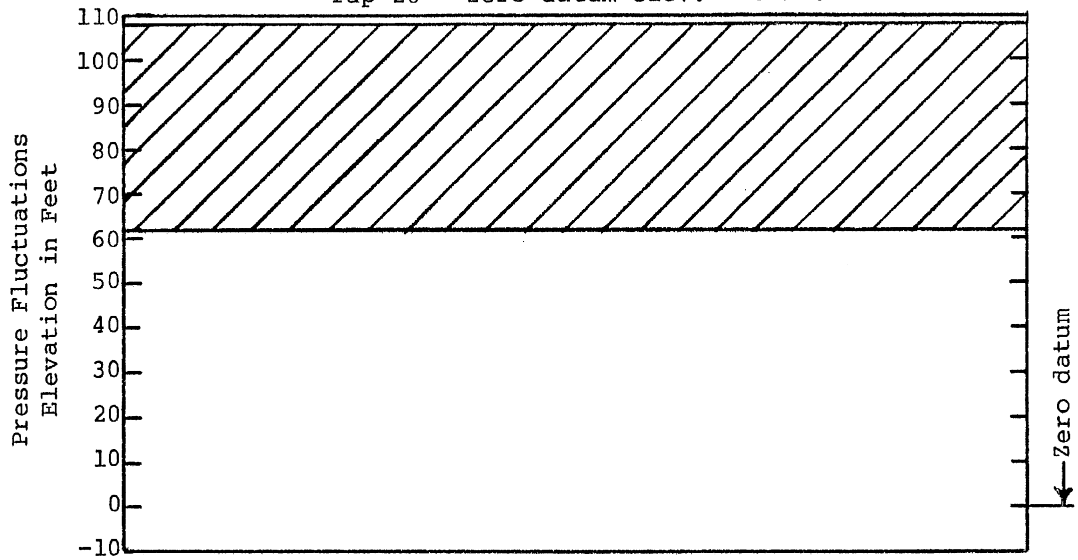


ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

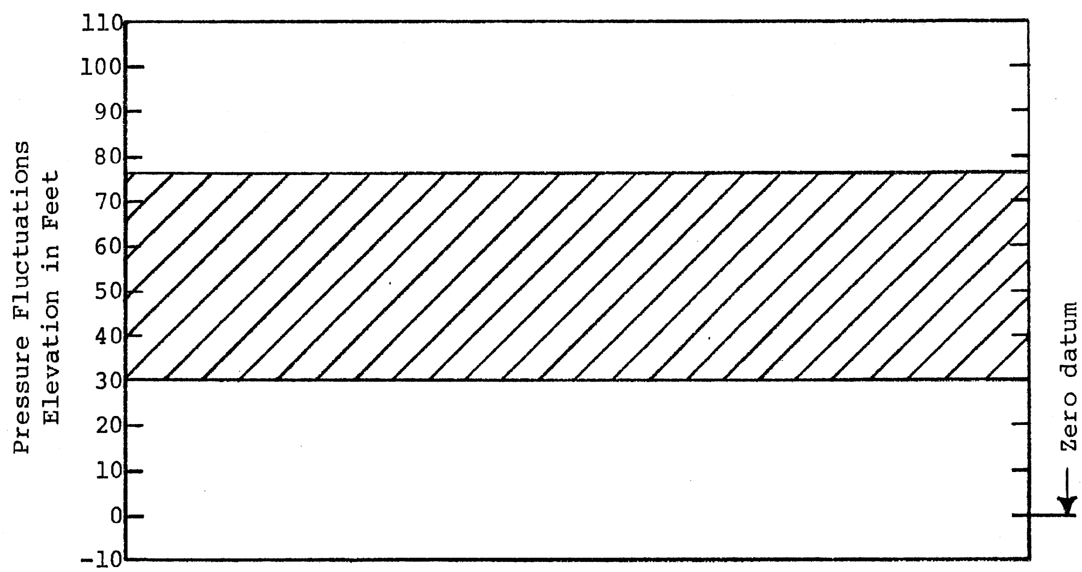
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 2/17/82	NO. 302A2321-180

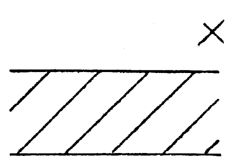
Tap 20 - Zero datum elev. = 0 ft.



Tailwater Elevation = 75 ft.

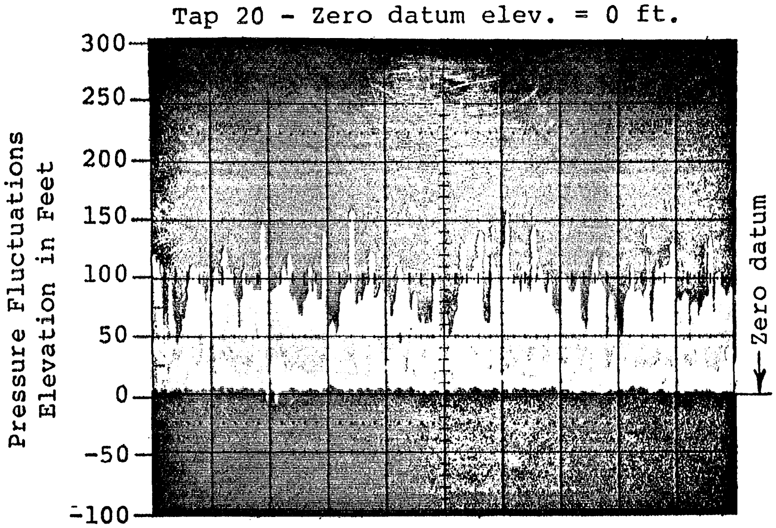


Tailwater Elevation = 45 ft.

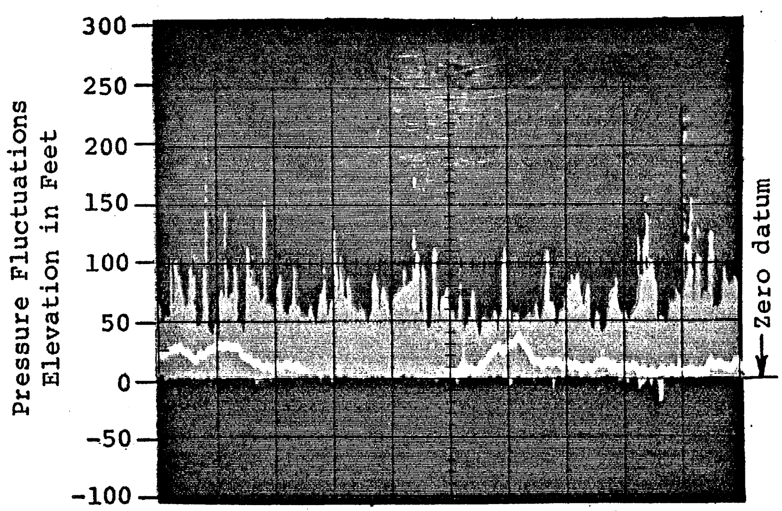


ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 2/17/82	NO. 302A2321-181



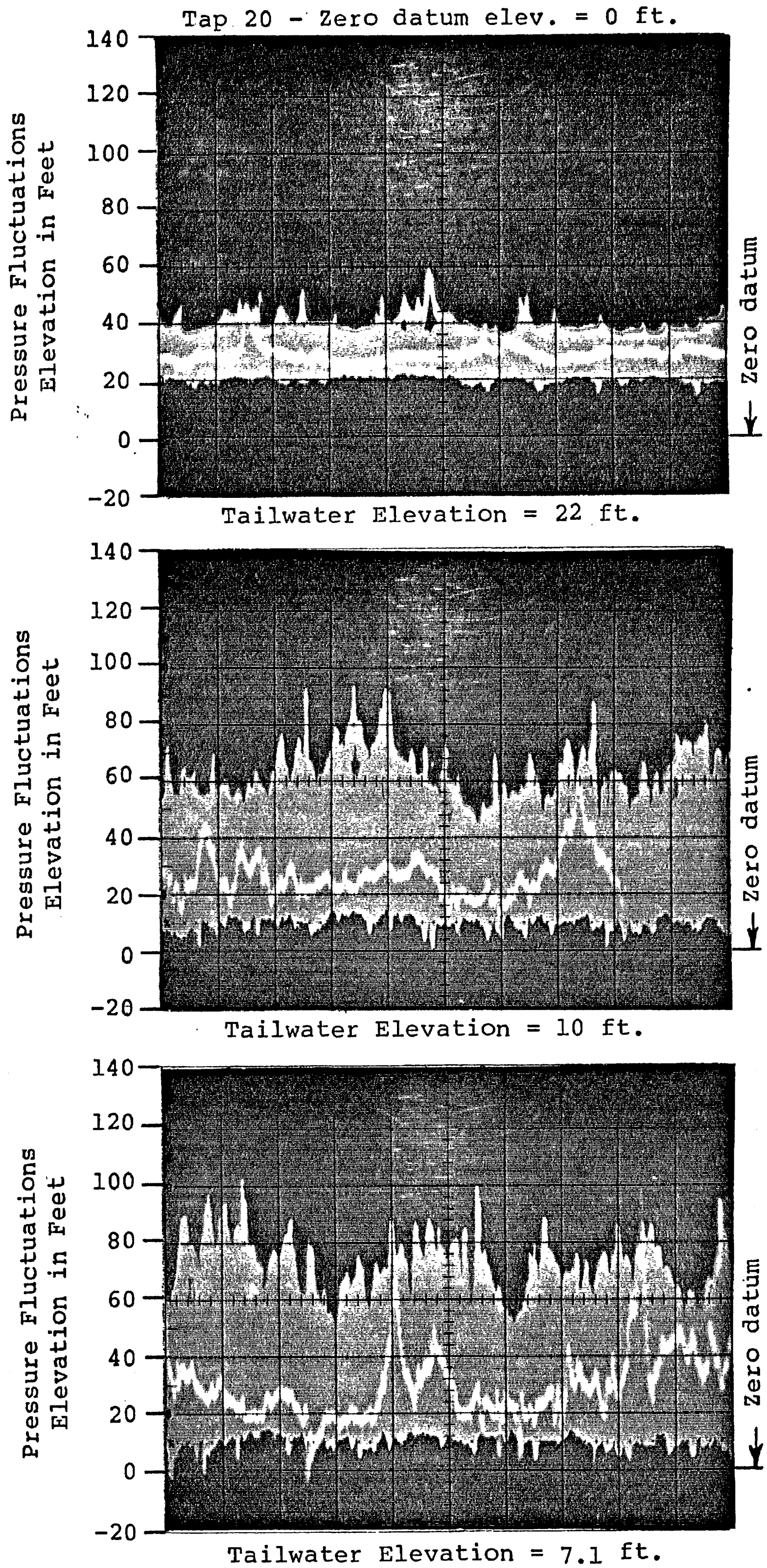
Tailwater Elevation = 0 ft.
Q = 0 to 600 cfs, Model turned on rapidly
Model time of record = 10 seconds



Tailwater Elevation = 0 ft.
Q = 600 to 0 cfs, Model turned off rapidly
Model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R32 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations

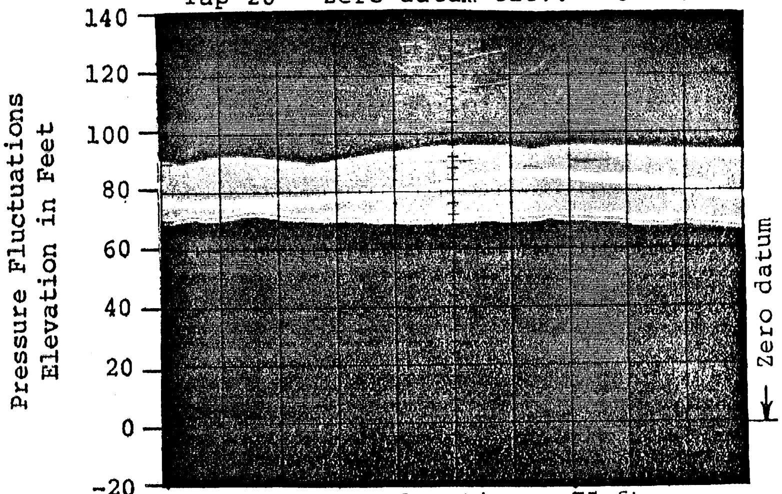
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 1/18/82	NO. 302A2321-142



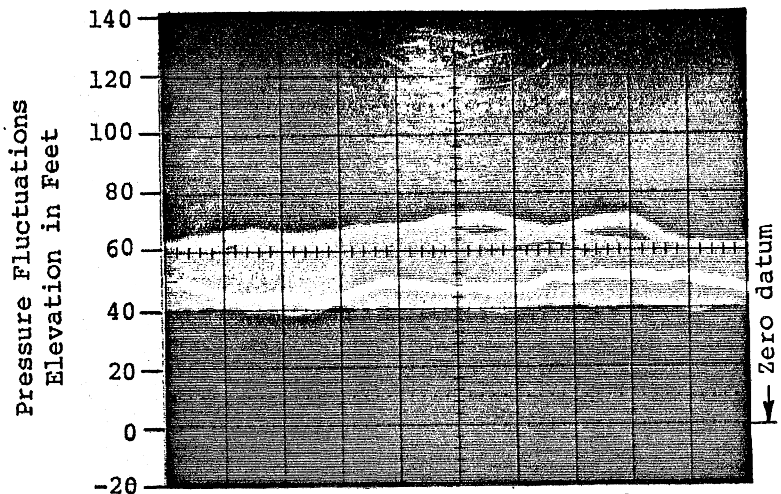
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 1/18/82	NO. 302A2321-138

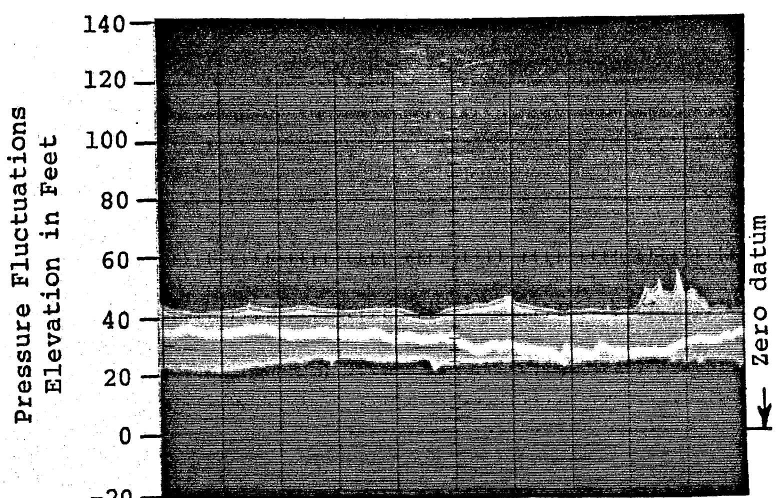
Tap 20 - Zero datum elev. = 0 ft.



Tailwater Elevation = 75 ft.



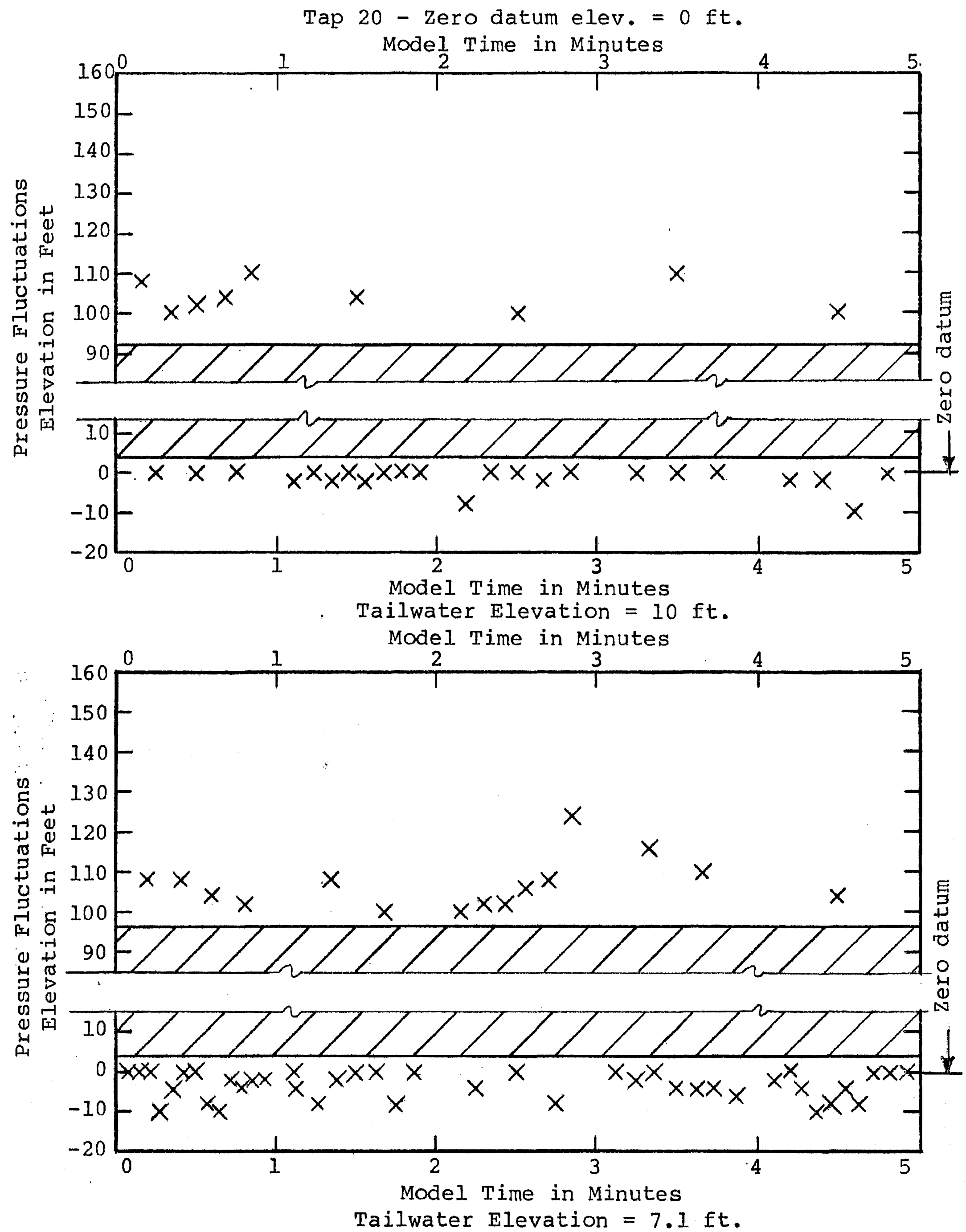
Tailwater Elevation = 45 ft.



Tailwater Elevation = 30 ft.

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 1/18/82	NO. 302A2321-139

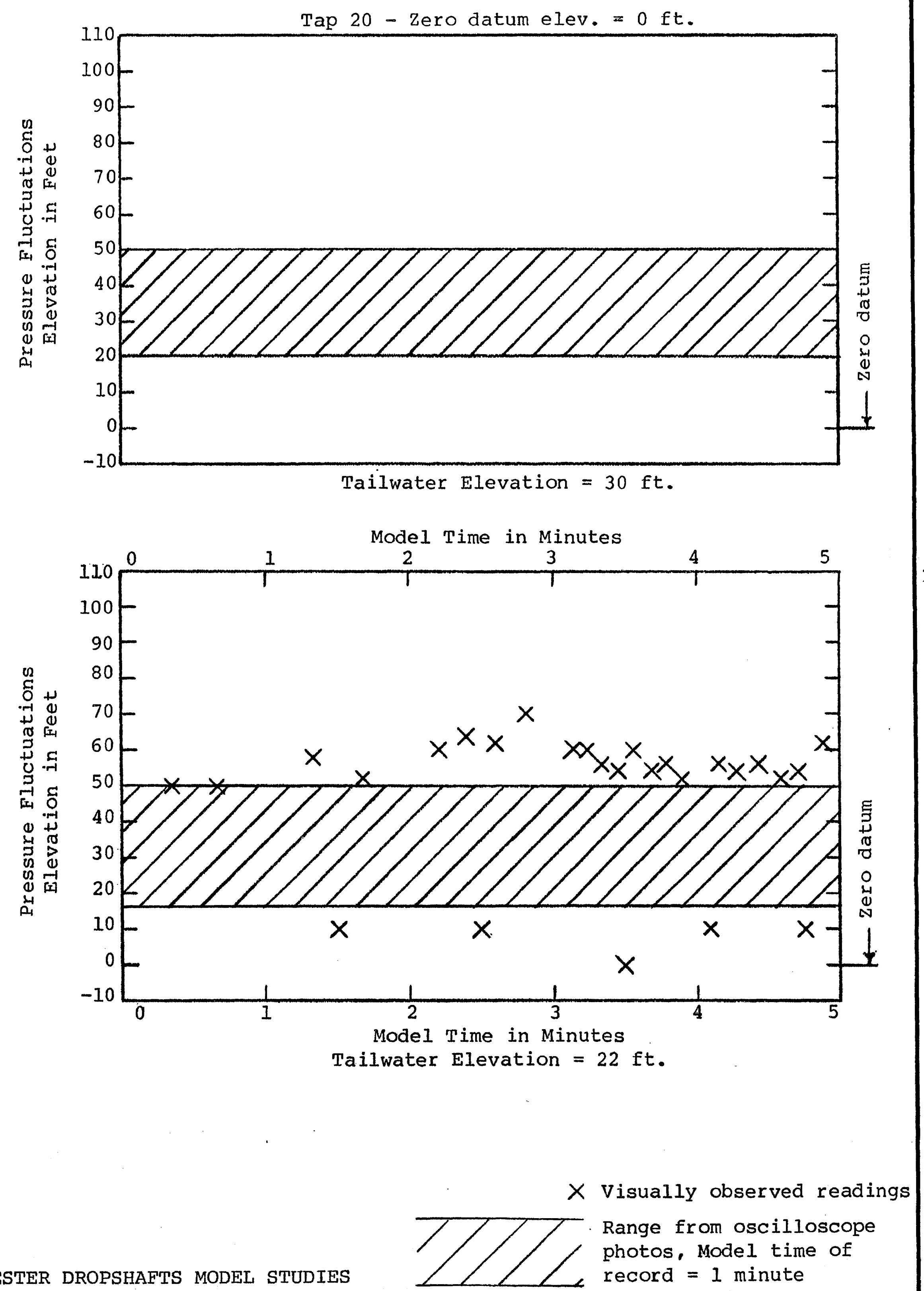


X Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

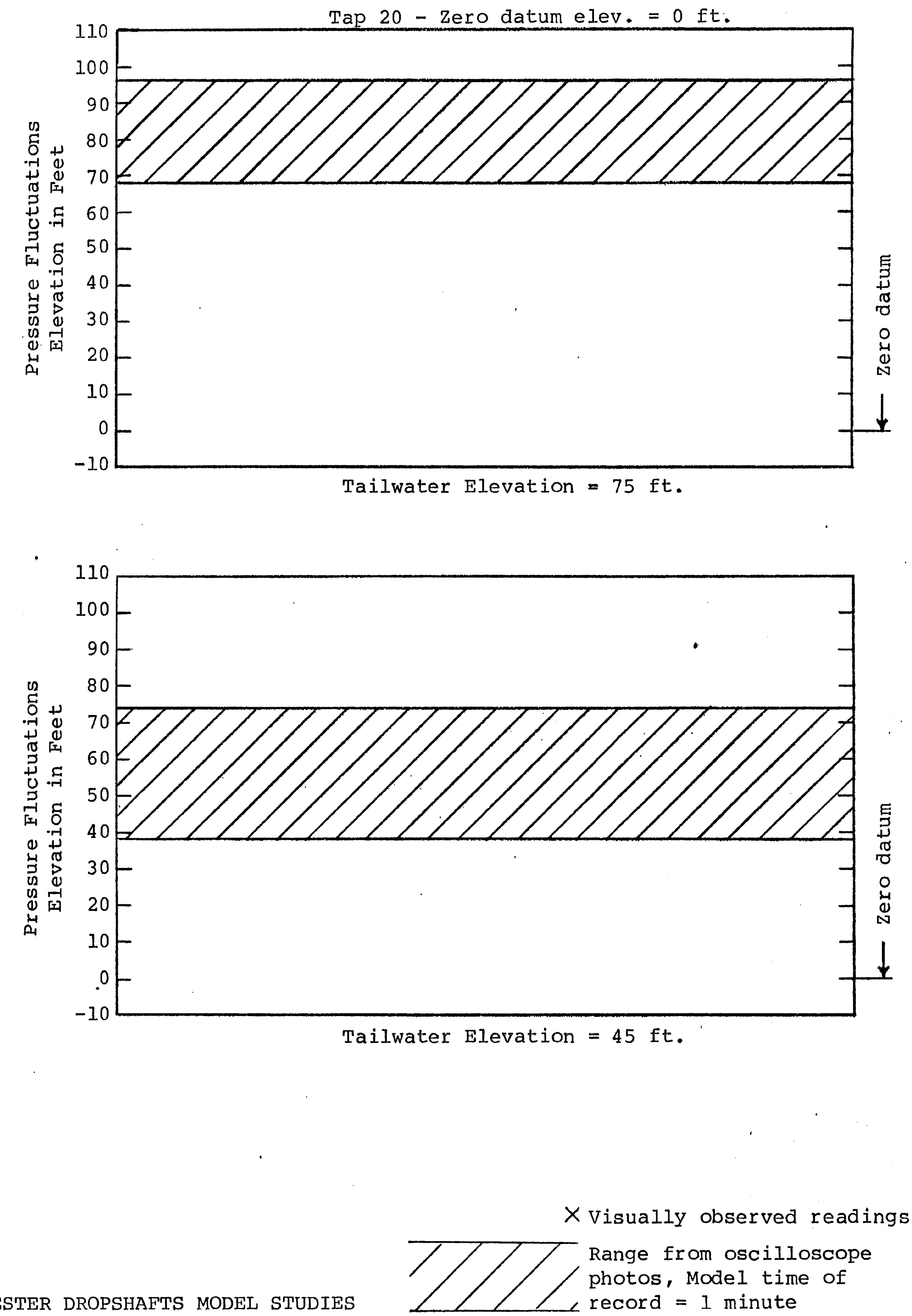
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 2/17/82	NO. 302A2321-182



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

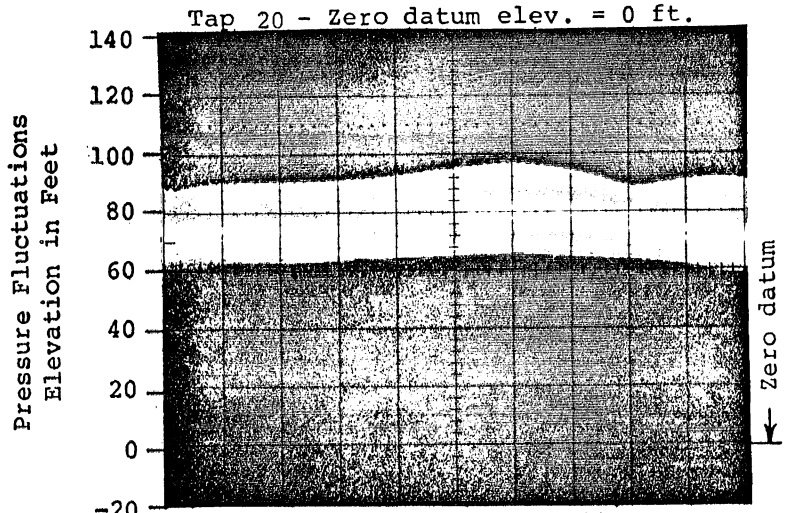
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 2/17/82	NO. 302A2321-183



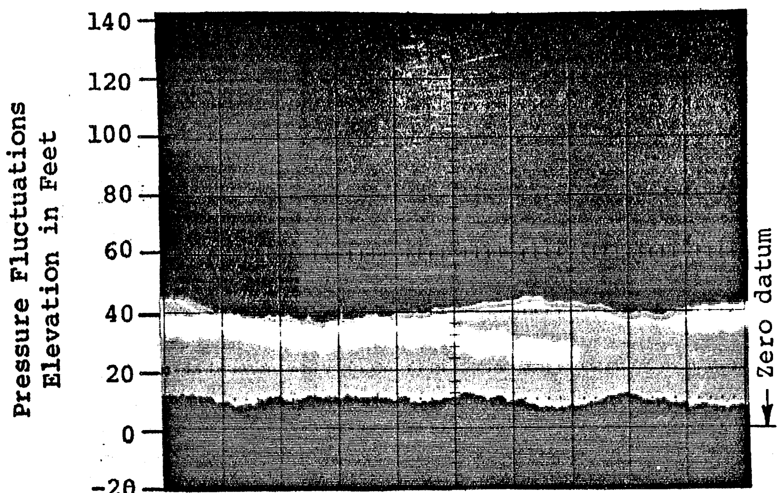
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 2/17/82	NO. 302A2321-184

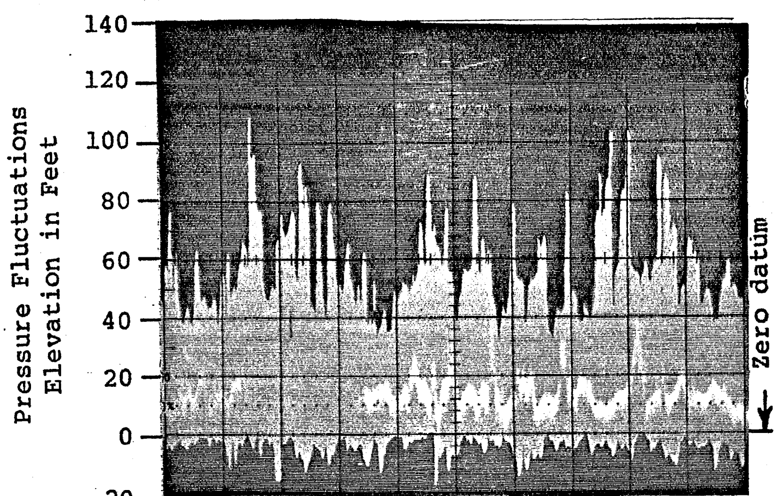
Tap 20 - Zero datum elev. = 0 ft.



Tailwater Elevation = 75 ft.



Tailwater Elevation = 22 ft.

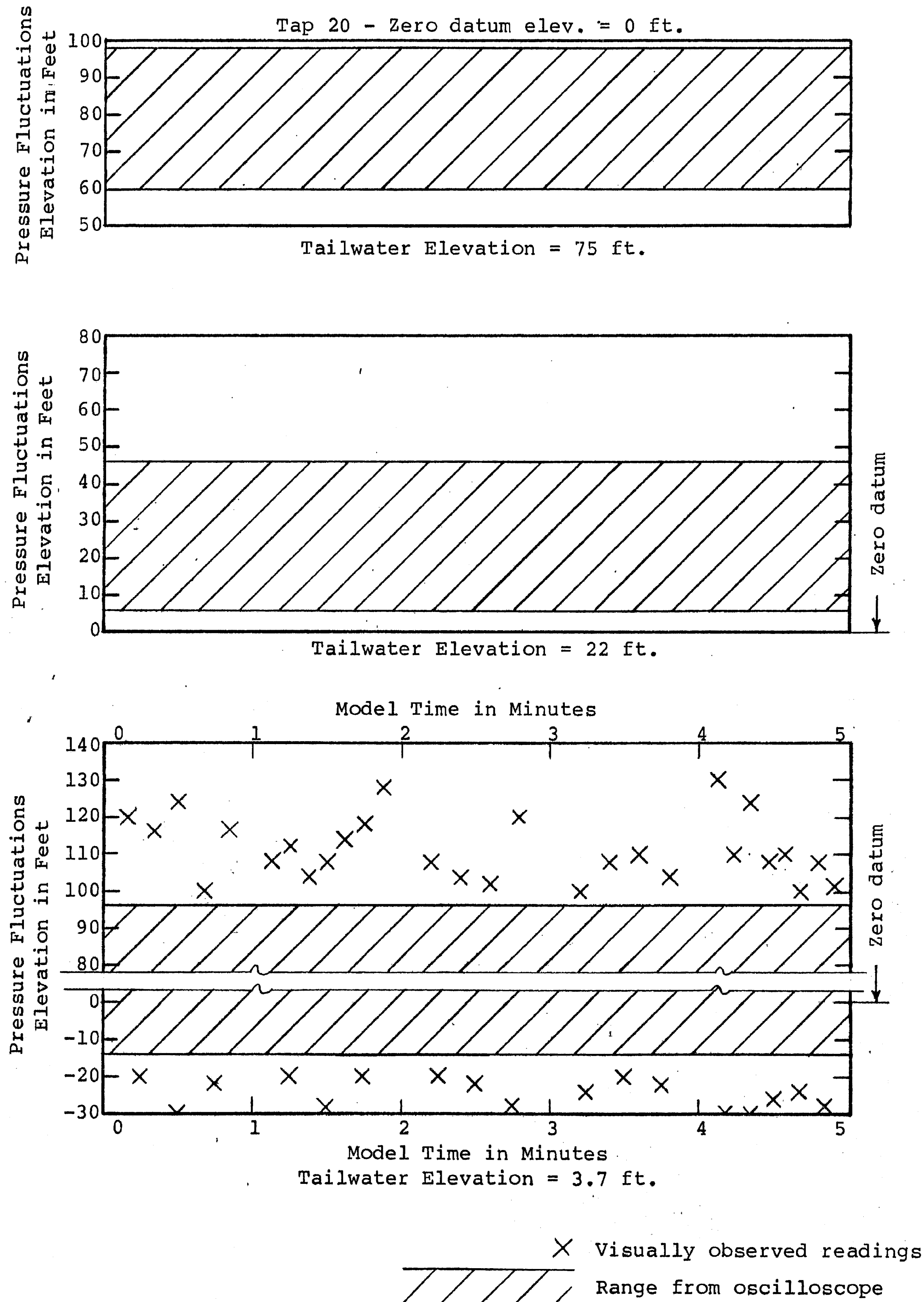


Tailwater Elevation = 3.7 ft.

ROCHESTER DROPSHAFTS MODEL STUDIES

Type L2 R35 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 200 cfs
Model time of record = 1 minute

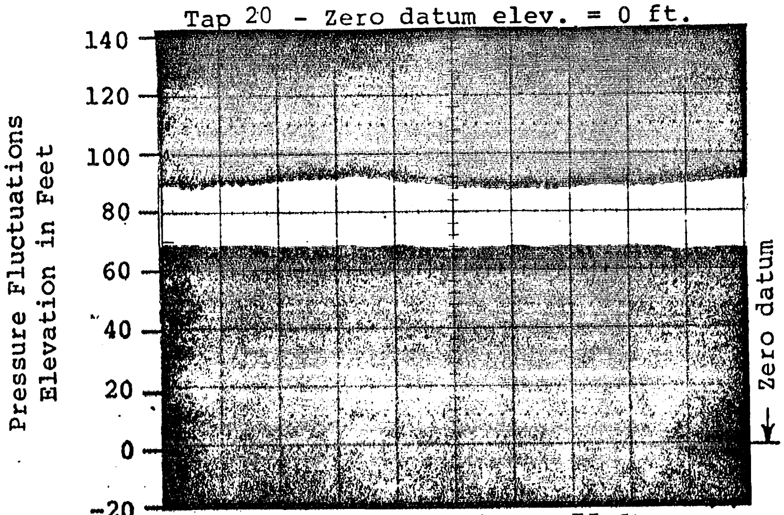
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 1/18/82	NO.302A2321-176



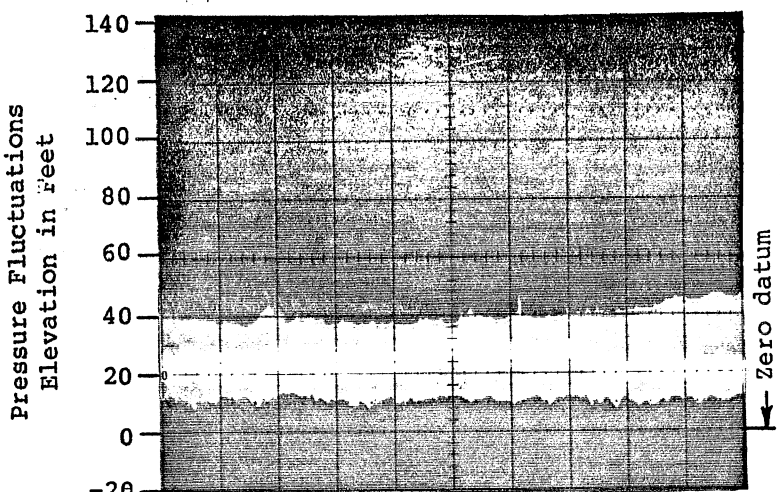
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 200 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-209

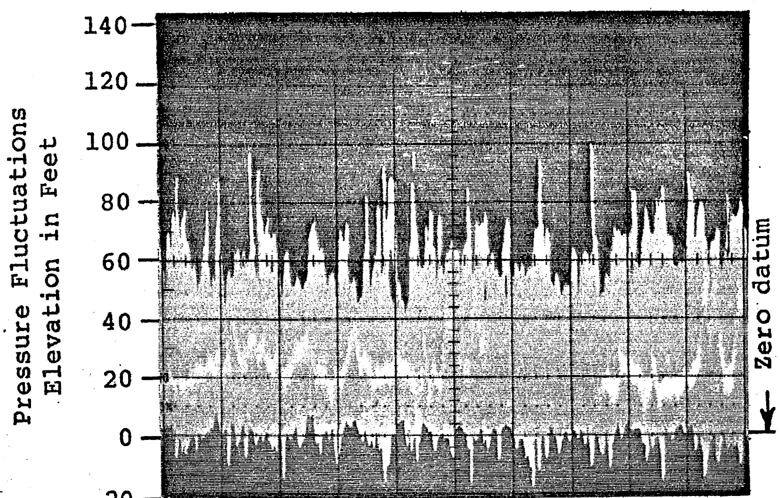
Tap 20 - Zero datum elev. = 0 ft.



Tailwater Elevation = 75 ft.



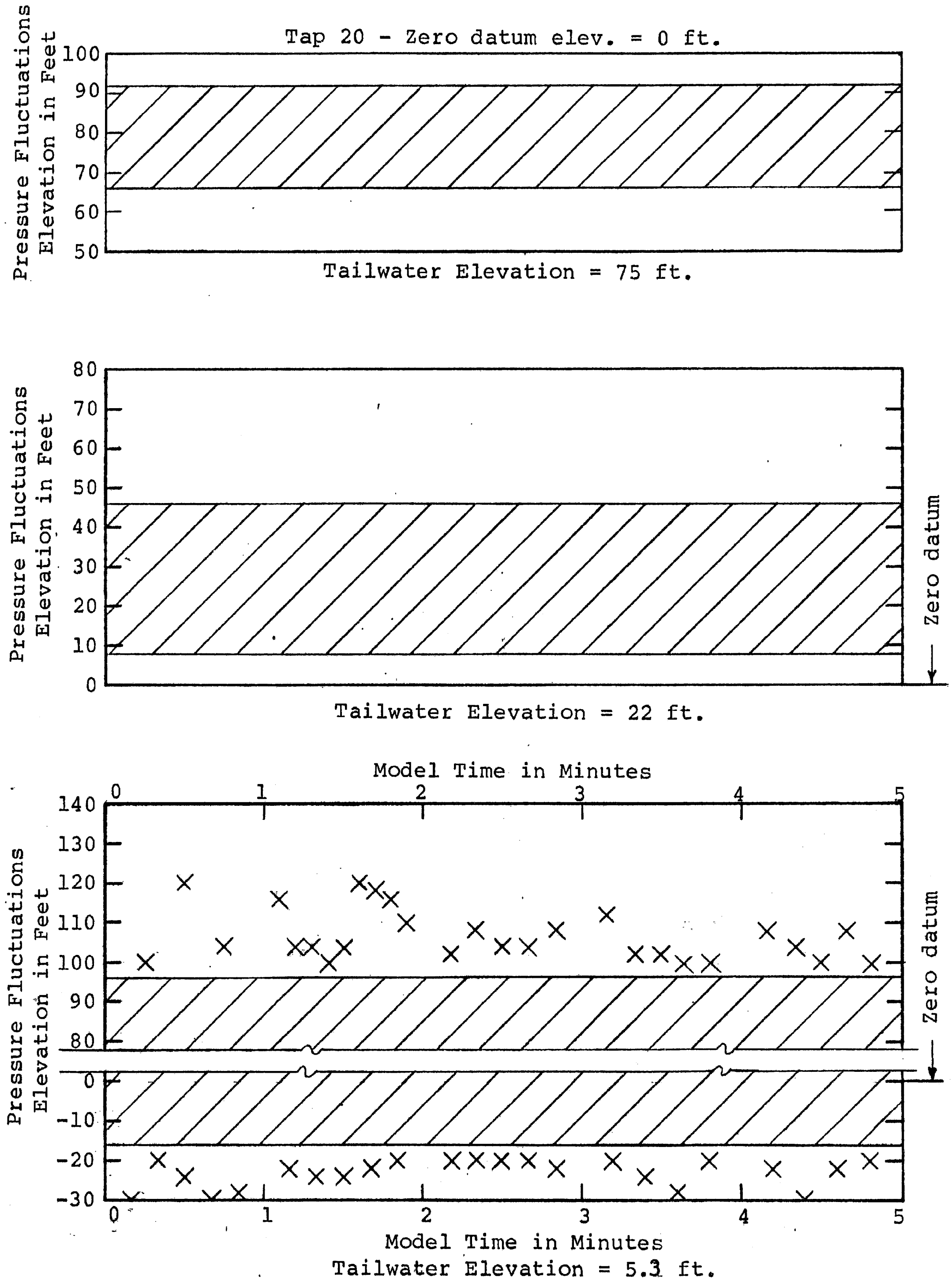
Tailwater Elevation = 22 ft.



Tailwater Elevation = 5.3 ft.

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 400 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 1/18/82	NO.302A2321-177

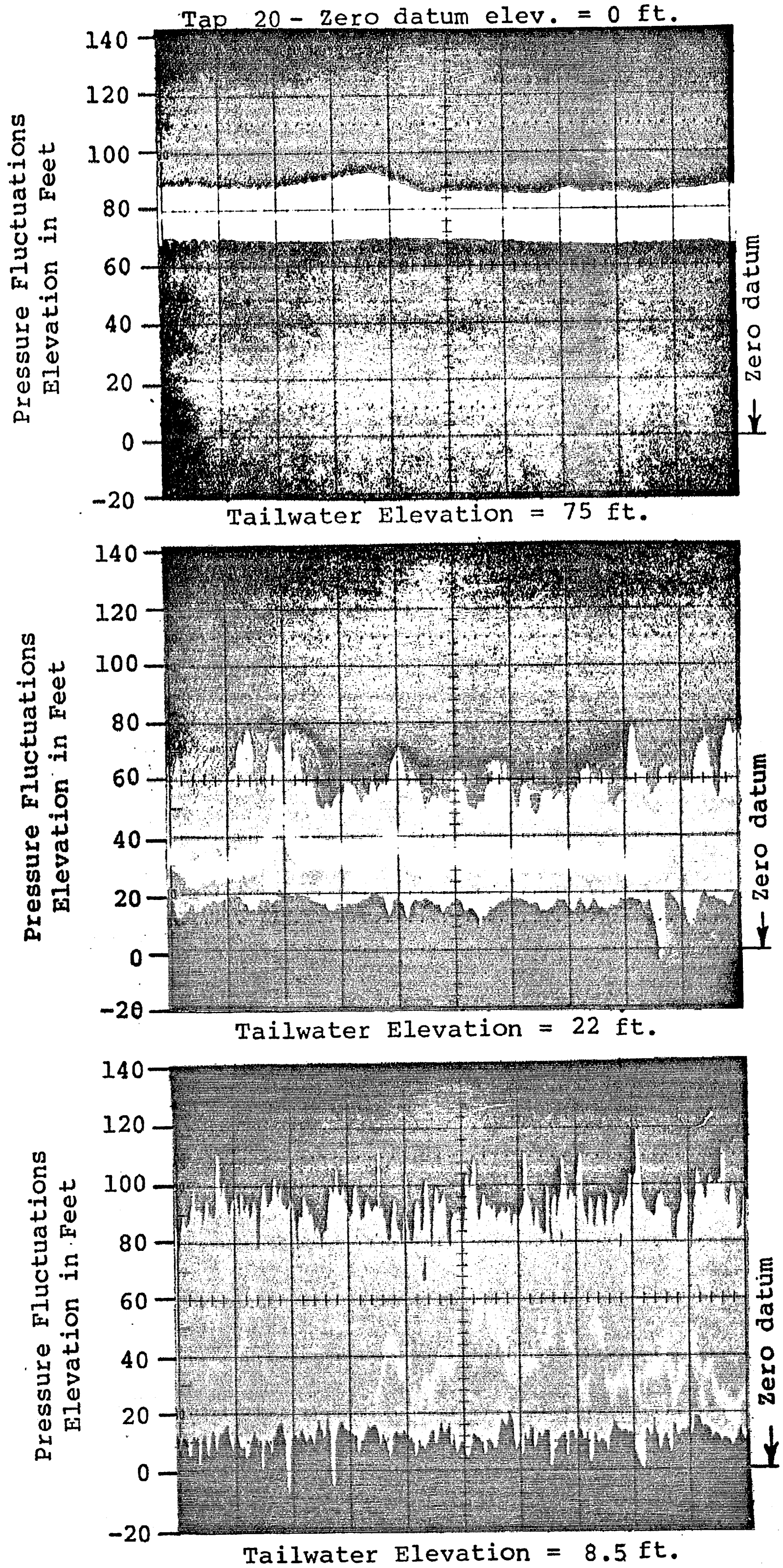


× Visually observed readings

(hatched) Range from oscilloscope photos, Model time of record = 1 minute

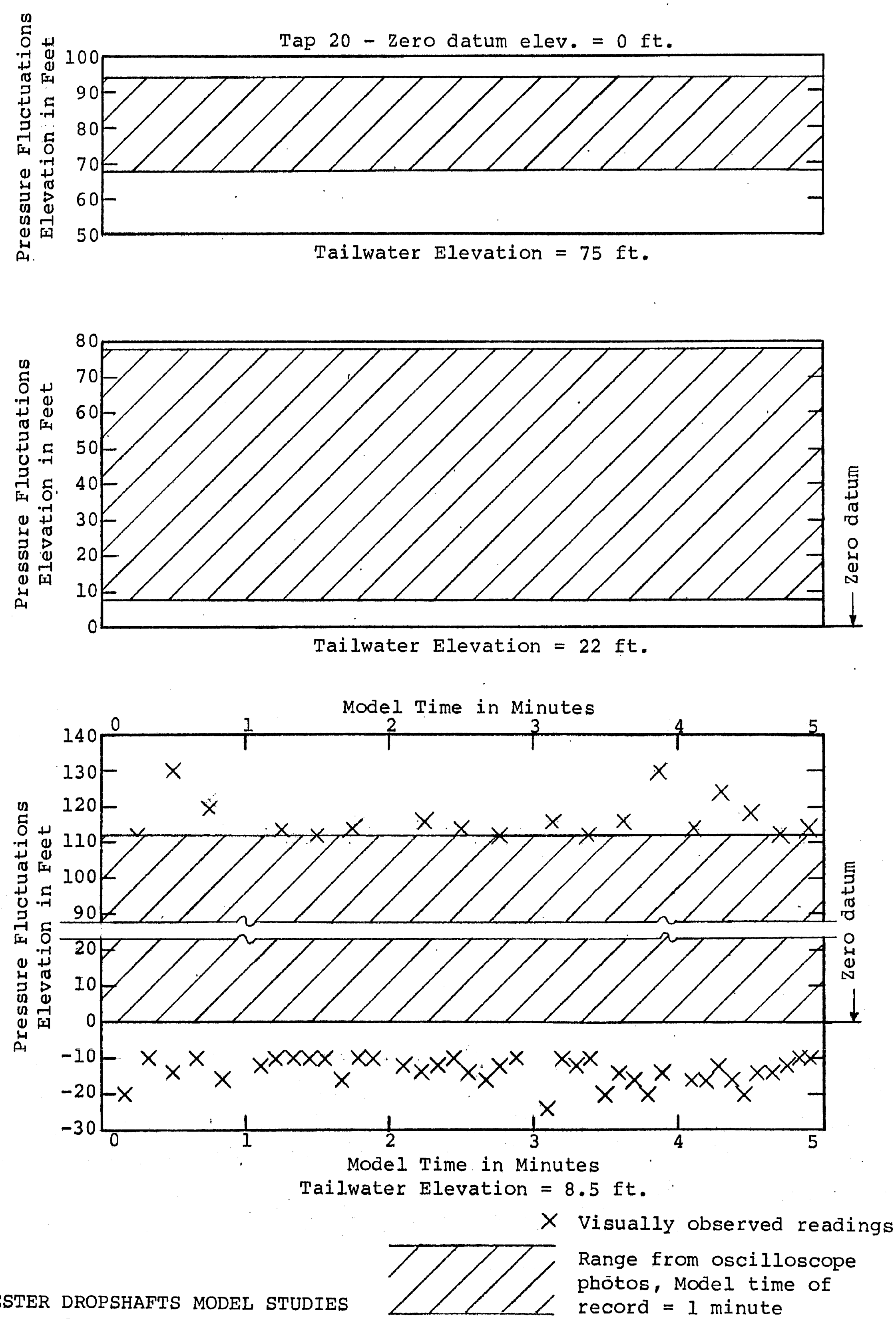
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 400 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-210



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 800 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY, UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 1/18/82	NO. 302A2321-178



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 800 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

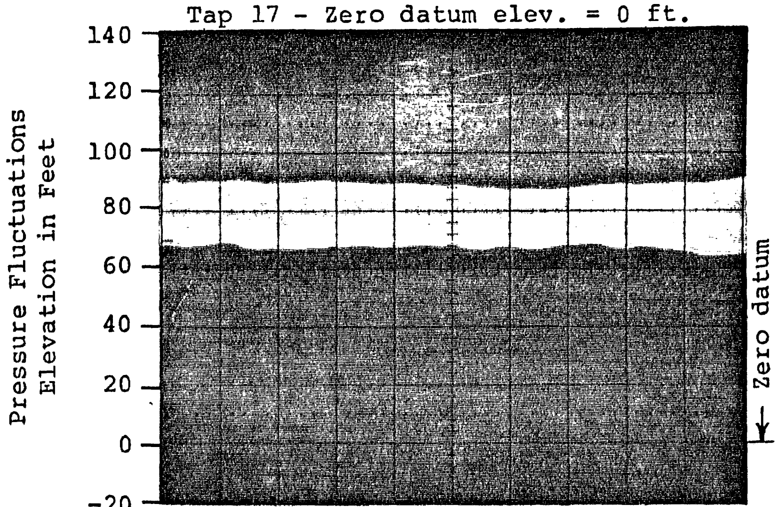
DRAWN BB	CHECKED HQ[illegible]	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-211

Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Range from Photos Max.-ft	Range from Photos Min.-ft	Observed Readings Max.-ft	Observed Readings Min.-ft
			Type L2 R32 - Tap 20 Elevation = 0 ft			
600	7.1	24.4	115	5	170	-30
600	10	25.3	95	5	130	-10
600	22	25.7	50	10	80	-2
600	30	31.2	56	18		
600	45	45.8	76	30		
600	75	75.8	108	62		
			Type L2 R35 - Tap 20 Elevation = 0 ft			
600	7.1	28.7	96	4	124	-10
600	10	28.2	92	4	110	-10
600	22	25.9	50	16	70	0
600	30	31.2	50	20		
600	45	45.6	74	38		
600	75	76.3	96	68		
200	3.7	9.4	96	-14	130	-30
200	22	21.7	46	6		
200	75	74.8	98	60		
400	5.3	14.6	96	-16	120	-30
400	22	22.1	46	8		
400	75	75.4	92	66		
800	8.5	31.6	112	0	130	-24
800	22	38.3	78	8		
800	75	77.5	94	68		

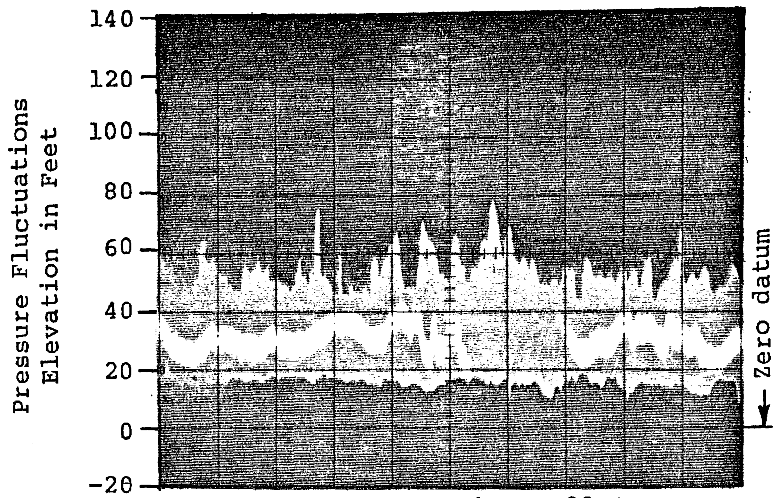
ROCHESTER DROPSHAFTS MODEL STUDIES
Model Scale 1:12.52
Summary of Typical
Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED B B	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-230

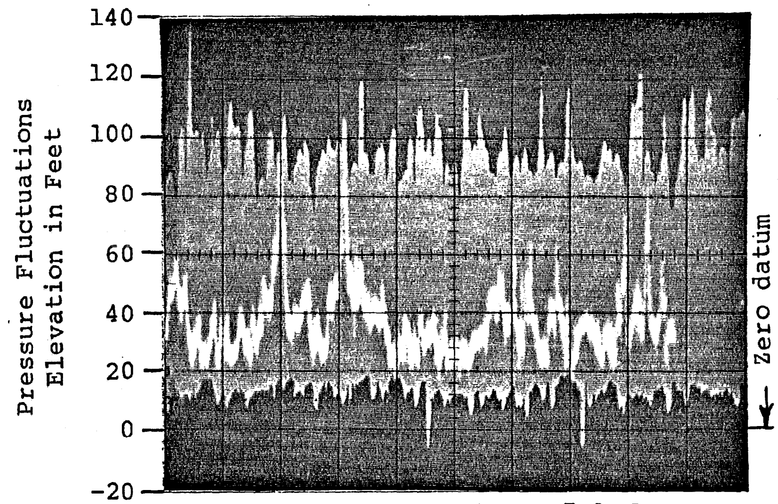
Tap 17 - Zero datum elev. = 0 ft.



Tailwater Elevation = 75 ft.



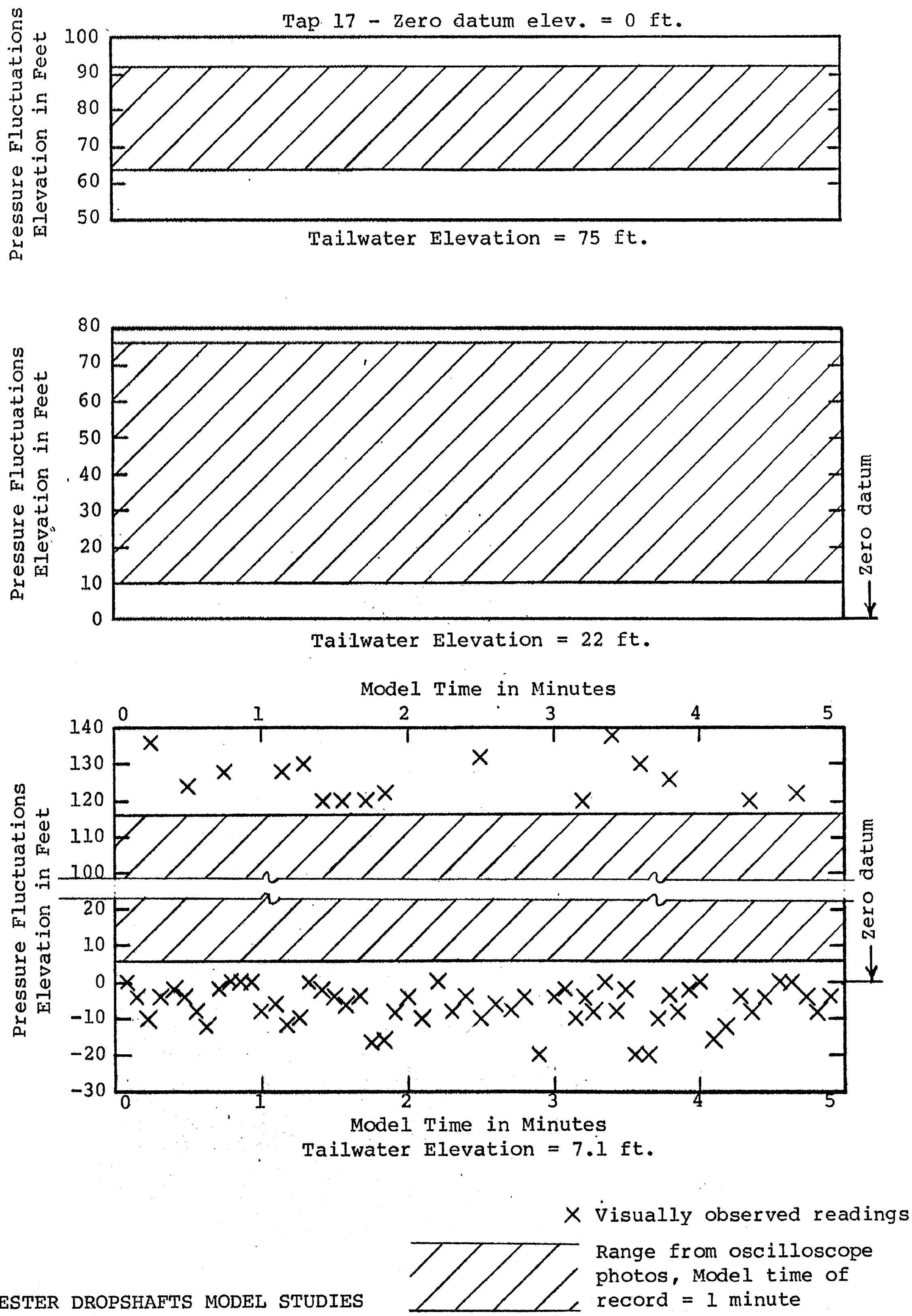
Tailwater Elevation = 22 ft.



Tailwater Elevation = 7.1 ft.

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

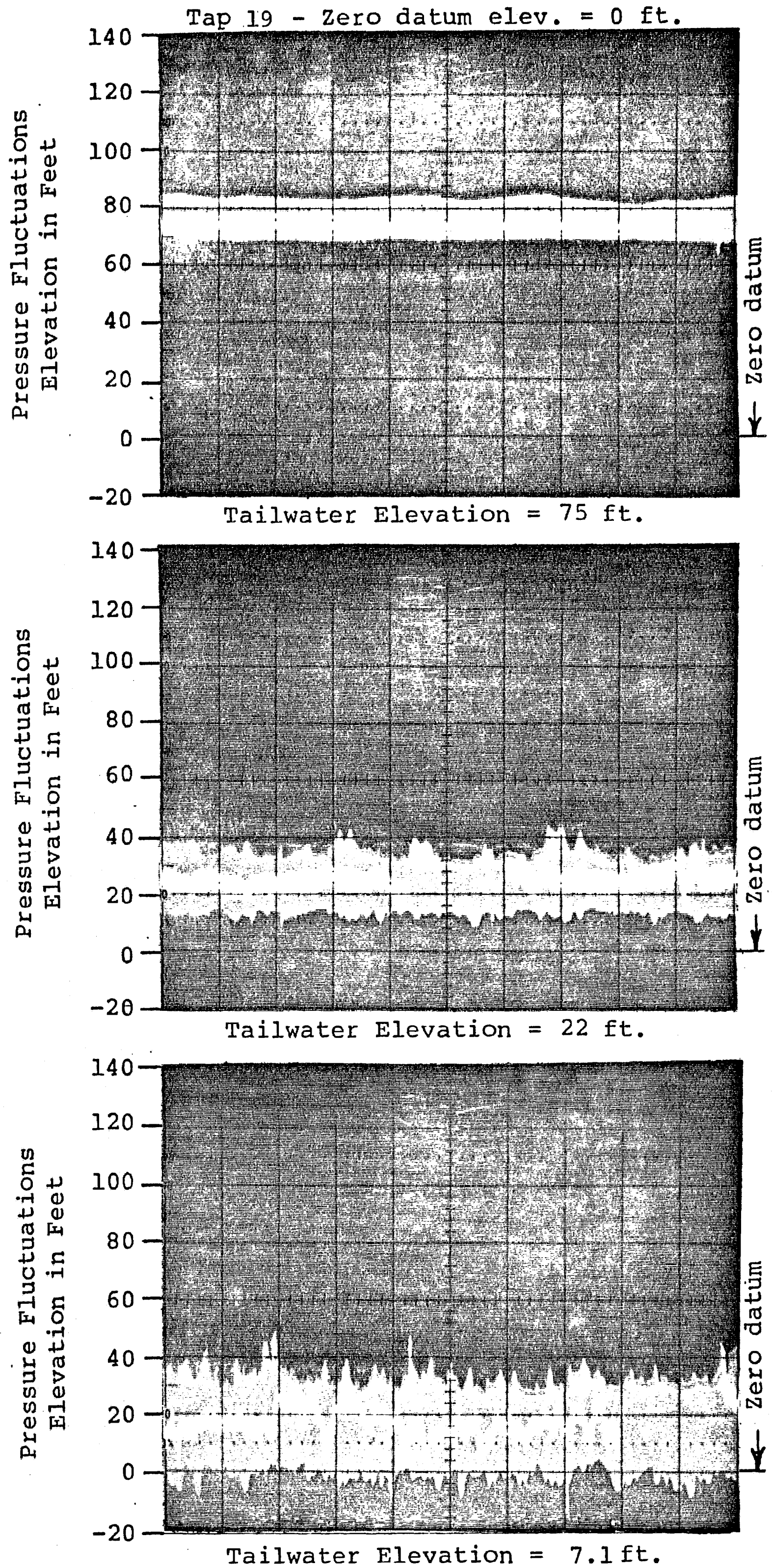
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 1/18/82	NO. 302A2321-173



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

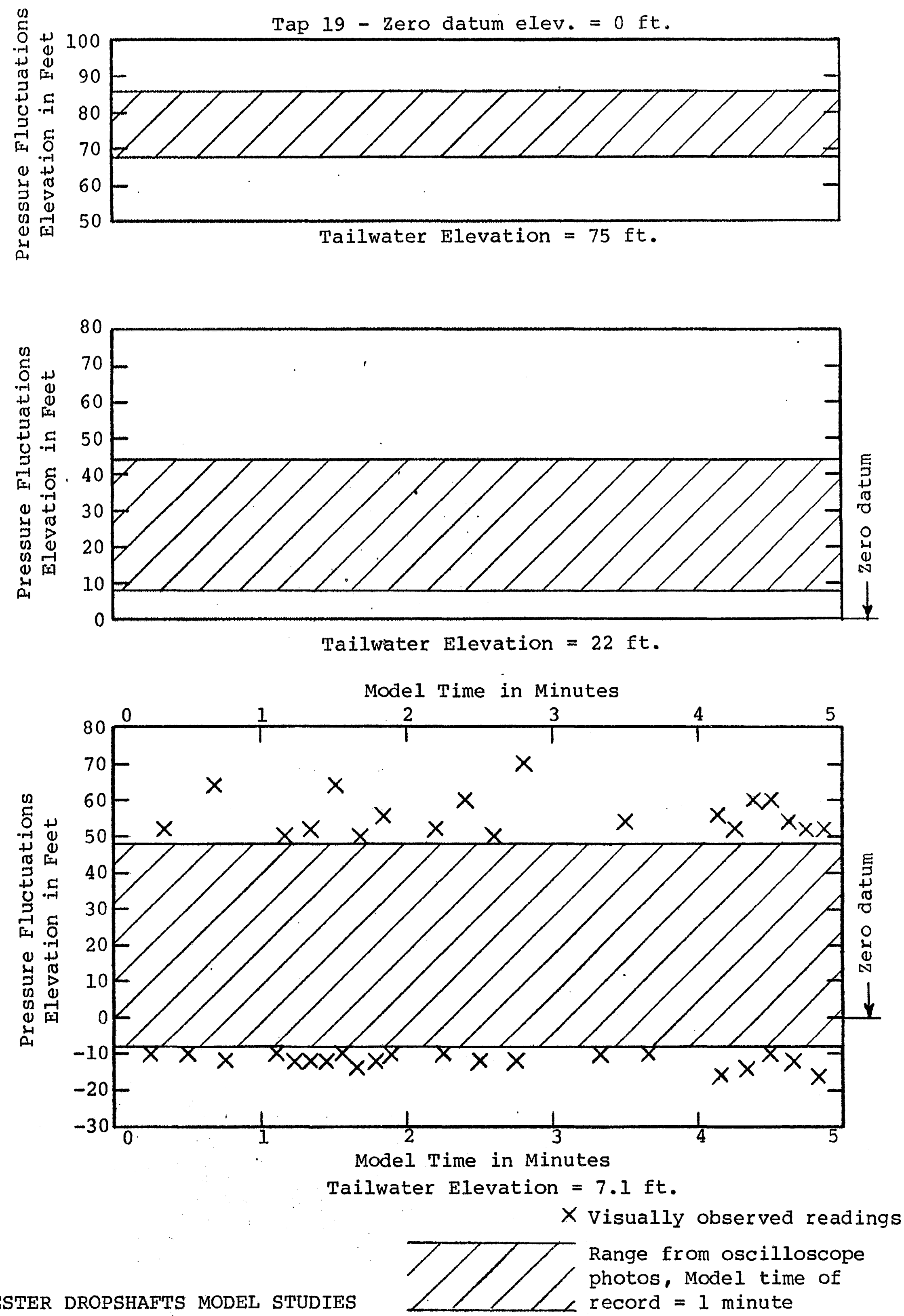
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-206

CHART 65



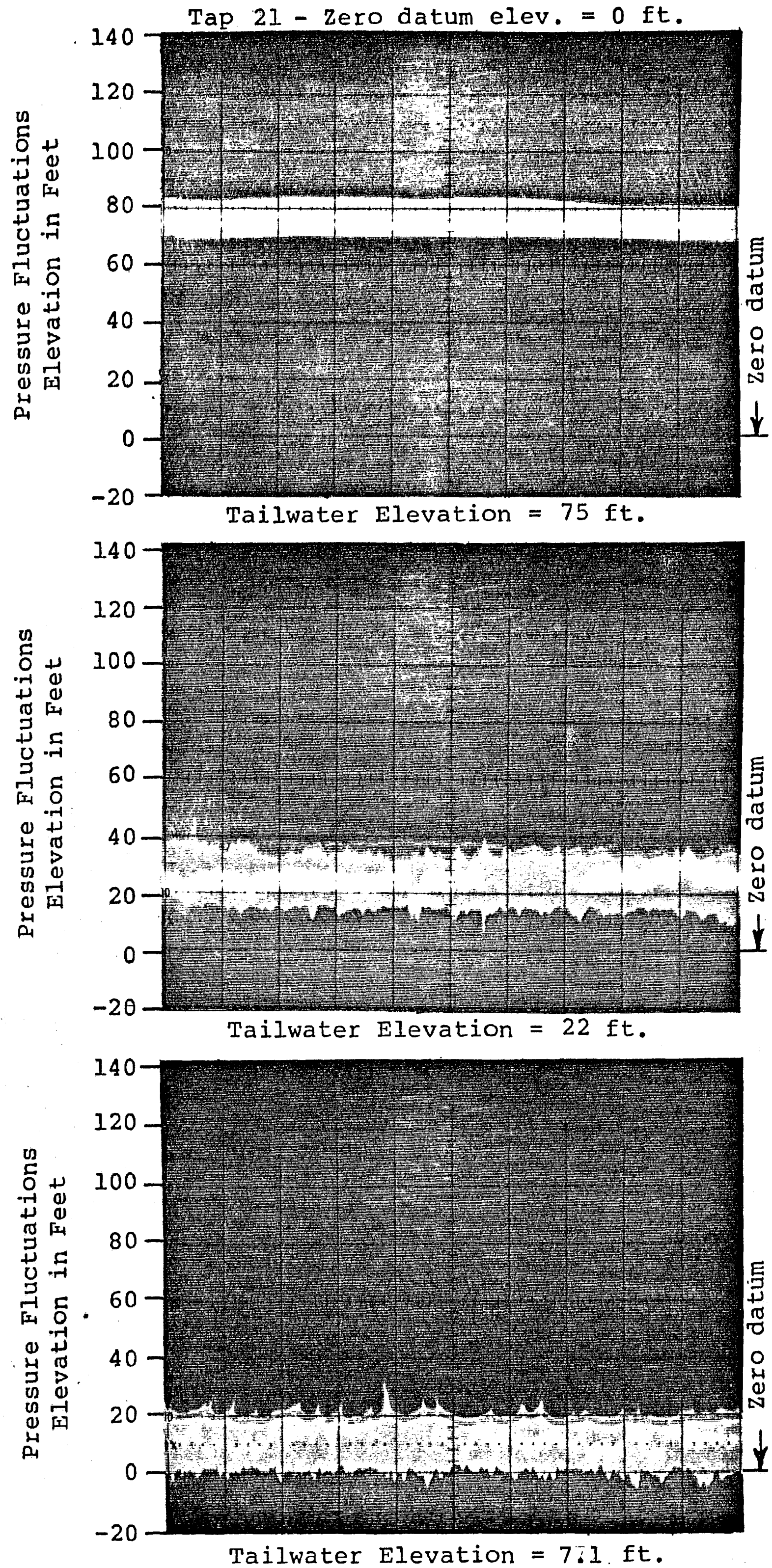
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 1/18/82	NO. 302A2321-174



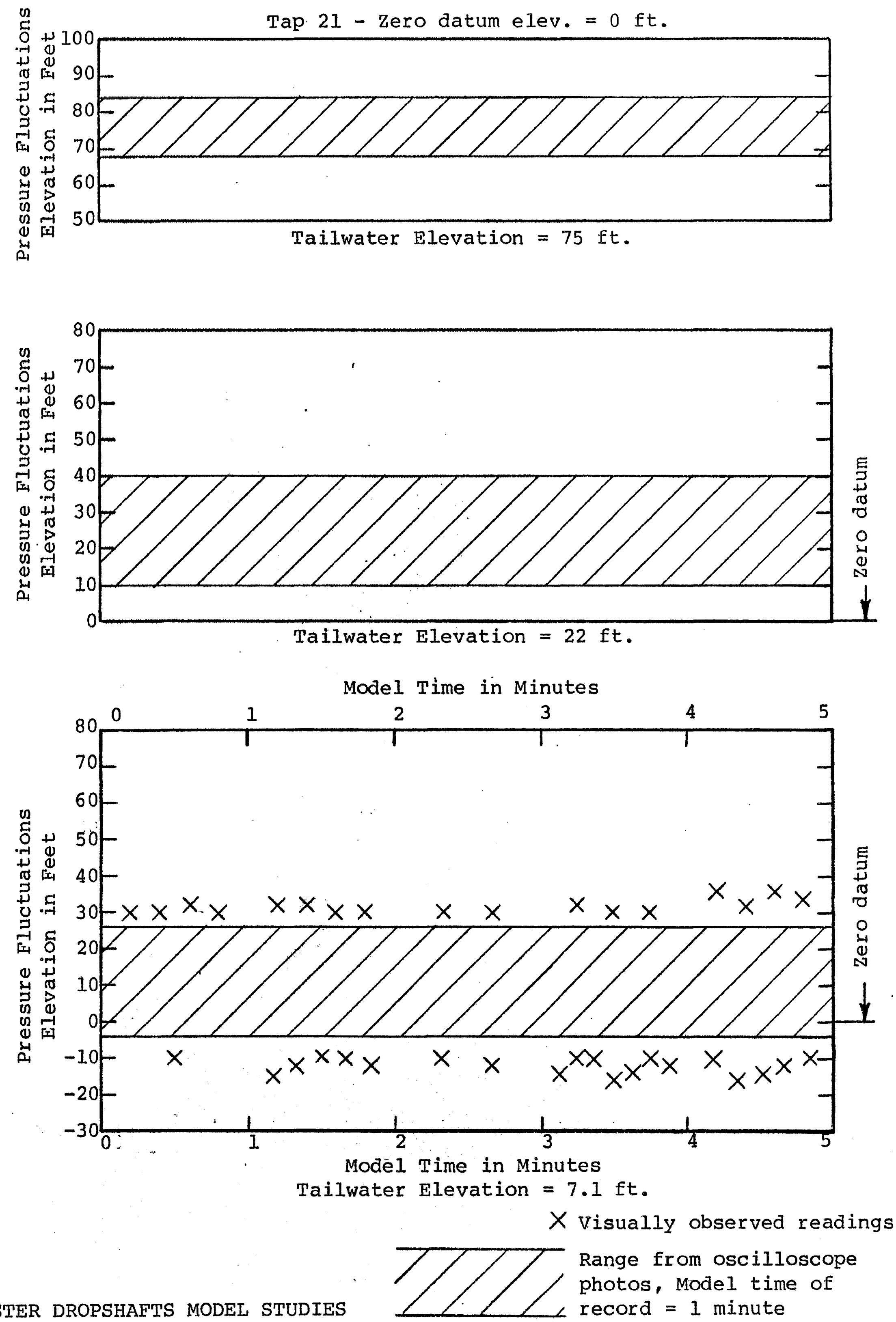
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED MOS	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-207



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Dropshaft Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 1/18/82	NO. 302A2321-175



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

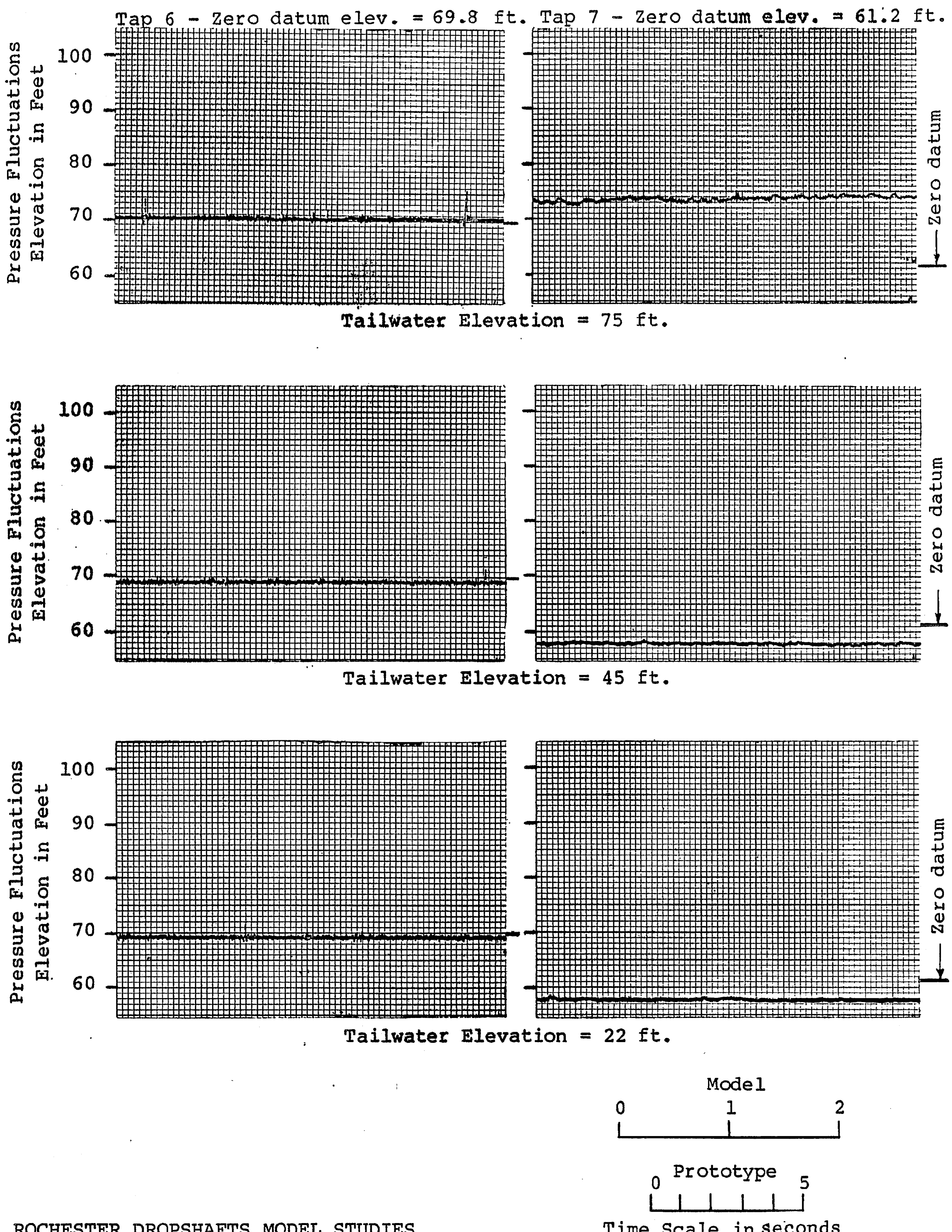
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-208

Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Range from Photos Max.-ft	Range from Photos Min.-ft	Observed Readings Max.-ft	Observed Readings Min.-ft
			Type L2 R35 - Tap 17 Elevation = 0 ft			
600	7.1		116	6	138	-20
600	22		76	10		
600	75		92	64		
			Type L2 R35 - Tap 19 Elevation = 0 ft			
600	7.1		48	-8	70	-16
600	22		44	8		
600	75		86	68		
			Type L2 R35 - Tap 21 Elevation = 0 ft			
600	7.1		26	-4	36	-16
600	22		40	10		
600	75		84	68		

ROCHESTER DROPSHAFTS MODEL STUDIES
Model Scale 1:12.52
Summary of Typical
Pressure Fluctuations

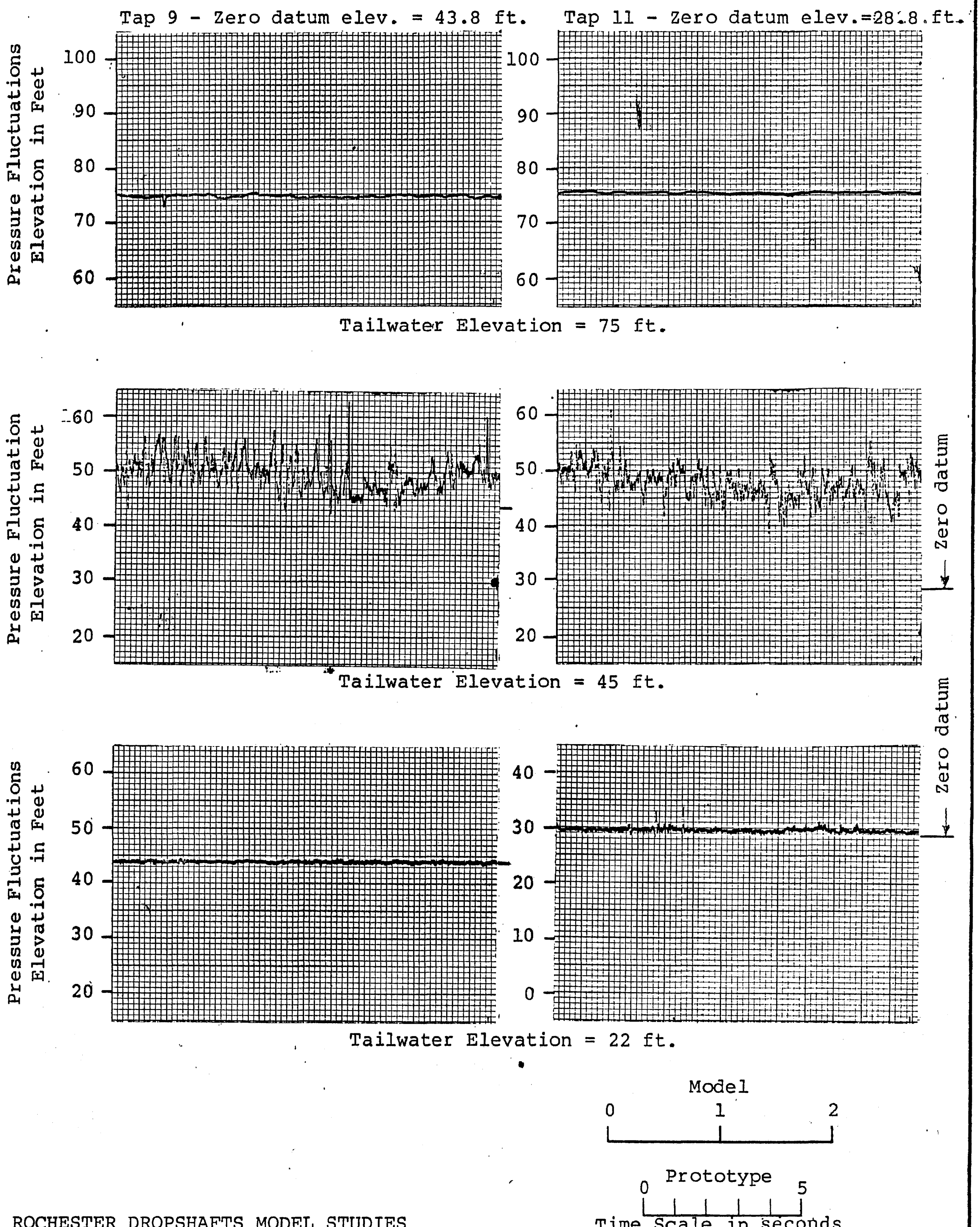
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED ZB	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-231



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

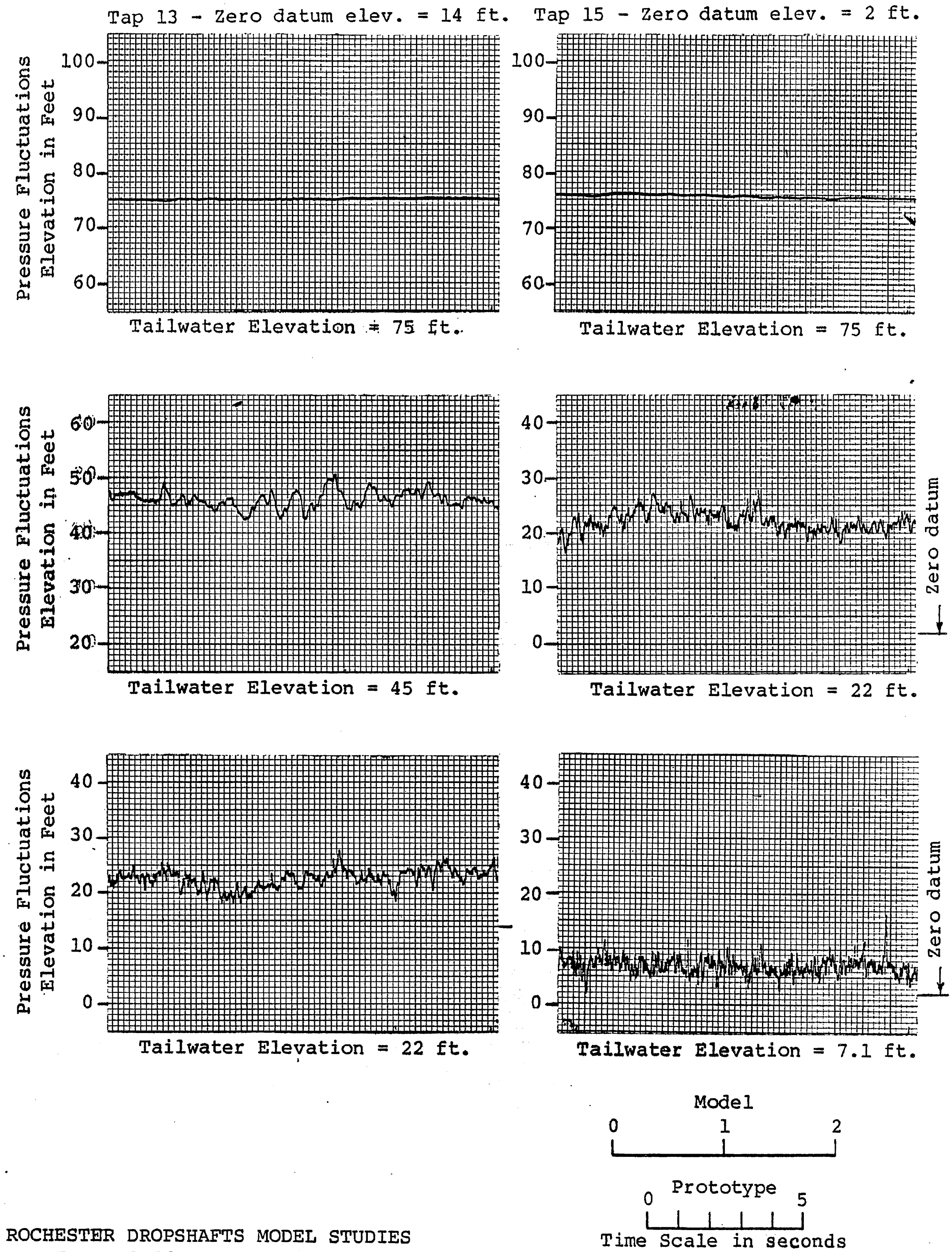
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-196



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

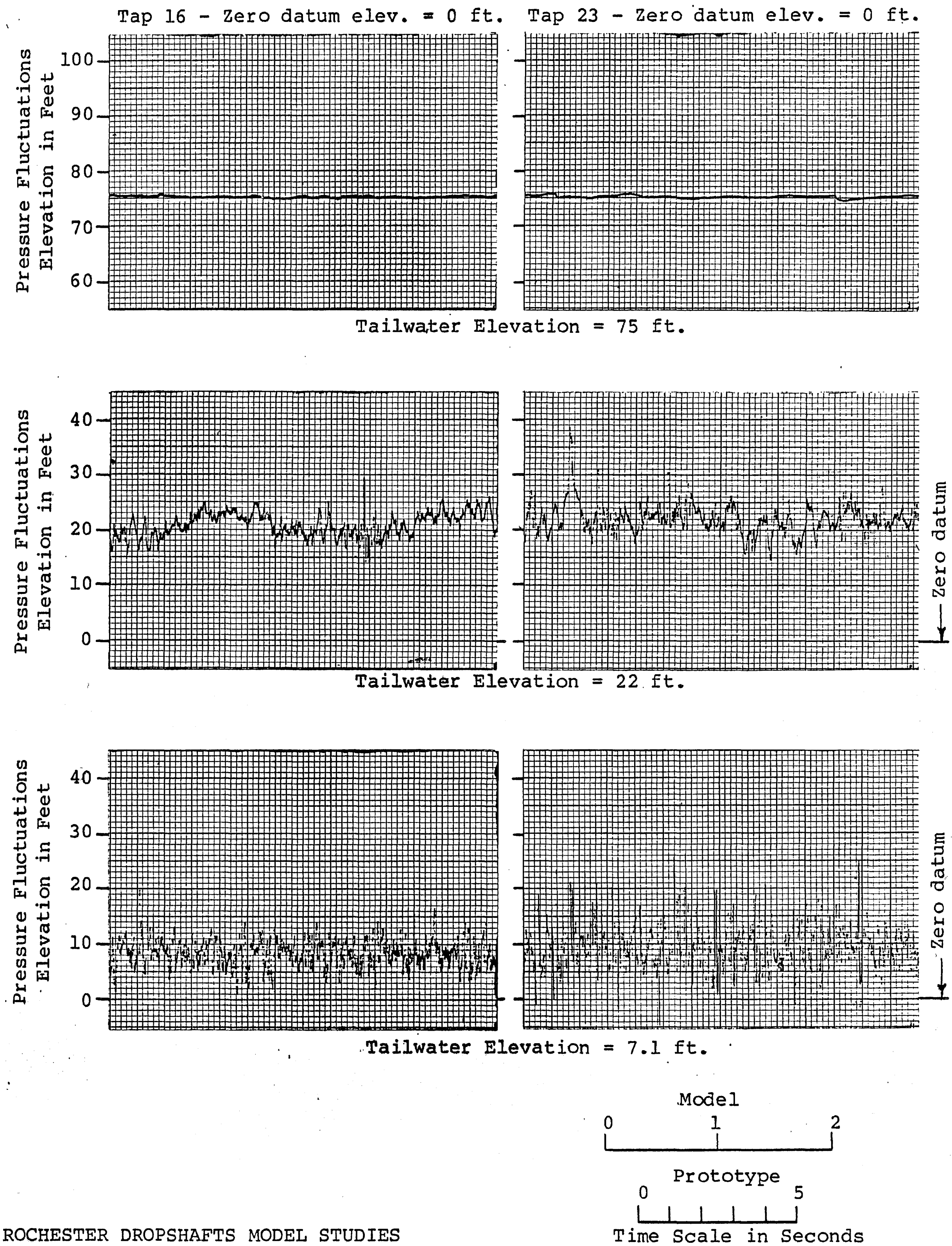
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-197



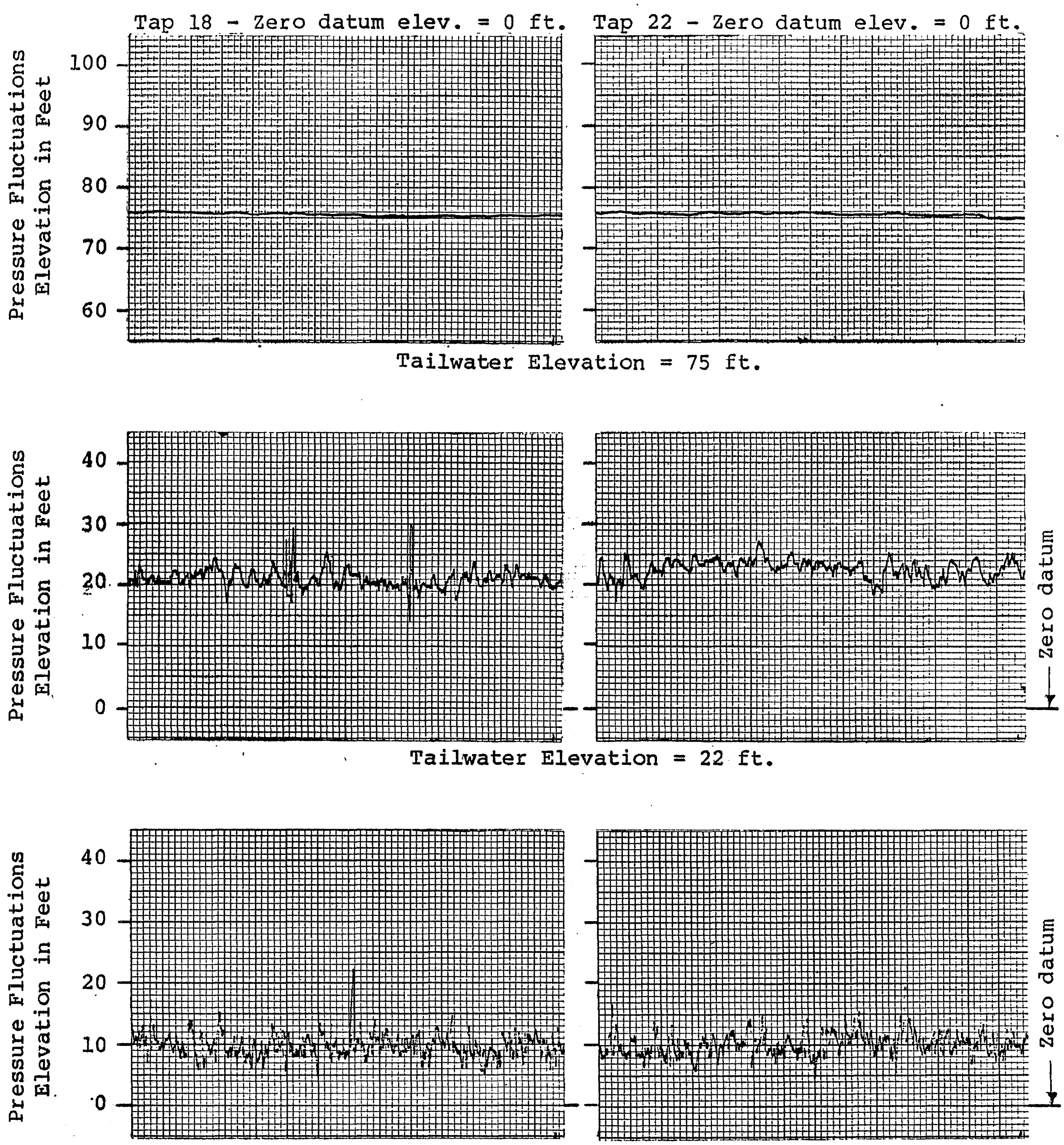
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2-R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

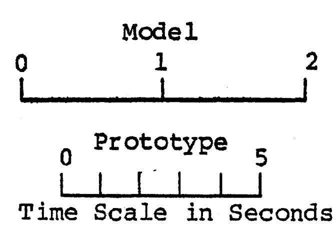
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-198



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

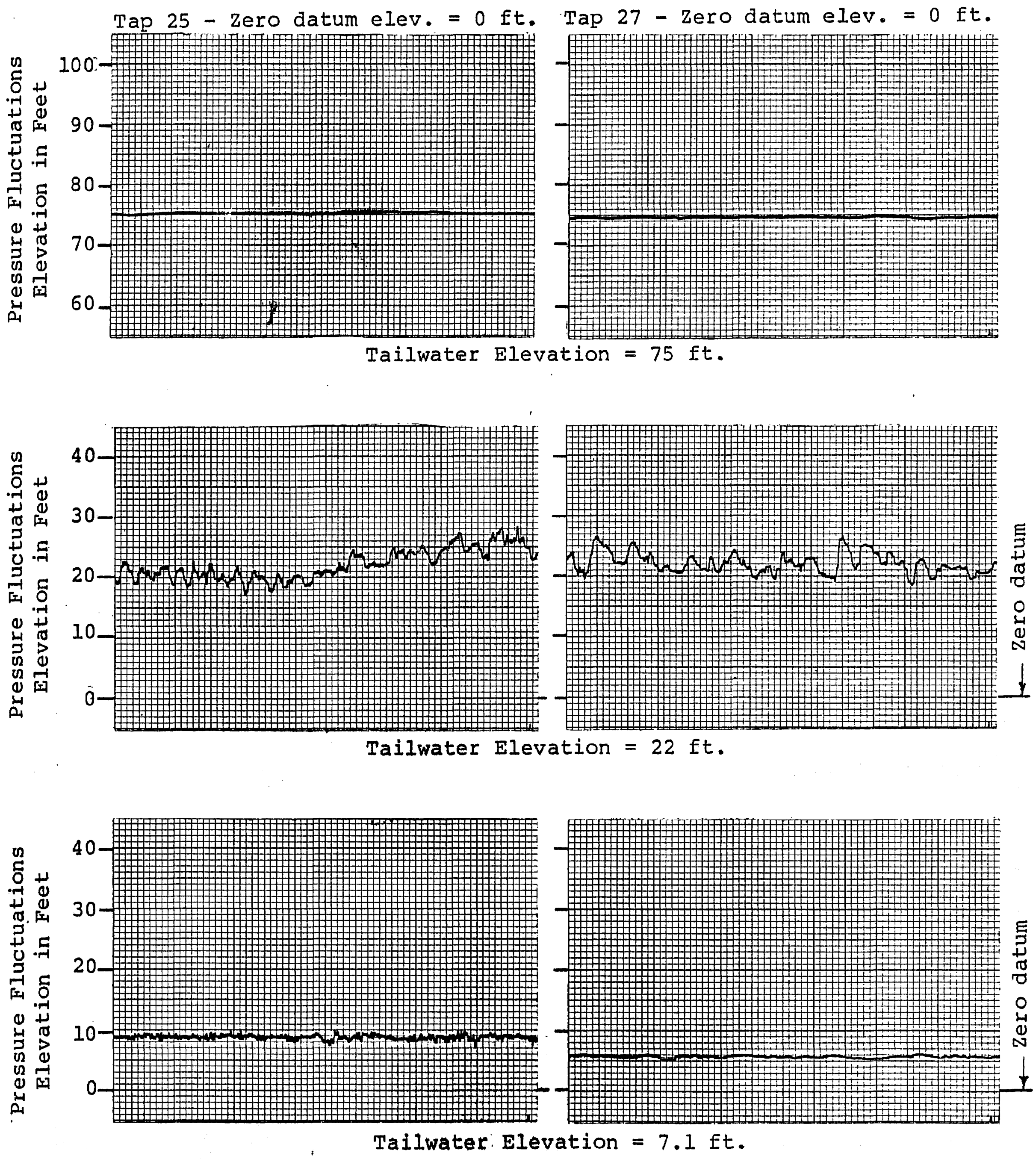
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-199

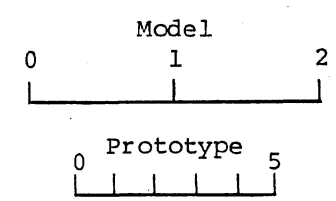




ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-200

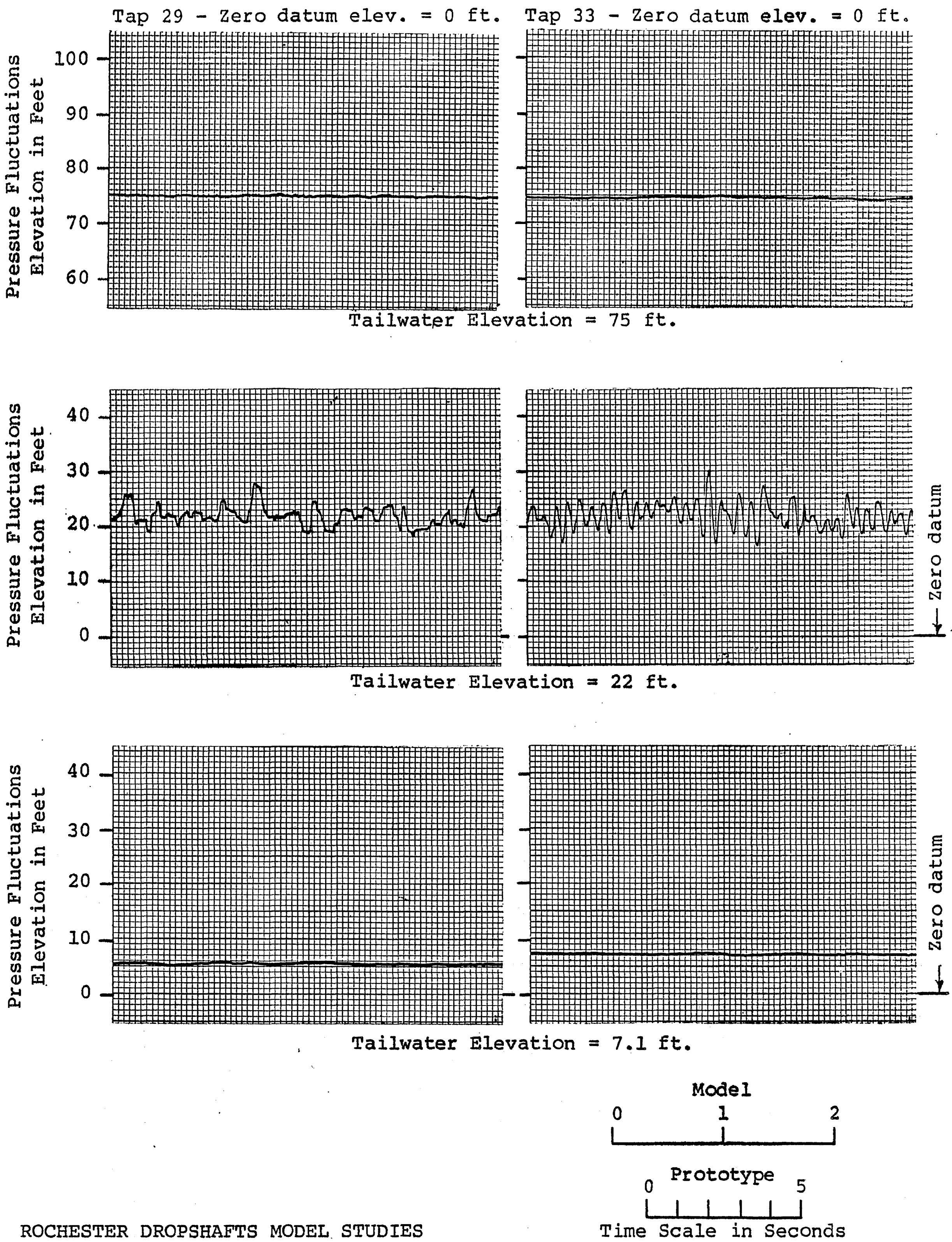




Time Scale in Seconds

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-201



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Typical Pressure Fluctuations
Q = 600 cfs

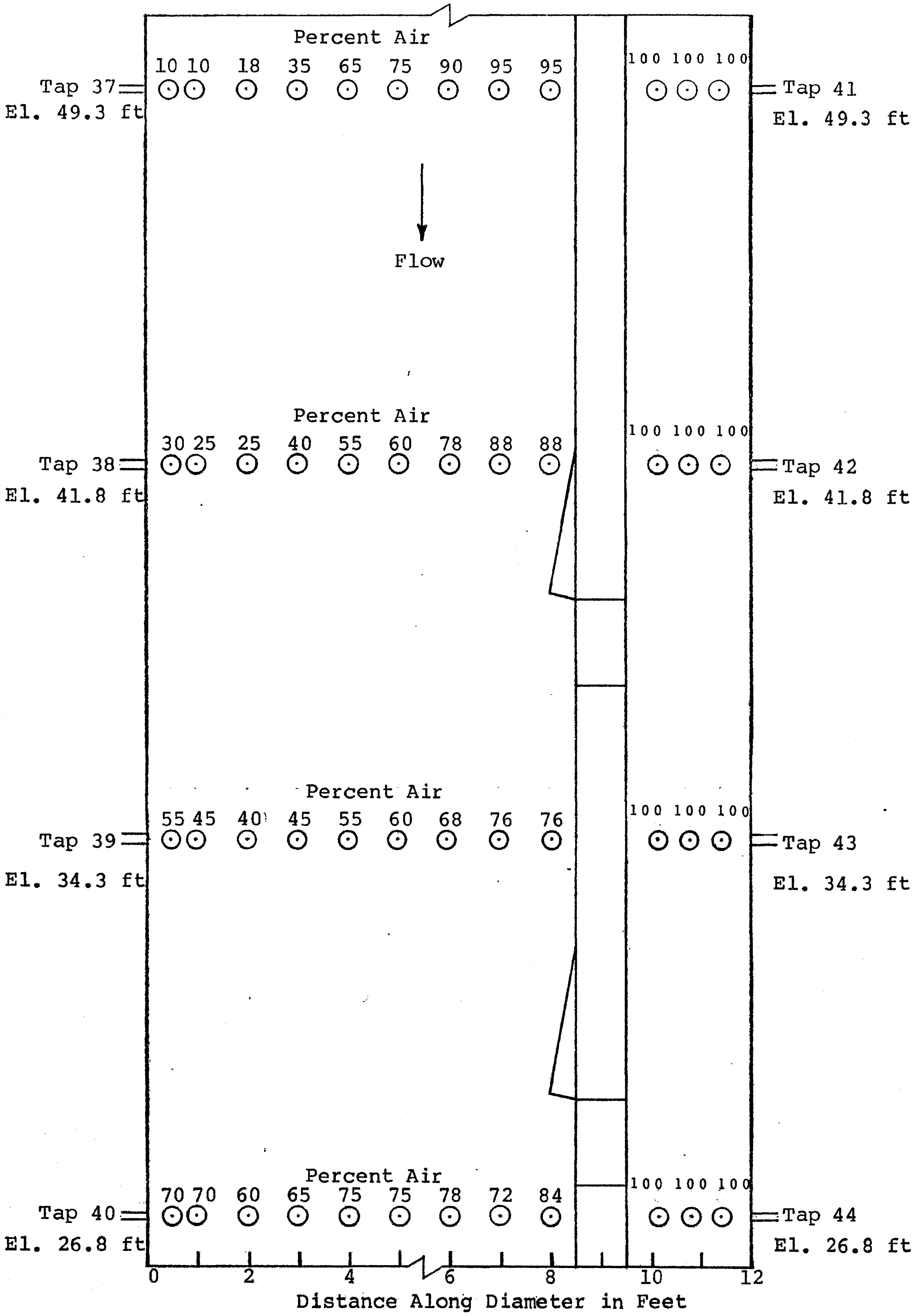
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-202

Tap No.	Tap El. ft	Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Pressure Fluctuations Max.-ft	Min.-ft
6	69.8	600	22	69.3	71.6	68.4
6	69.8	600	45	69.3	71.5	68.2
6	69.8	600	75	70.5	75.8	69.0
7	61.2	600	22	57.7	58.8	57.2
7	61.2	600	45	57.7	58.6	57.0
7	61.2	600	75	73.1	75.0	72.2
9	43.8	600	22	44.0	45.2	42.8
9	43.8	600	45	49.9	62.8	38.8
9	43.8	600	75	75.2	76.2	72.8
11	28.8	600	22	29.8	33.8	27.8
11	28.8	600	45	48.0	61.0	37.5
11	28.8	600	75	75.6	76.0	74.6
13	14.0	600	22	22.3	28.4	18.0
13	14.0	600	45	45.4	50.8	40.8
13	14.0	600	75	75.5	76.0	74.6
15	2.0	600	7.1	6.9	16.2	2.0
15	2.0	600	22	20.9	27.8	15.0
15	2.0	600	75	75.6	76.2	74.8
16	0	600	7.1	6.9	19.8	-4.0
16	0	600	22	20.8	29.4	11.5
16	0	600	75	75.7	76.8	73.8
18	0	600	7.1	9.4	22.4	0.6
18	0	600	22	21.8	29.8	14.2
18	0	600	75	75.9	76.2	74.6
22	0	600	7.1	10.0	19.4	1.0
22	0	600	22	21.7	27.2	16.8
22	0	600	75	75.9	76.8	74.8
23	0	600	7.1	8.3	30.0	-5.0
23	0	600	22	21.7	38.8	14.0
23	0	600	75	75.5	76.7	74.4
25	0	600	7.1	8.6	11.0	7.0
25	0	600	22	21.3	28.6	17.0
25	0	600	75	75.2	75.8	74.2
27	0	600	7.1	5.1	6.8	5.0
27	0	600	22	21.7	25.6	17.0
27	0	600	75	74.5	75.0	74.0
29	0	600	7.1	5.1	6.0	5.0
29	0	600	22	21.7	27.8	17.4
29	0	600	75	74.9	75.6	74.0
33	0	600	7.1	7.1	8.0	6.8
33	0	600	22	21.9	30.0	15.0
33	0	600	75	74.9	75.6	74.2

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Summary of Typical
Pressure Fluctuations

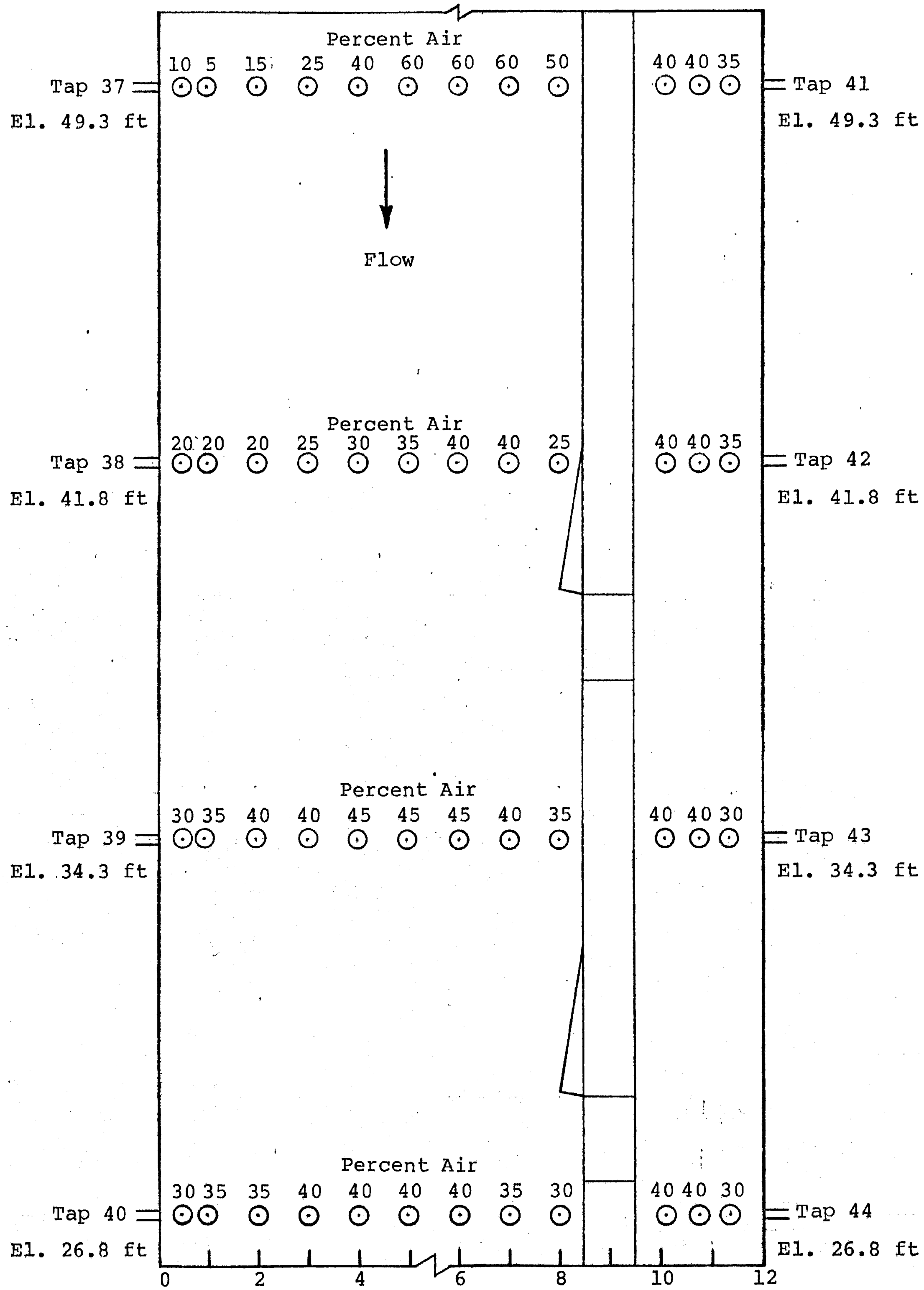
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-232



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Air Concentrations in Dropshaft
Q = 600 cfs, T.W. Elev. = 7.1 ft.

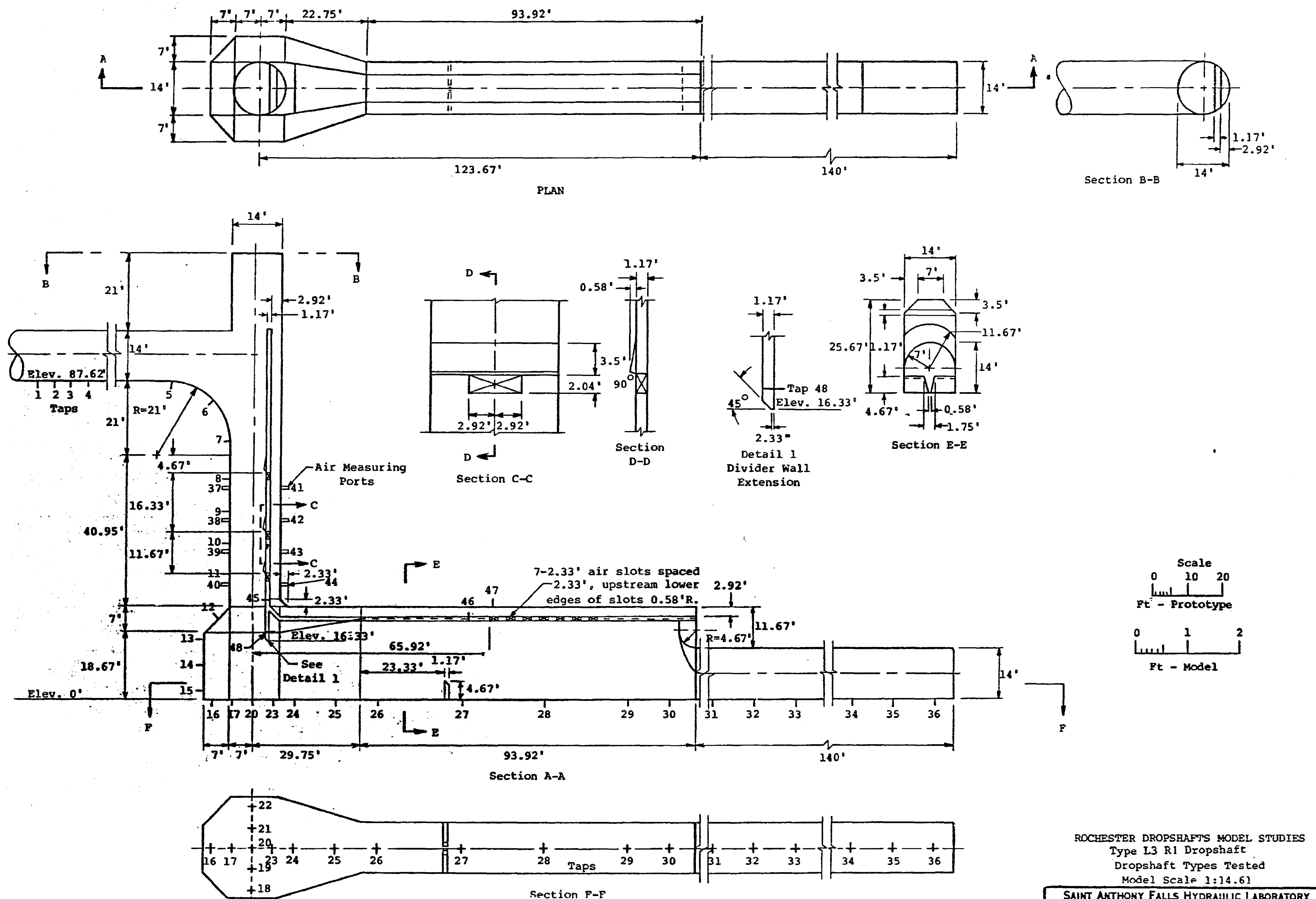
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-204



Note: For a Tailwater elevation of 75 ft, 0 to 2% air was present in both dropshaft and air vent.

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R35 Scale 1:12.52
Air Concentrations in Dropshaft
Q = 600 cfs, T.W. Elev. = 45 ft.

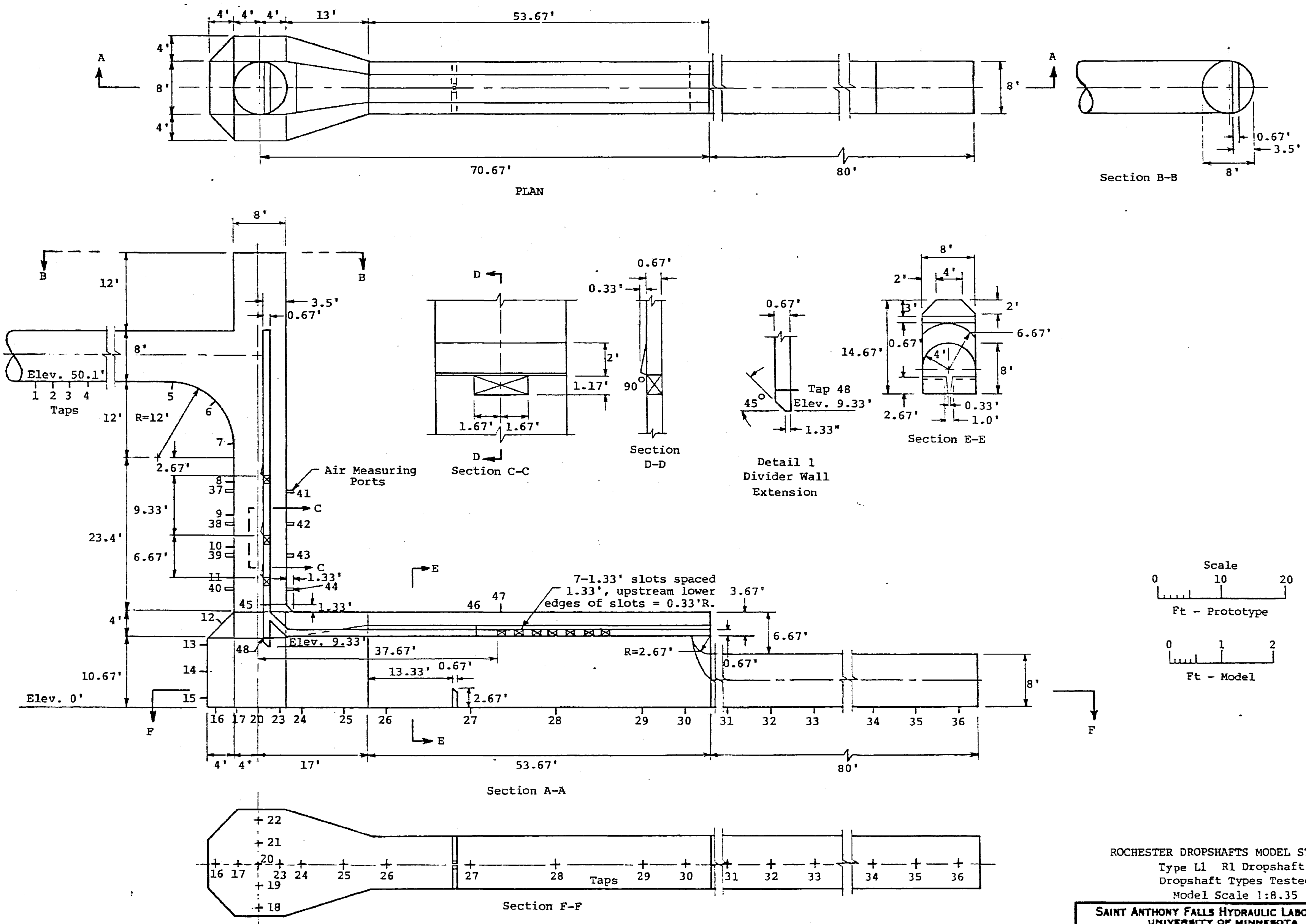
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED HQS	APPROVED
SCALE	DATE 2/18/82	NO. 302A2321-205



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L3 R1 Dropshaft
Dropshaft Types Tested
Model Scale 1:14.61

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/8/82	NO. 302B511-8

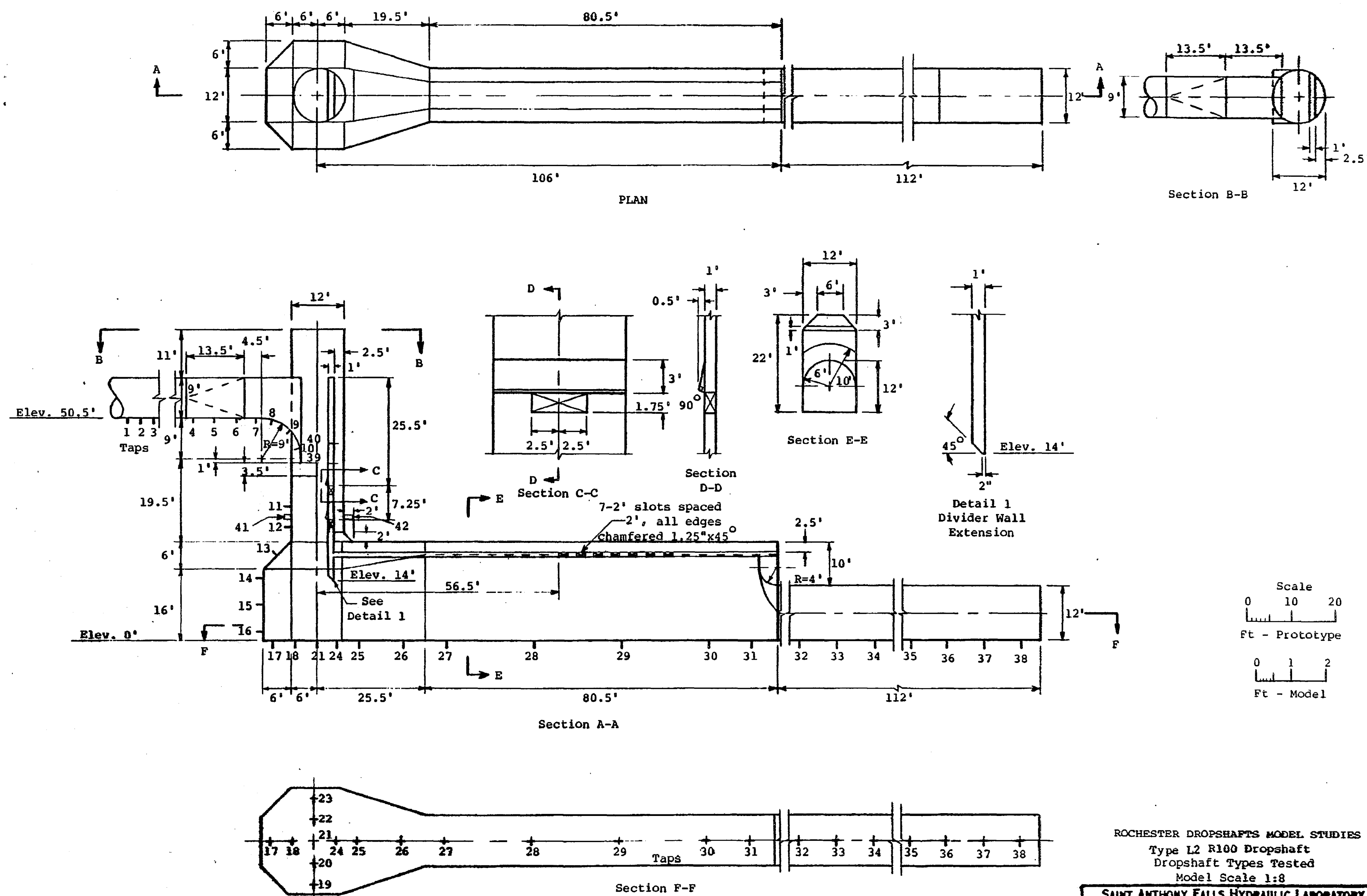


ROCHESTER DROPSHAFTS MODEL STUDIES
Type L1 R1 Dropshaft
Dropshaft Types Tested
Model Scale 1:8.35

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/11/82	NO. 302B511-10

CHART 81

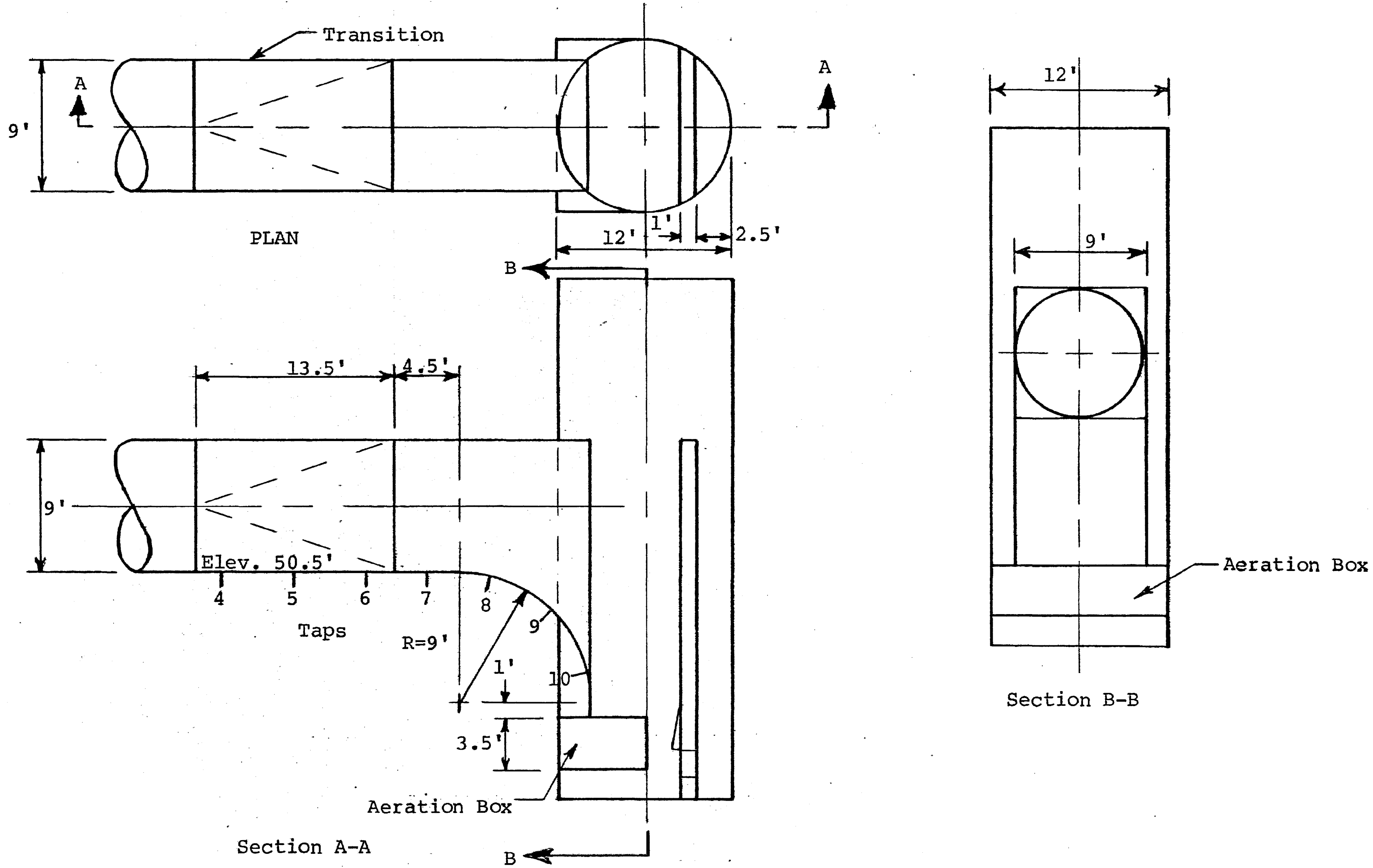


ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Dropshaft
Dropshaft Types Tested
Model Scale 1:8

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/6/82	NO. 302B511-9

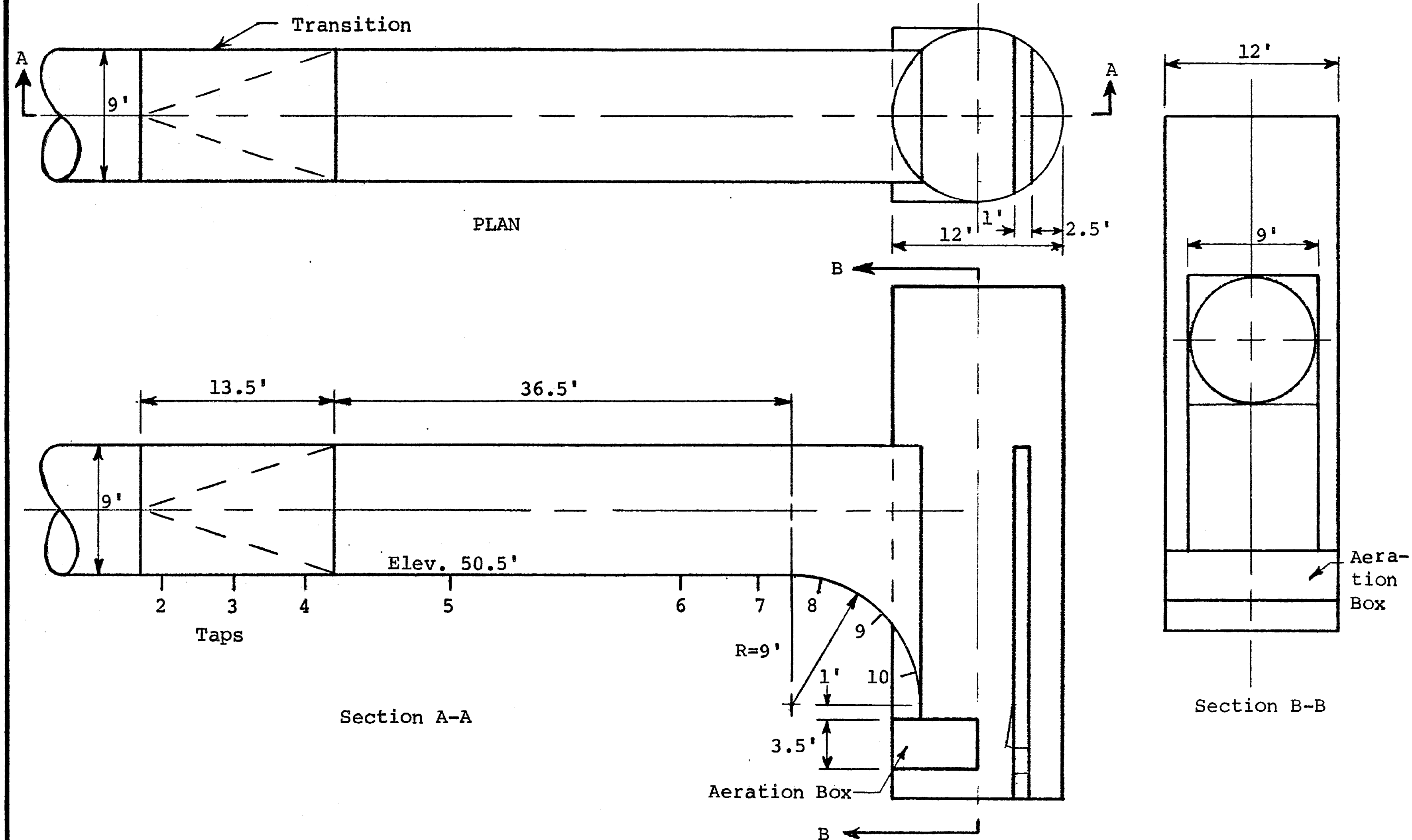
CHART 82



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Dropshaft
Dropshaft Types Tested
Model Scale 1:8

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 1/19/82	NO 302A2321-118

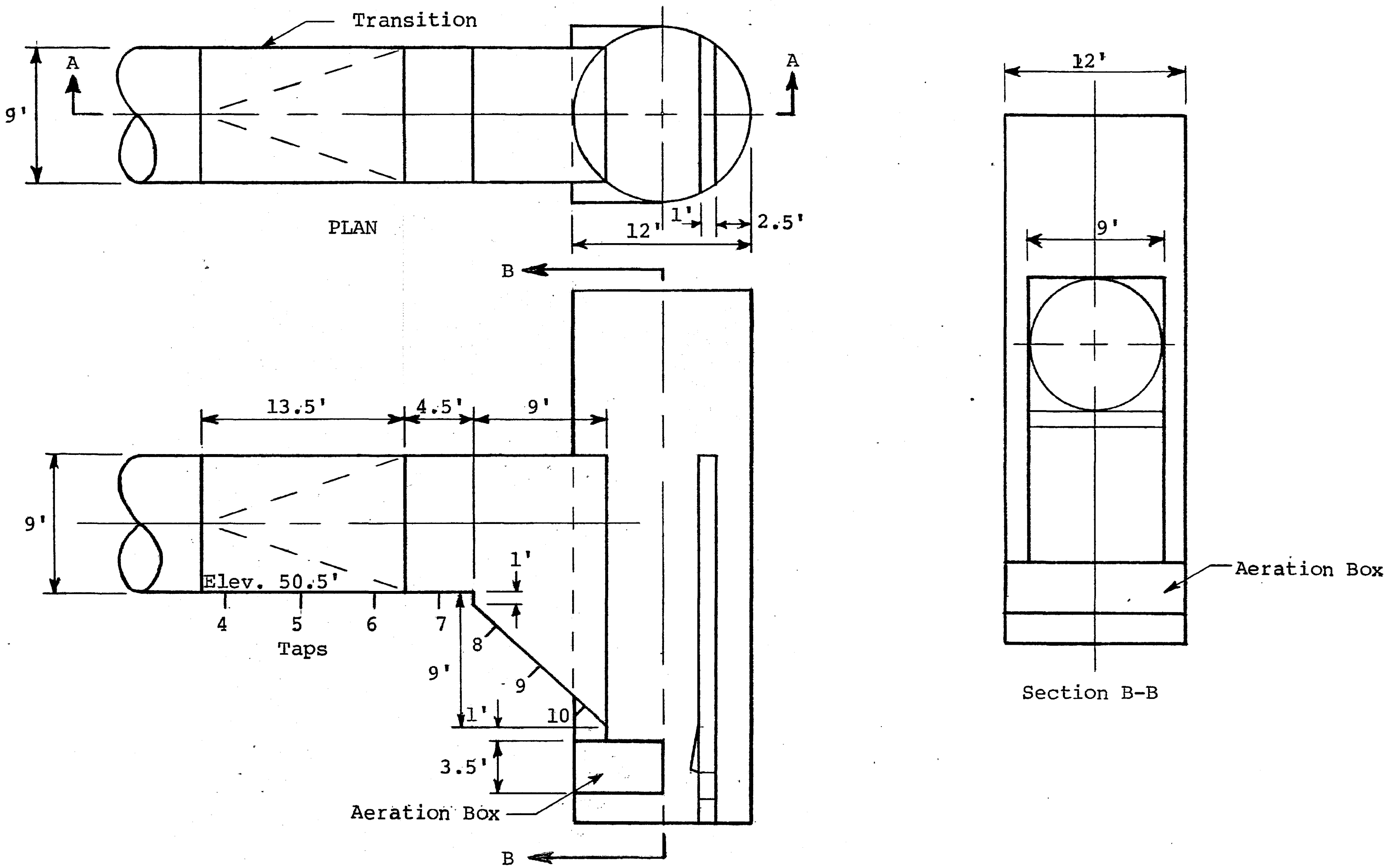
CHART 83



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R101 Dropshaft
Dropshaft Types Tested
Model Scale 1:8

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED HGS	APPROVED
SCALE	DATE 1/12/82	NO. 302A2321-119

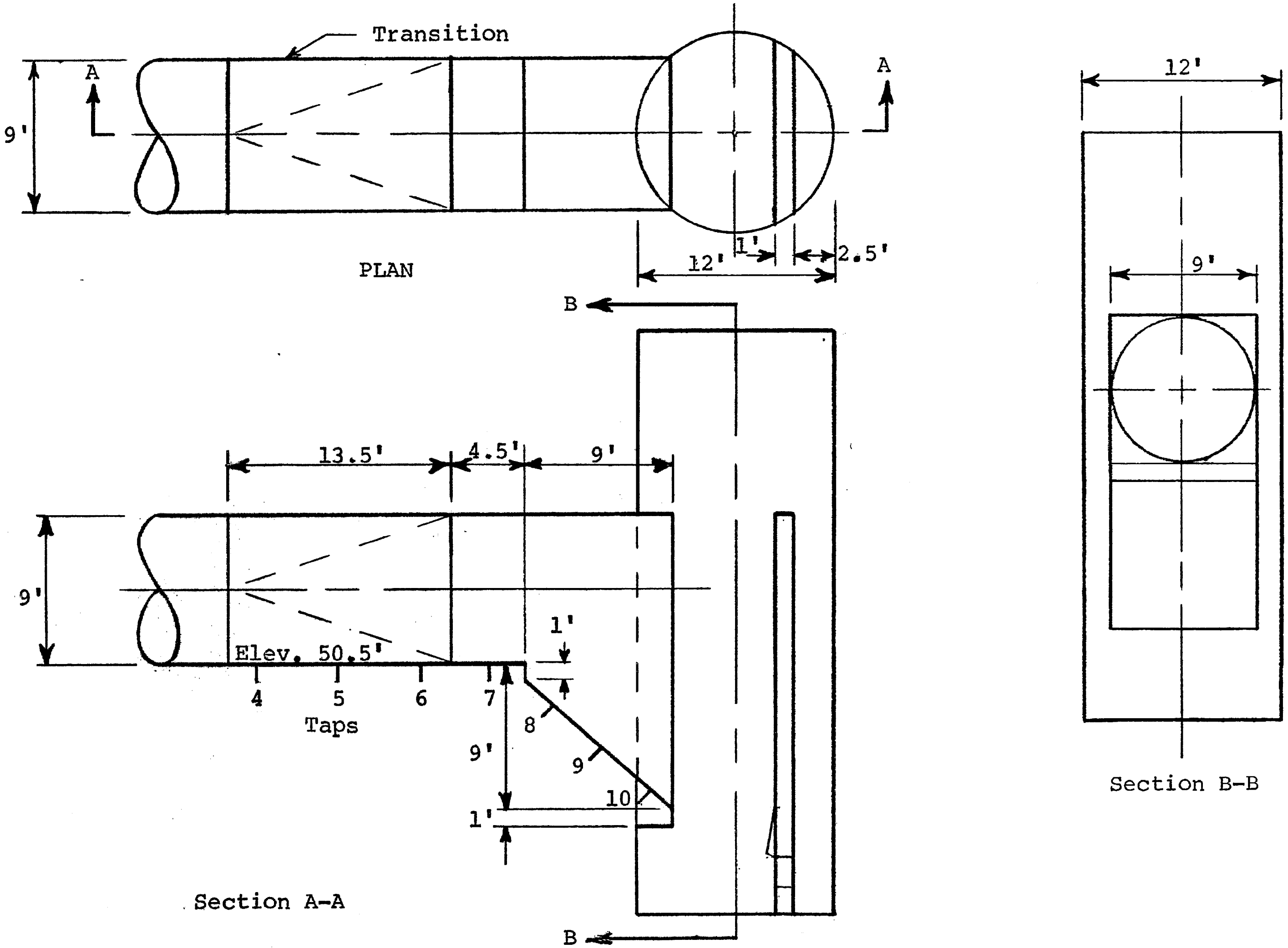
CHART 84



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R102 Dropshaft
Dropshaft Types Tested
Model Scale 1:8

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 1/19/82	NO. 302A2321-120

CHART 85



ROCHESTER DROPSHAFTS MODEL STUDIES
Types L2 R103 and 104 Dropshafts
Dropshaft Types Tested
Model Scale 1:8

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 1/19/82	NO. 302A2321-121

CHART 86

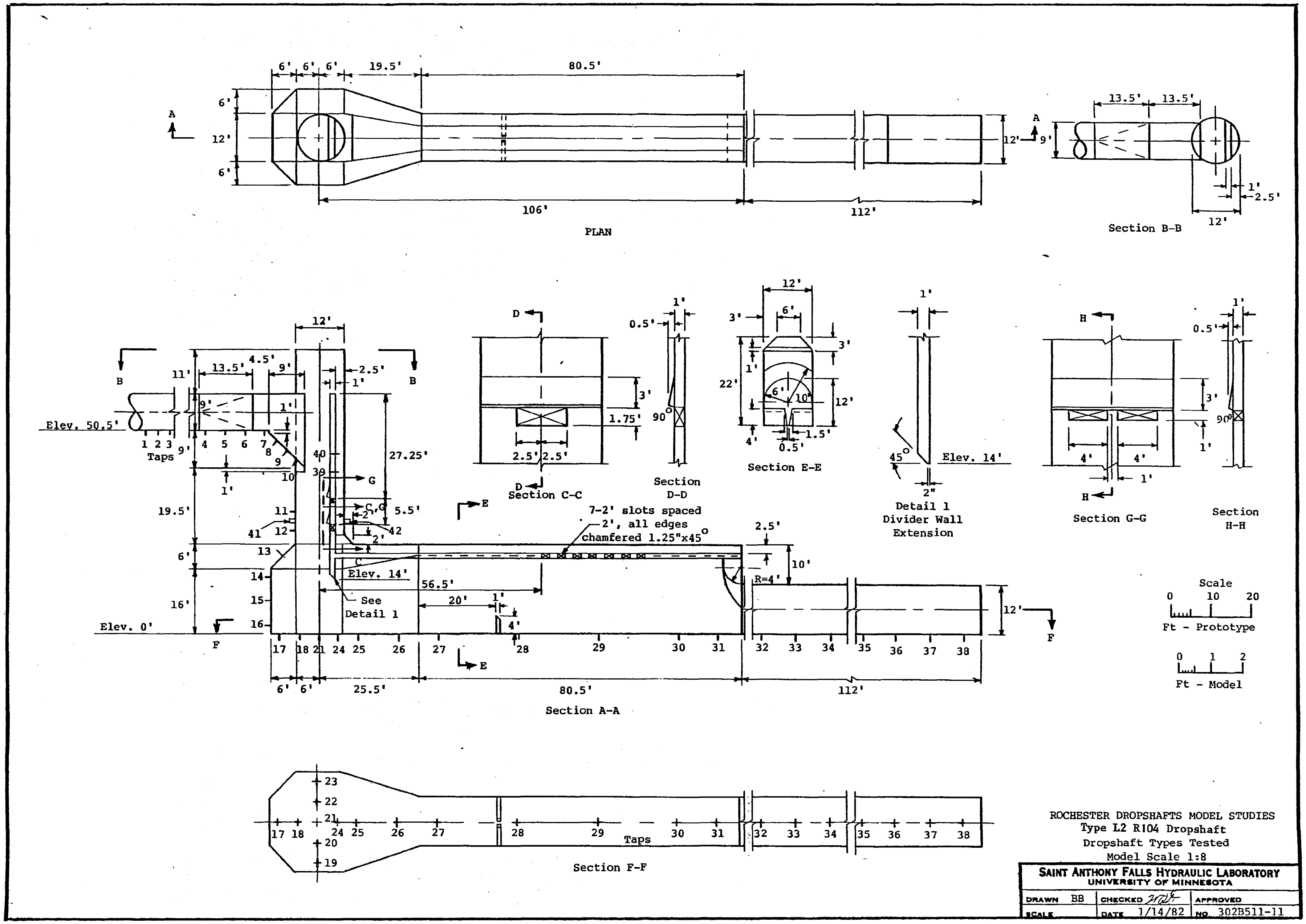
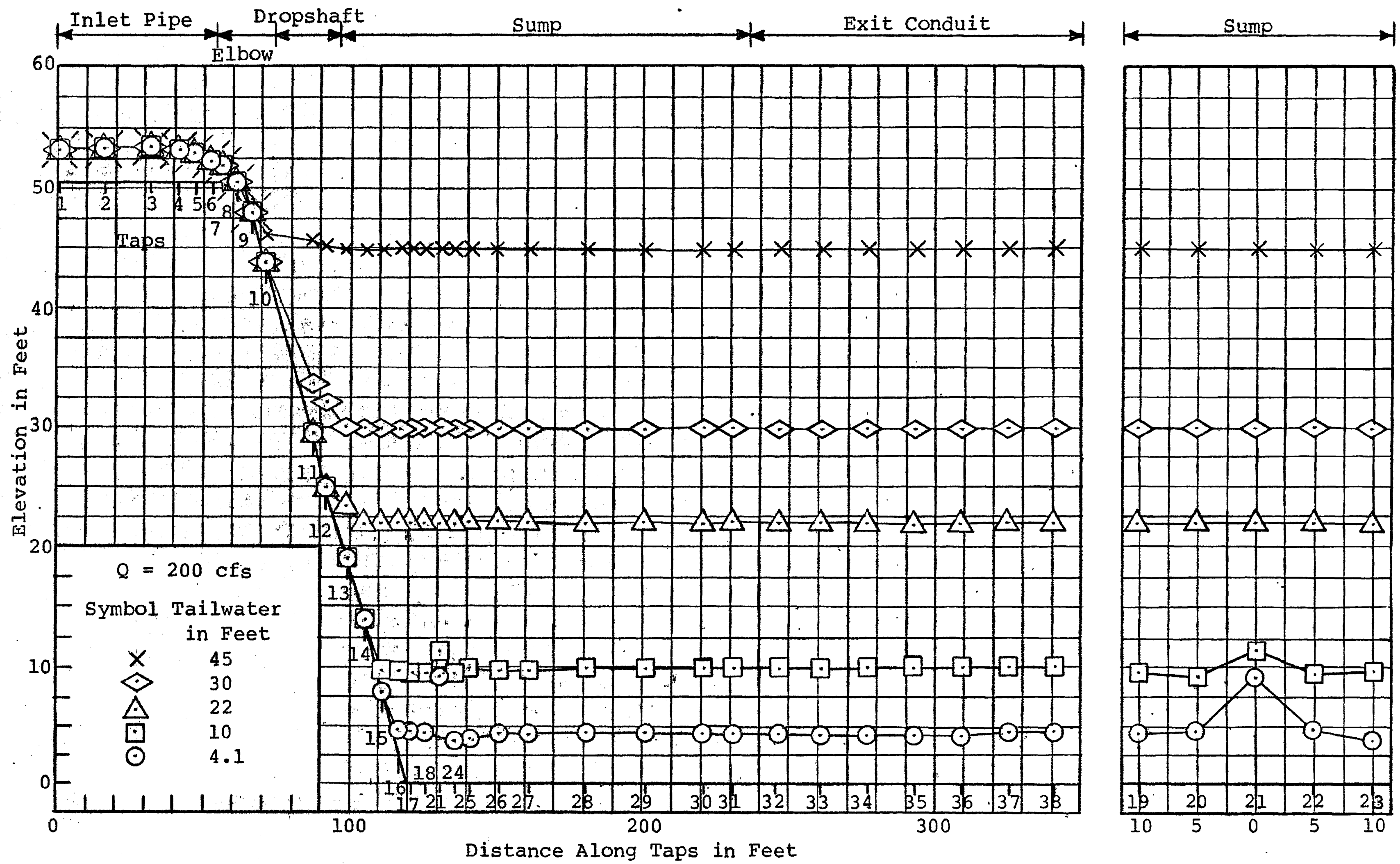

PLAN
Section B-B
Section A-A
Section C-C
Section D-D
Section E-E
Detail 1
Divider Wall
Extension
Section G-G
Section H-H
Section F-F
Elev. 50.5'
Elev. 14'
Elev. 0'
Taps
See
Detail 1
7-2' slots spaced
2', all edges
chamfered 1.25"x45°
R=4'
106'
112'
80.5'
56.5'
25.5'
Scale
0 10 20
Ft - Prototype
0 1 2
Ft - Model
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Dropshaft
Dropshaft Types Tested
Model Scale 1:8
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN BB
DATE 1/14/82
NO. 302B511-11

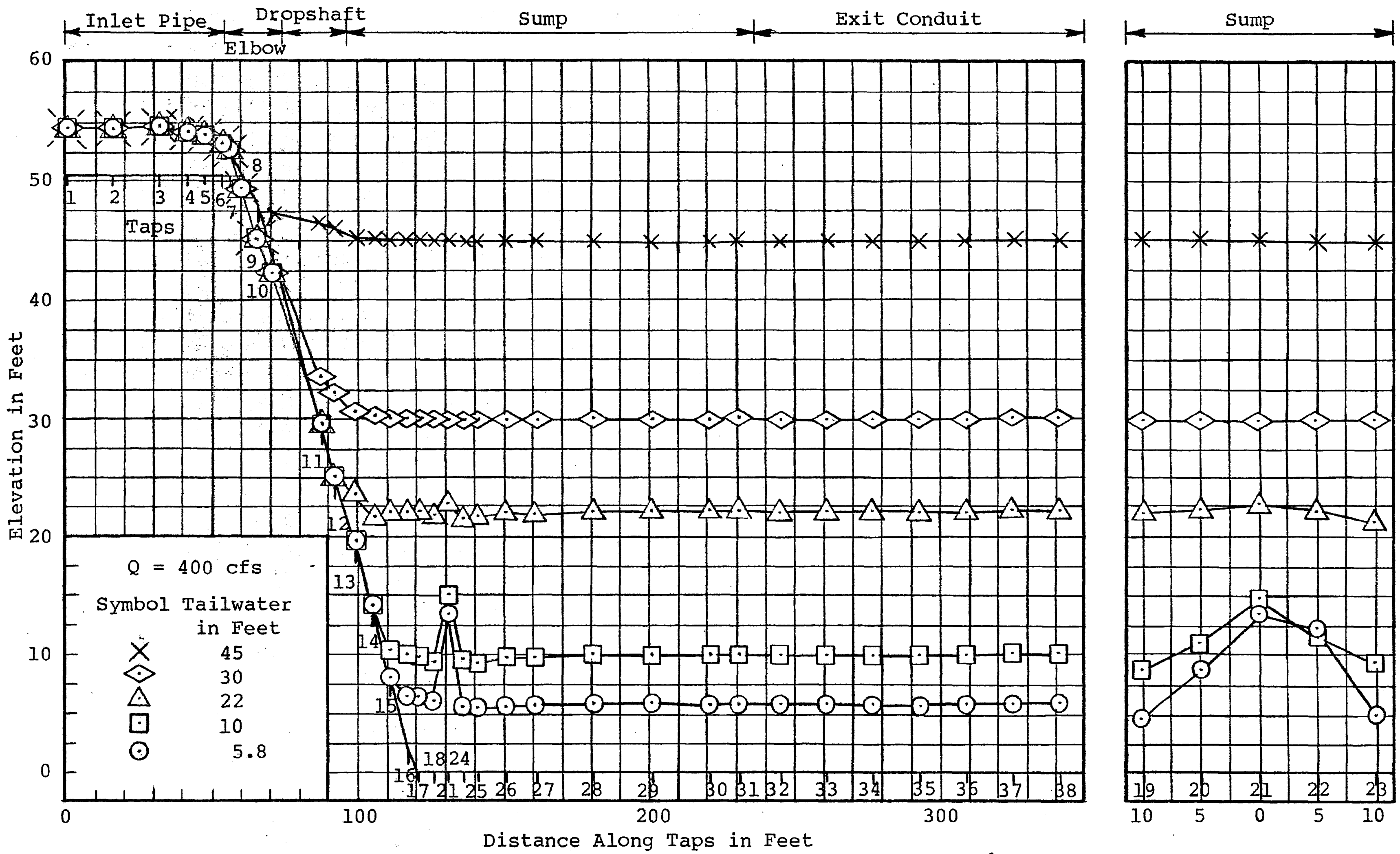
CHART 87



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/6/82	NO. 302A2321-105

CHART 88



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/6/82	NO. 302A2321-106

CHART 89

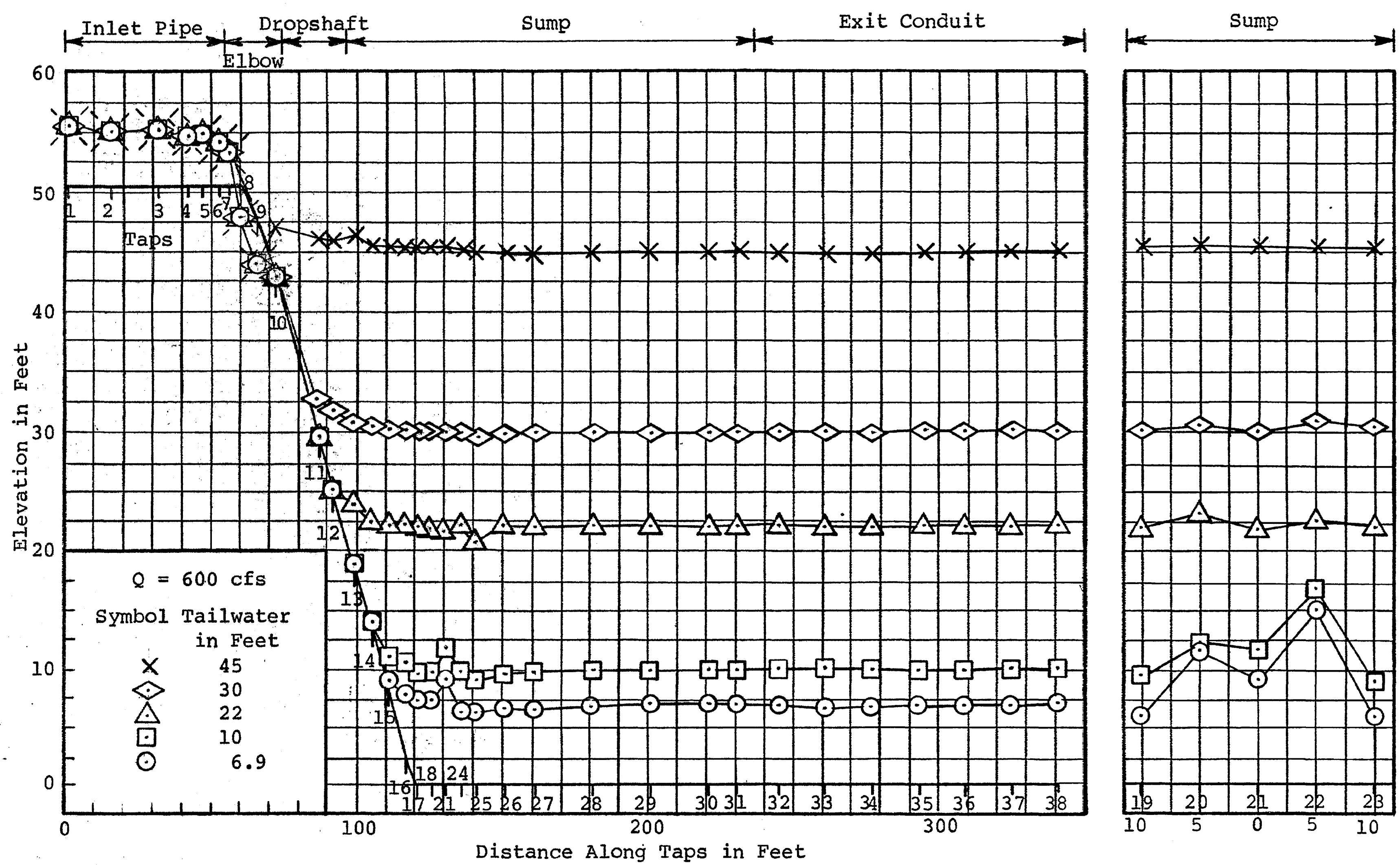
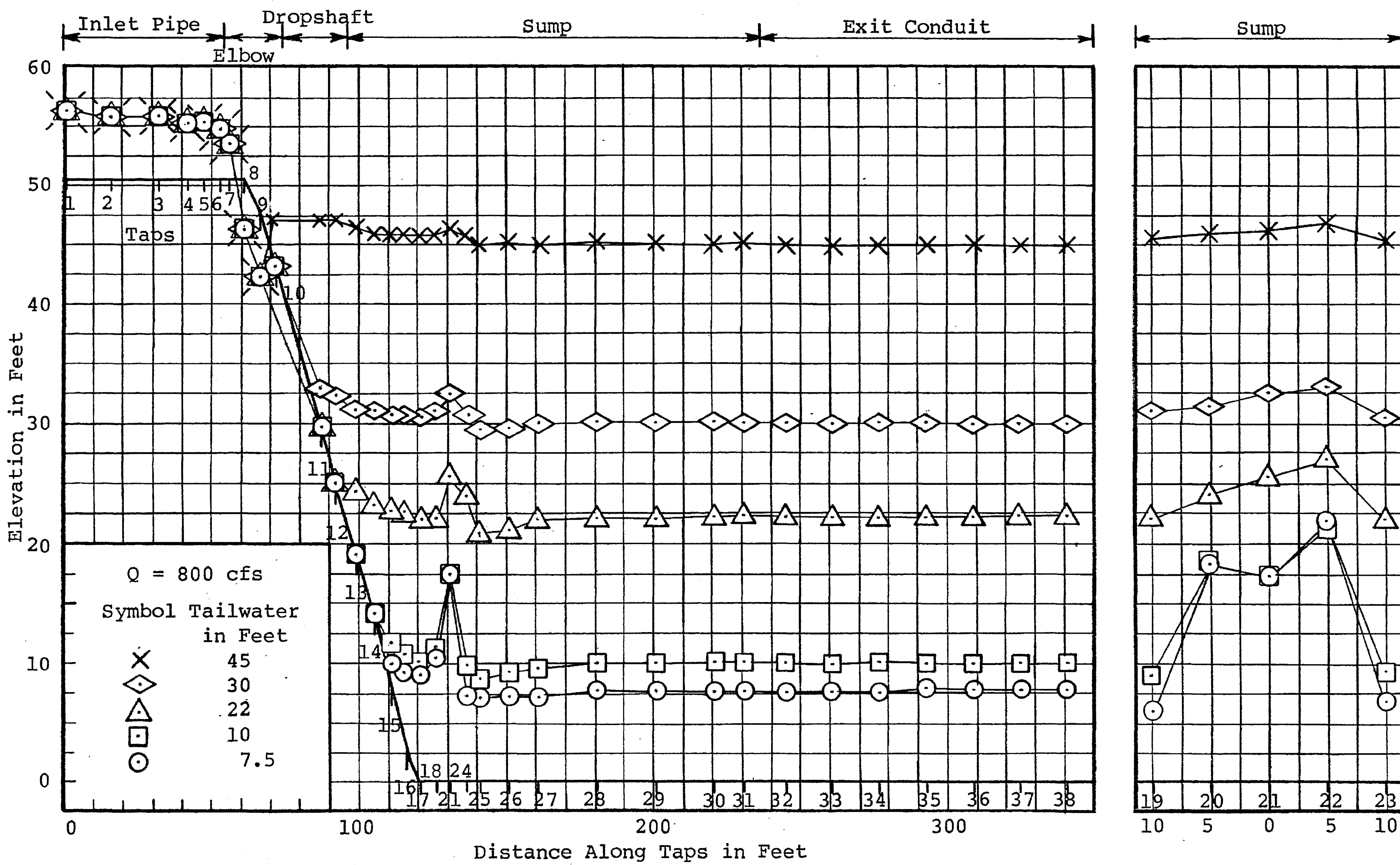


CHART 90

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

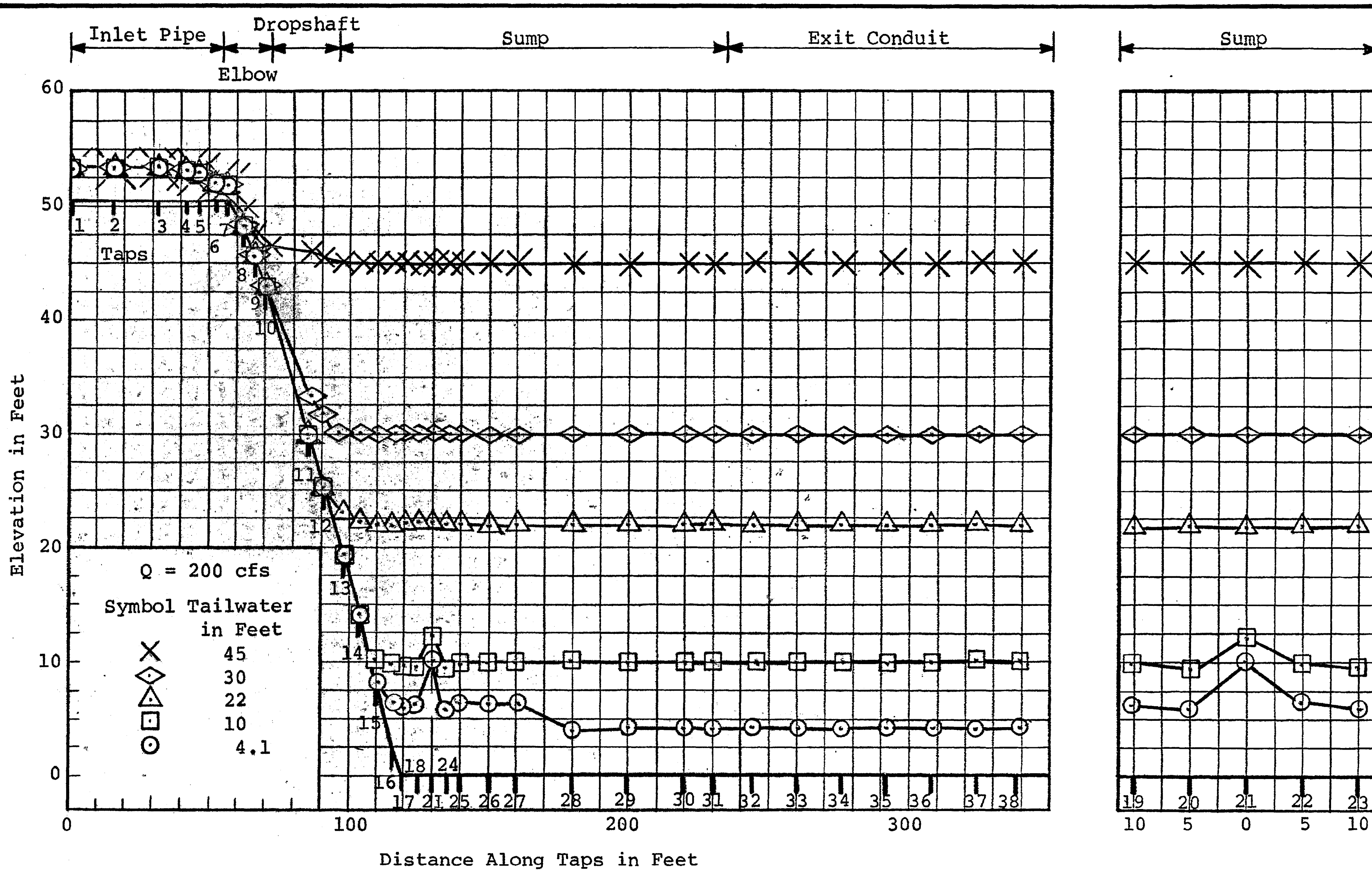
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/6/82	NO. 302A2321-107



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 1/6/82	NO. 302A2321-108

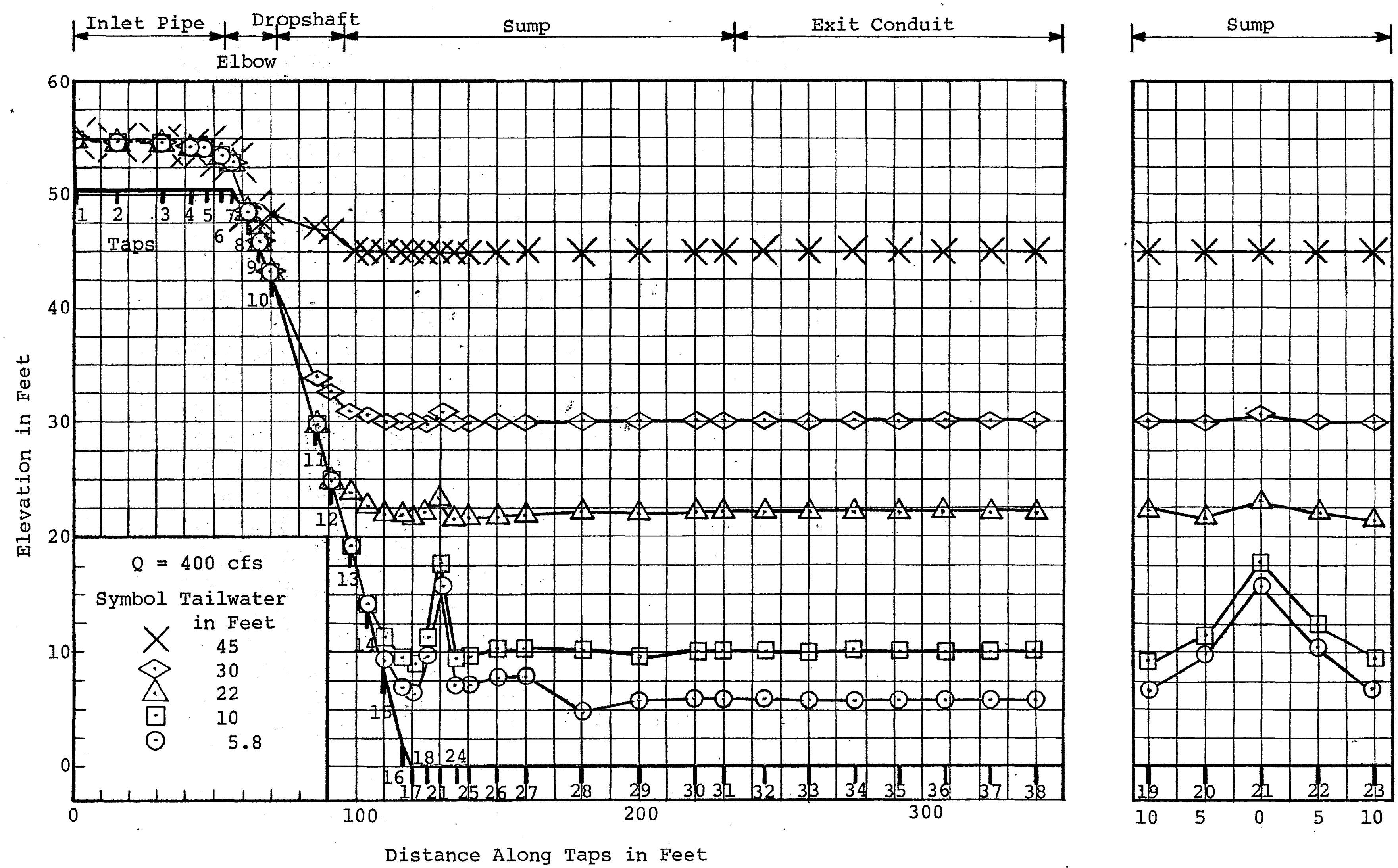
CHART 91



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED MRD	APPROVED
SCALE	DATE 11/11/81	NO. 302A2321-51

CHART 92

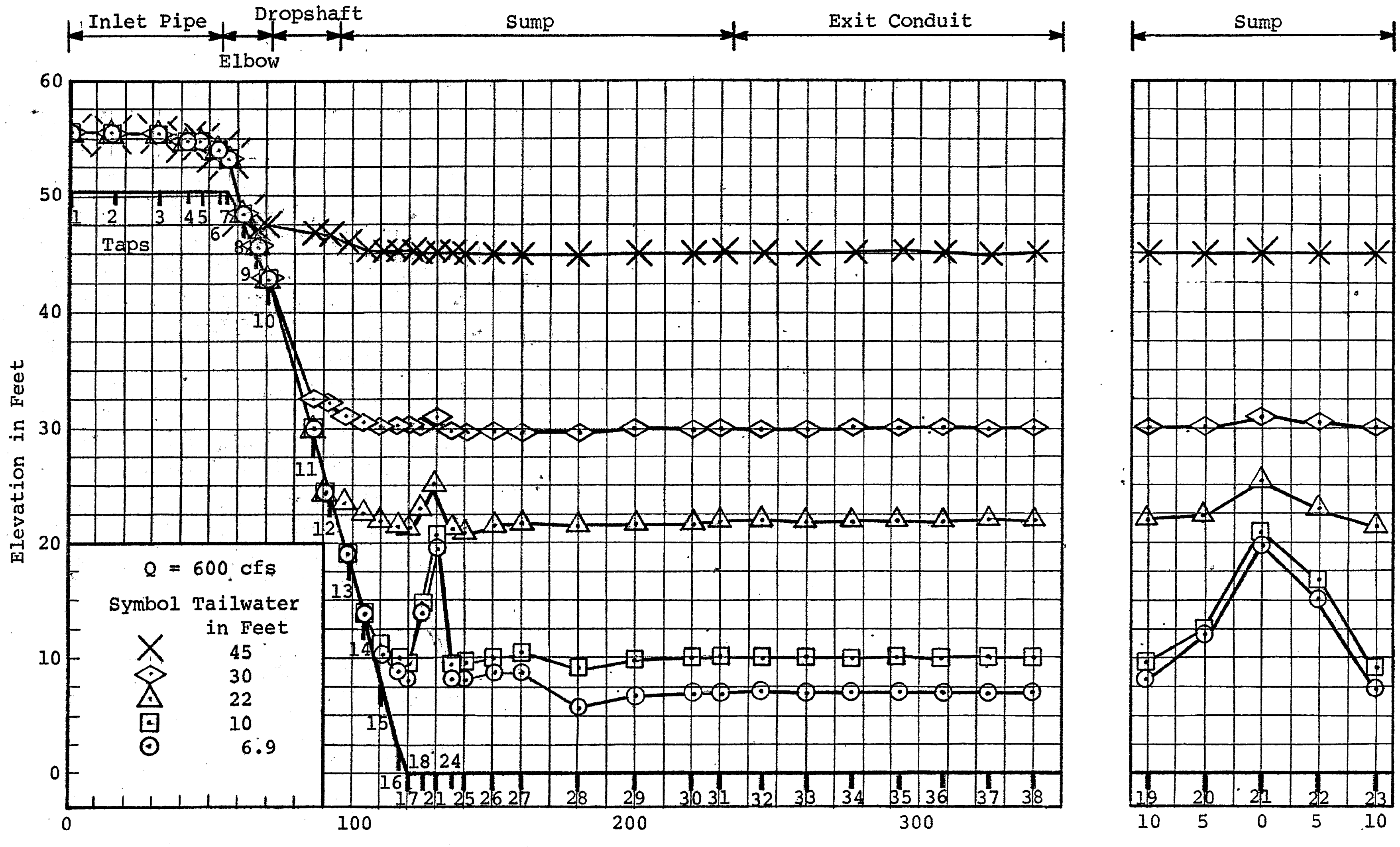


ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED WDD	APPROVED
SCALE	DATE 11/11/81	NO. 302A2321-52

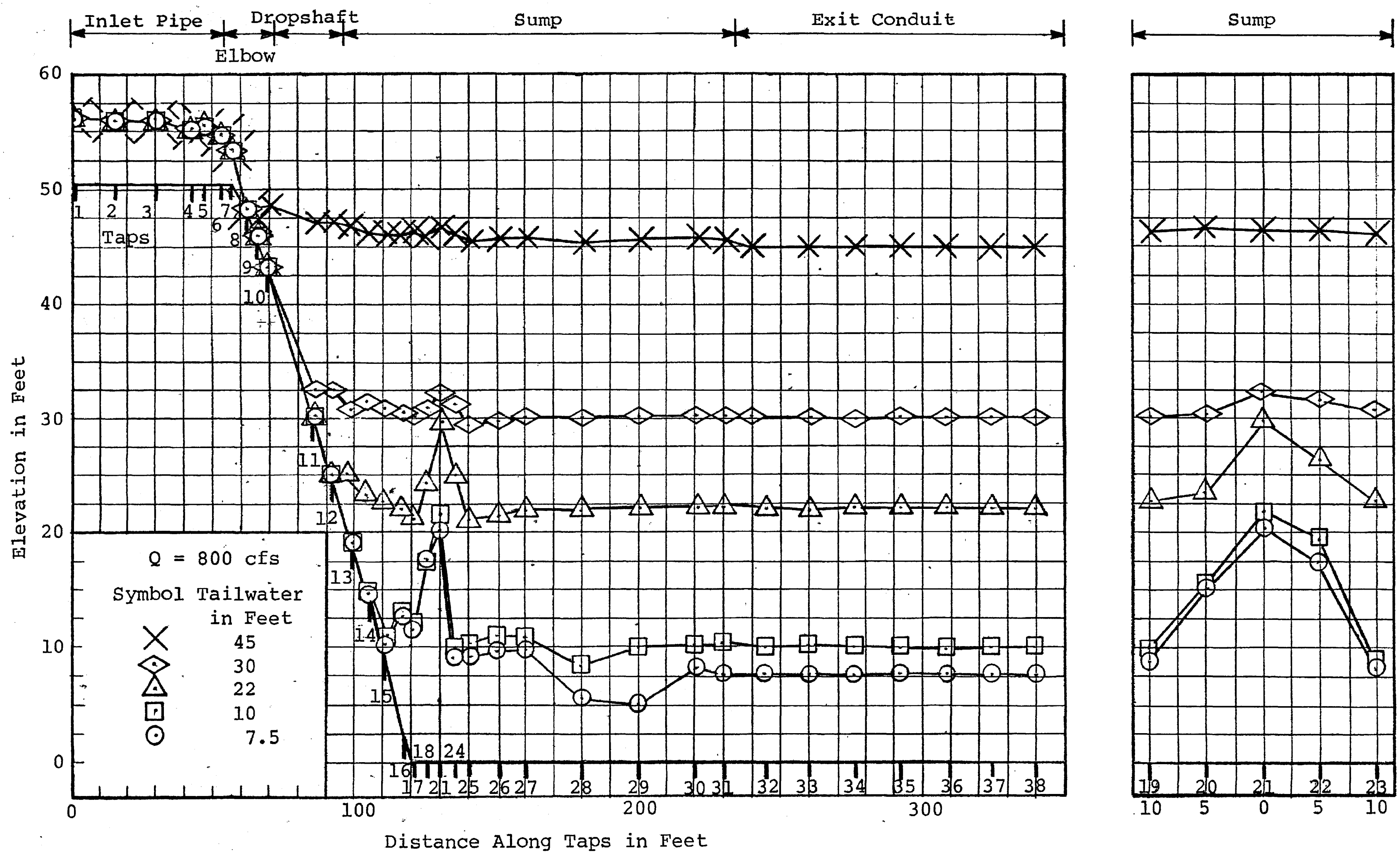
CHART 93



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 11/11/81	NO. 302A2321-53

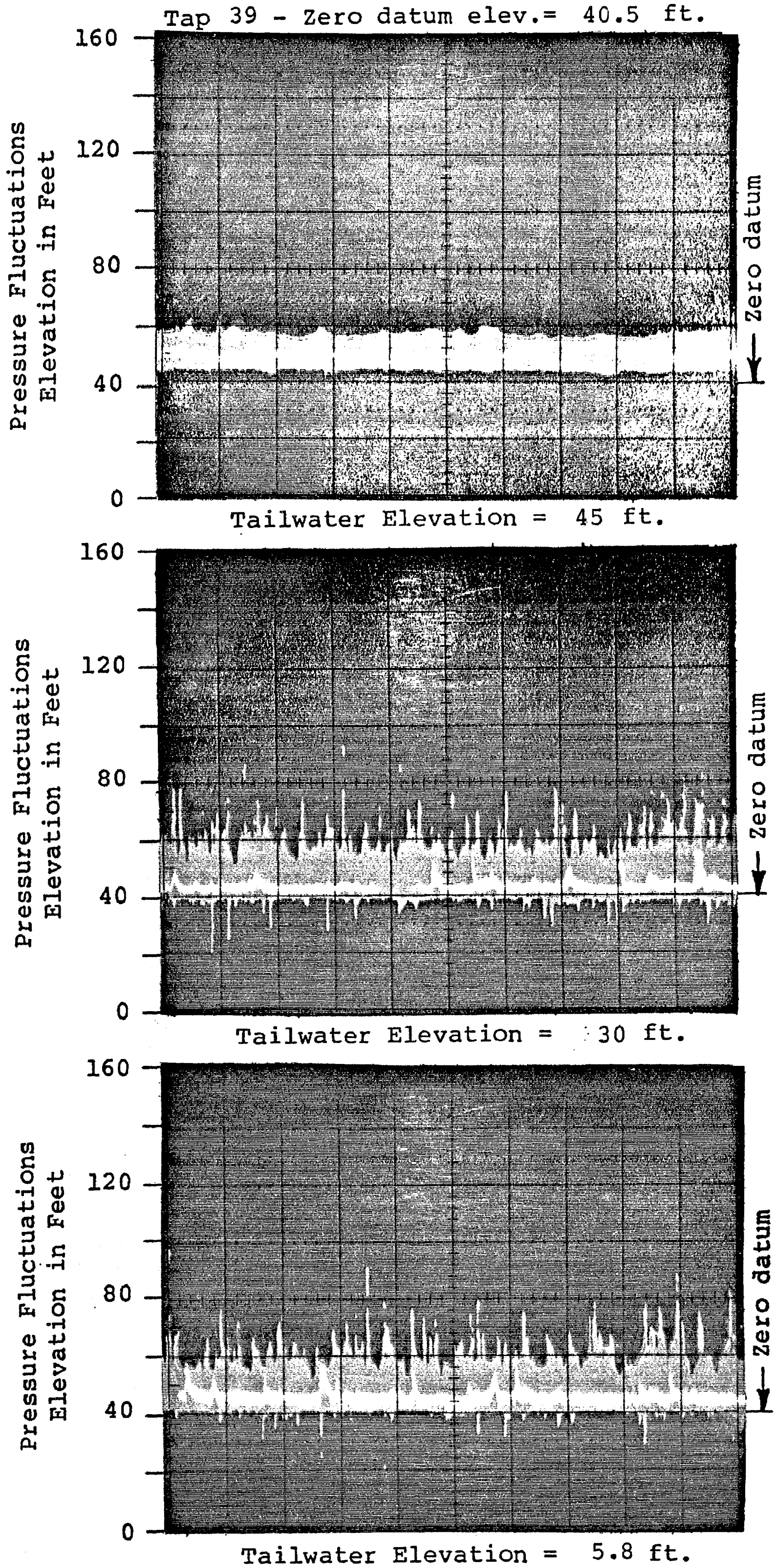
CHART 94



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 11/11/81	NO. 302A2321-54

CHART 95



ROCHESTER DROPSHAFTS MODEL STUDIES

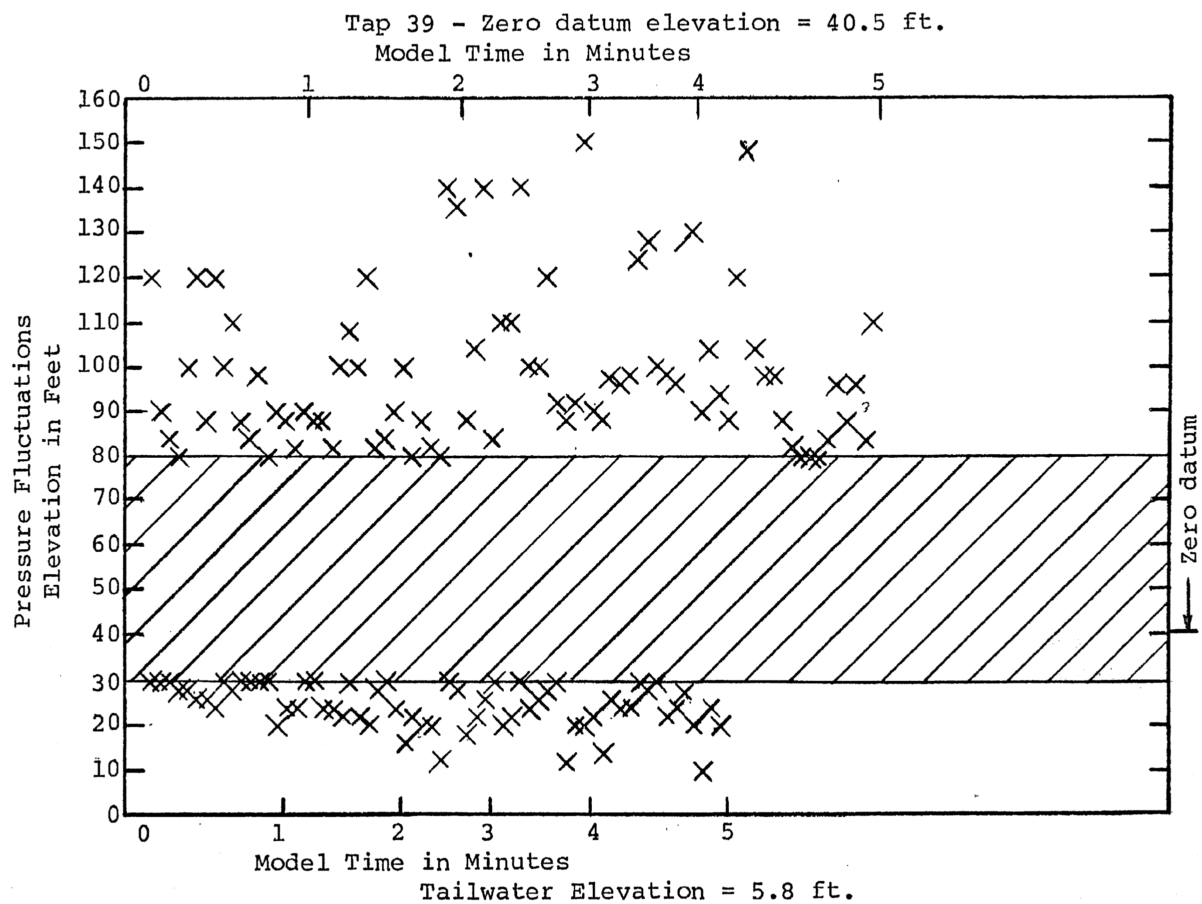
Type L2 R100 Dropshaft Scale 1:8

Typical Pressure Fluctuations

Q = 400 cfs

Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-21

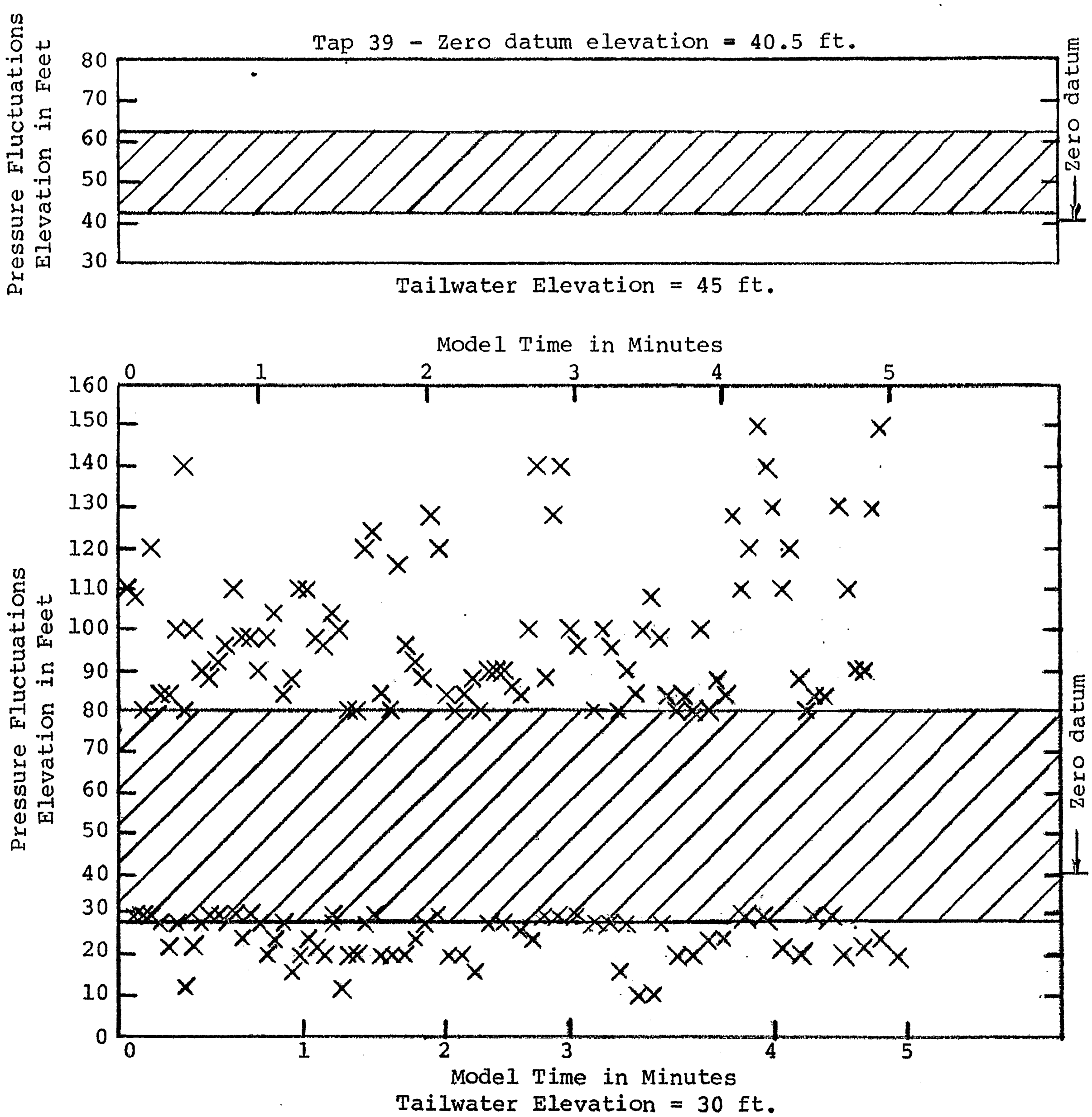


Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Typical Pressure Fluctuations
Q = 400 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 1/12/82	NO. 302A2321-126



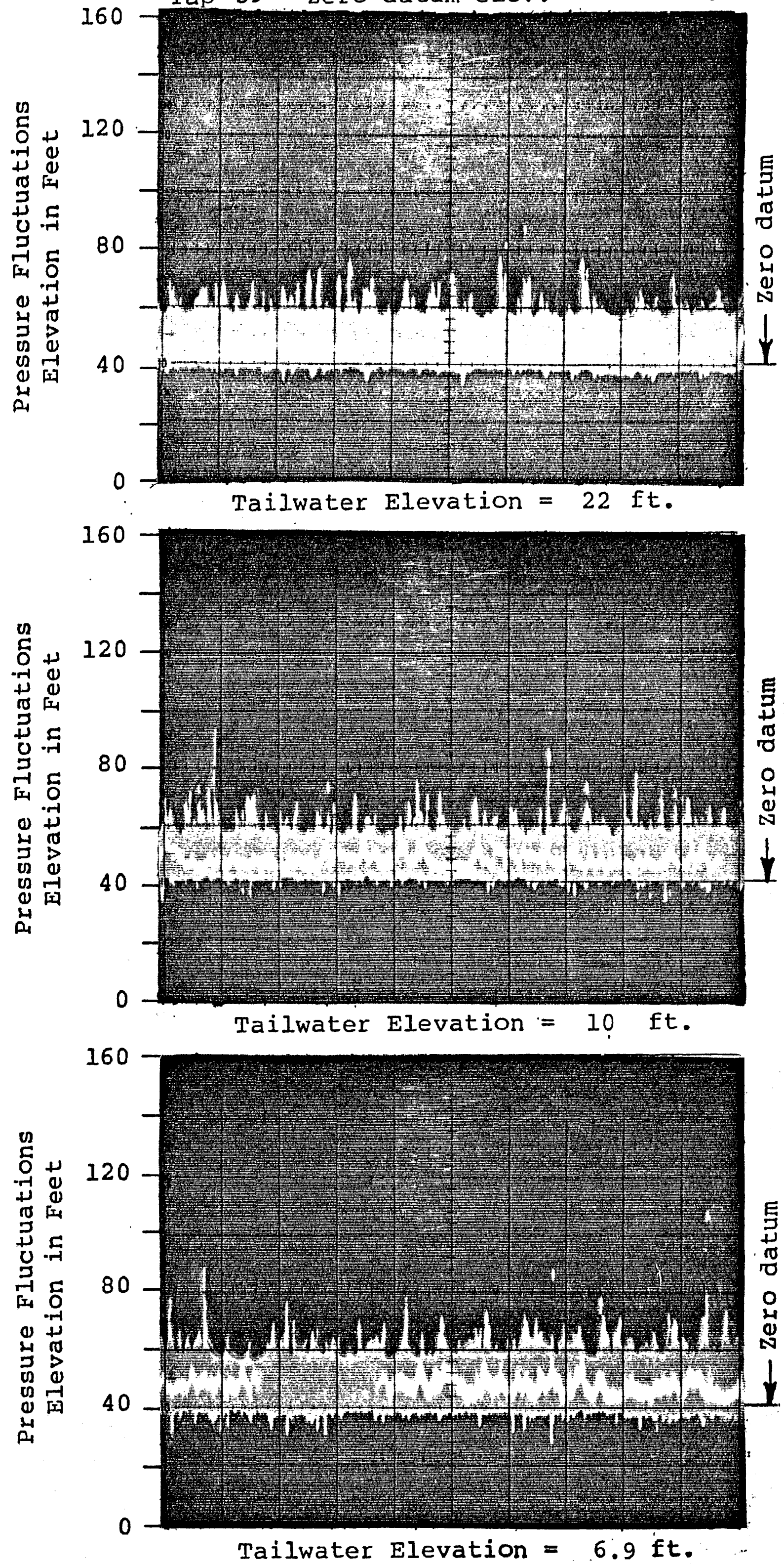
X Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Typical Pressure Fluctuations
Q = 400 cfs

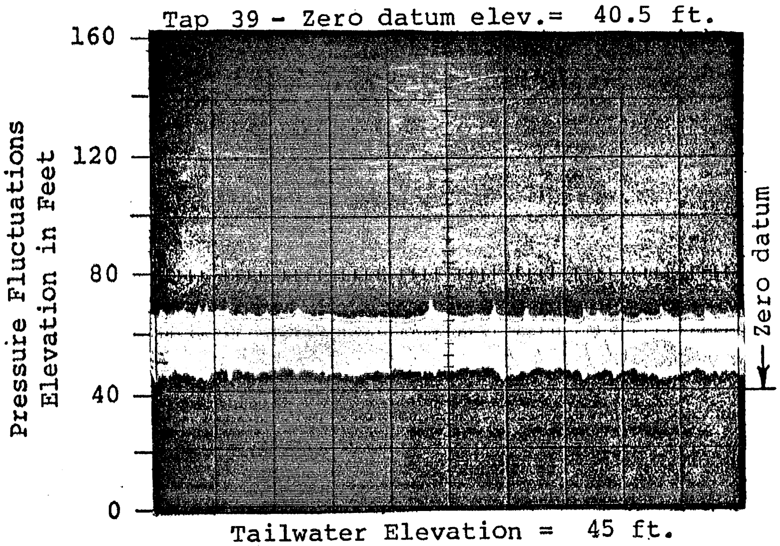
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/12/82	NO. 302A2321-127

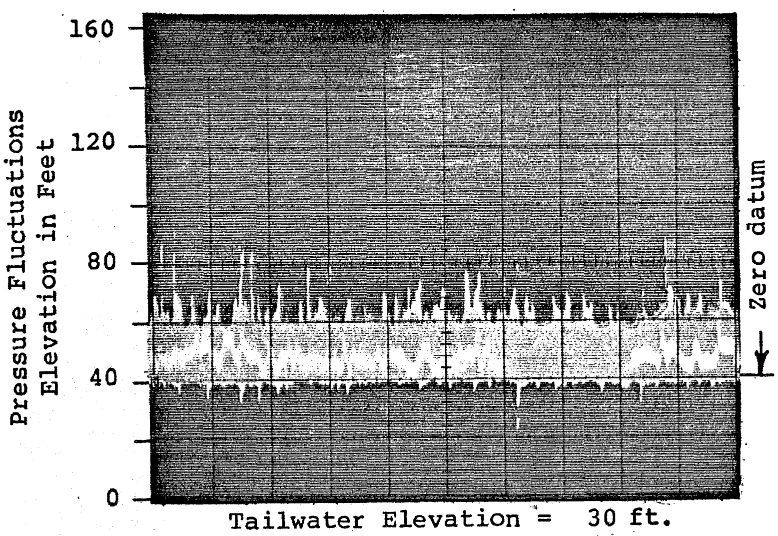
Tap 39 - Zero datum elev.= 40.5 ft.



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Dropshaft Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

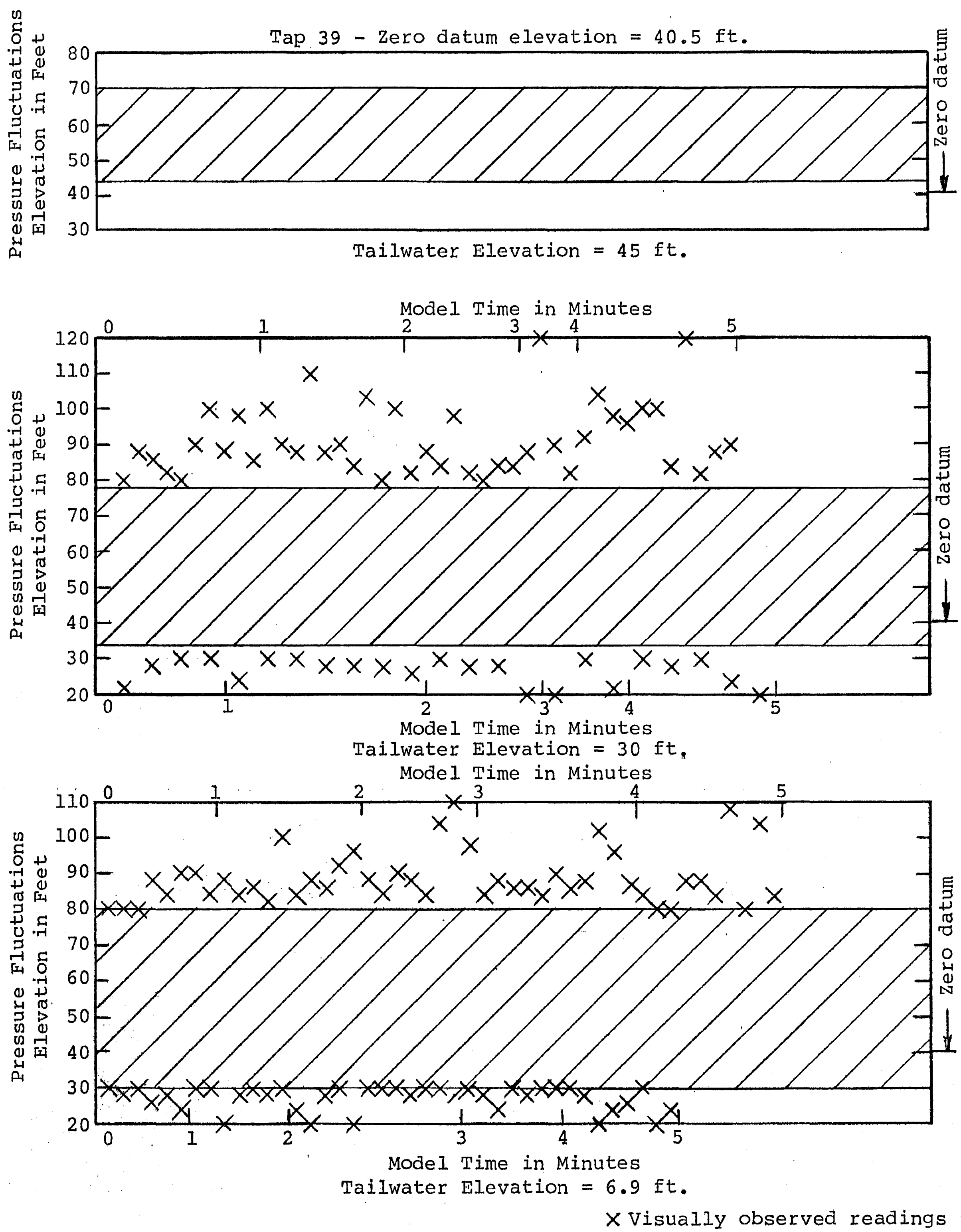
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 10/26/81	NO. 302 A2321-19





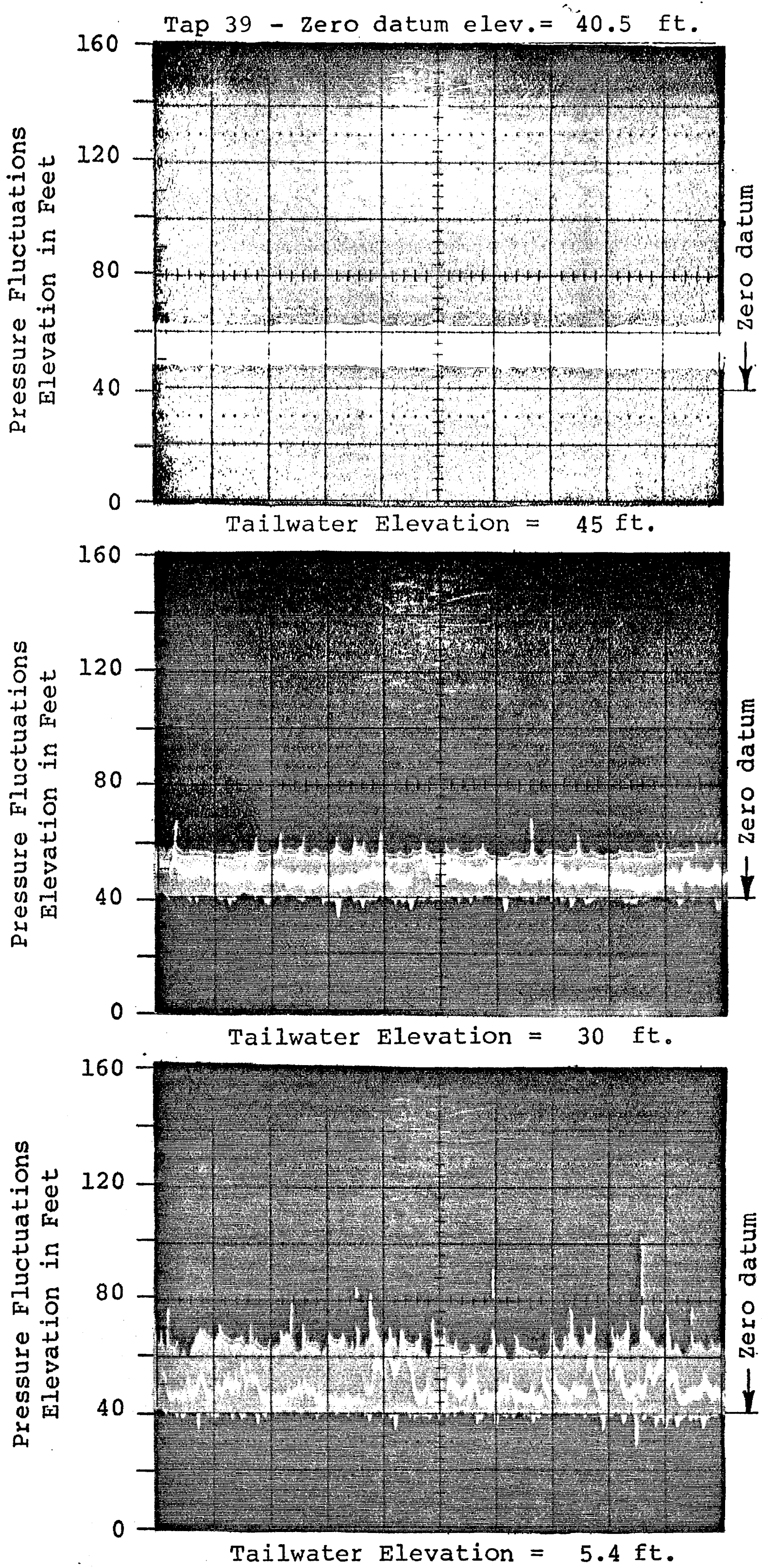
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Dropshaft Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-20



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 1/12/82	NO. 302A2321-125



ROCHESTER DROPSHAFTS MODEL STUDIES

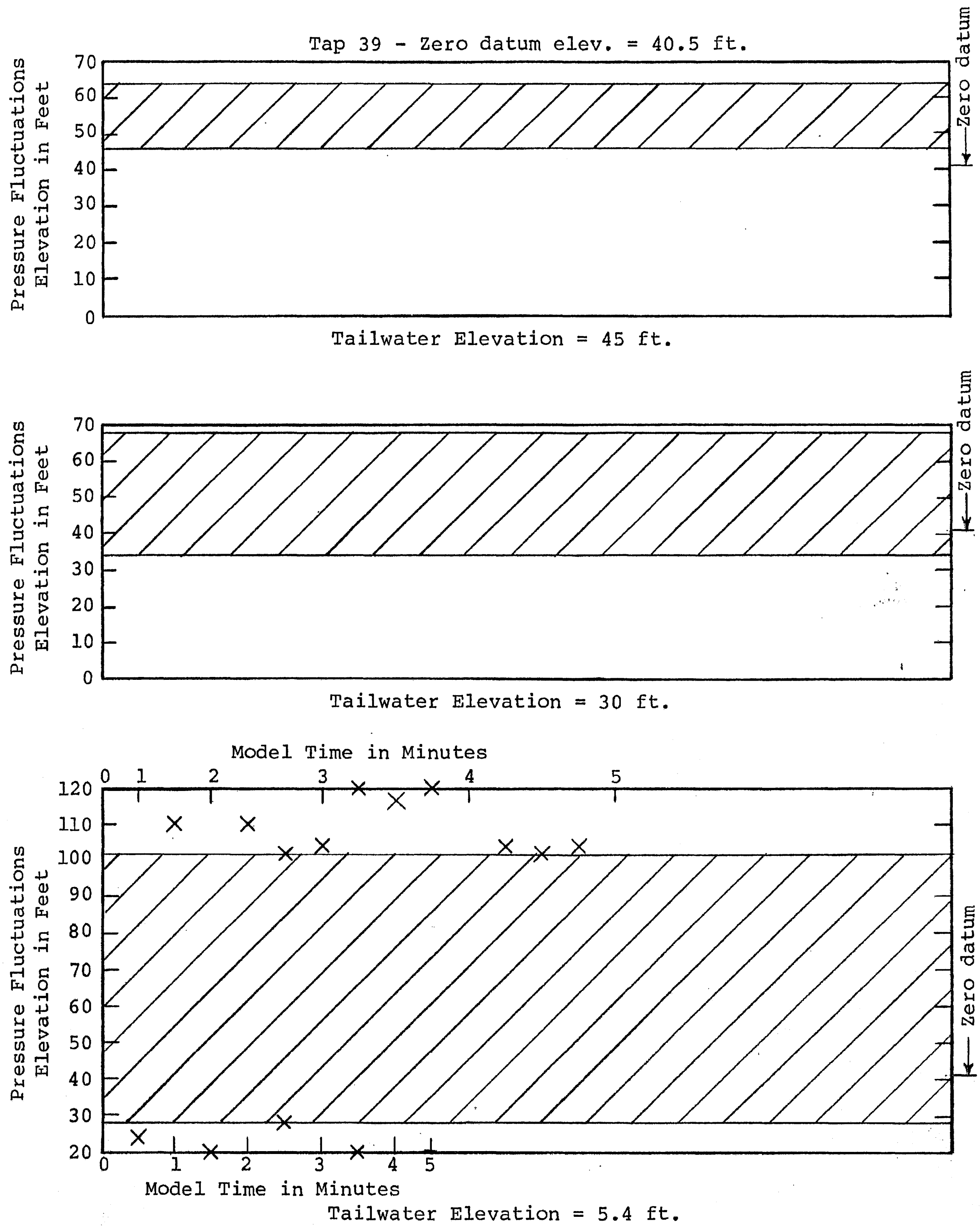
Type L2 R104 Dropshaft Scale 1:8

Typical Pressure Fluctuations

Q = 330 cfs

Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-74

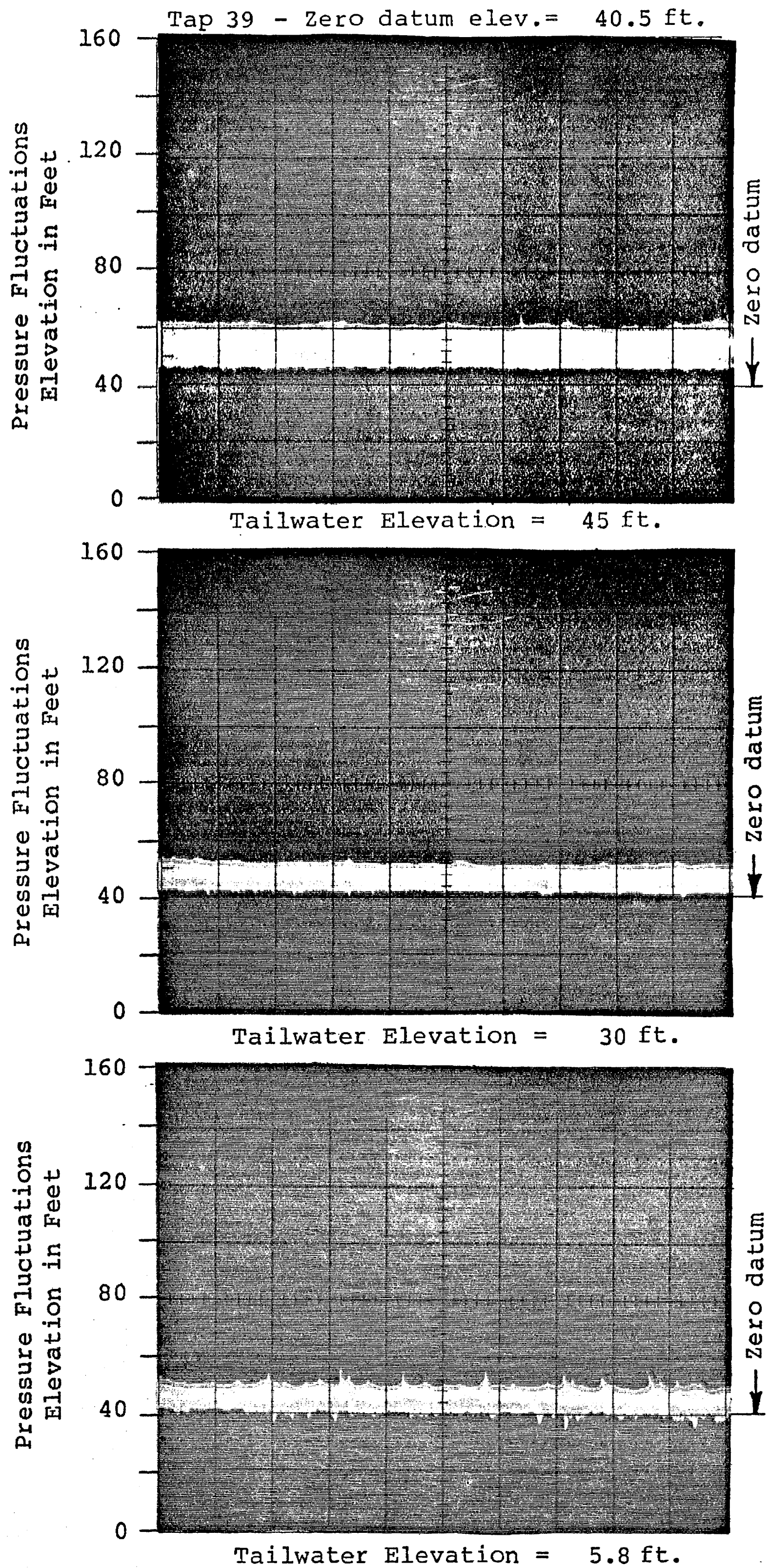


× Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 330 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 1/21/82	NO. 302A2321-147



ROCHESTER DROPSHAFTS MODEL STUDIES

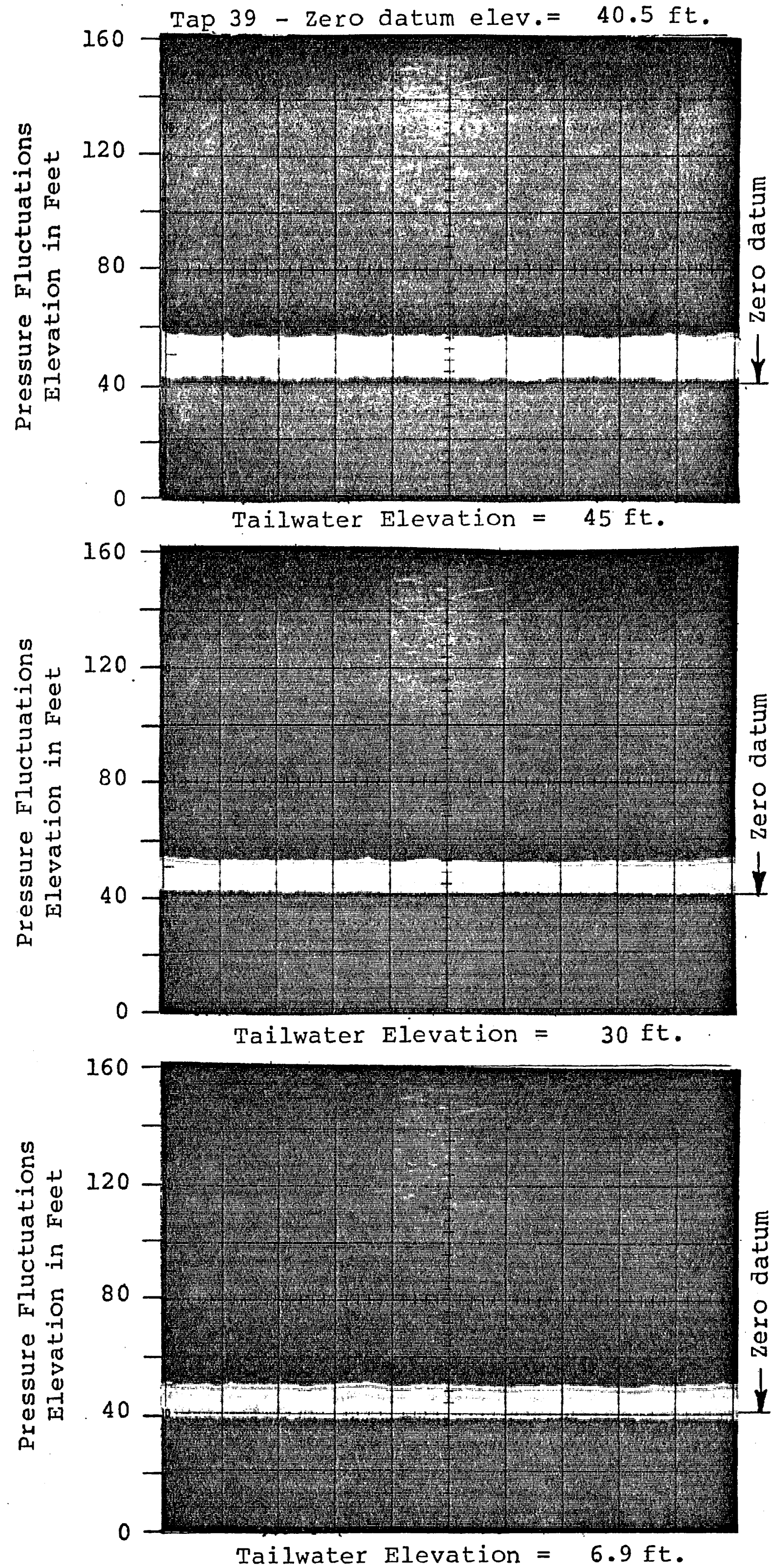
Type L2 R104 Dropshaft Scale 1:8

Typical Pressure Fluctuations

Q = 400 cfs

Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-75



ROCHESTER DROPSHAFTS MODEL STUDIES

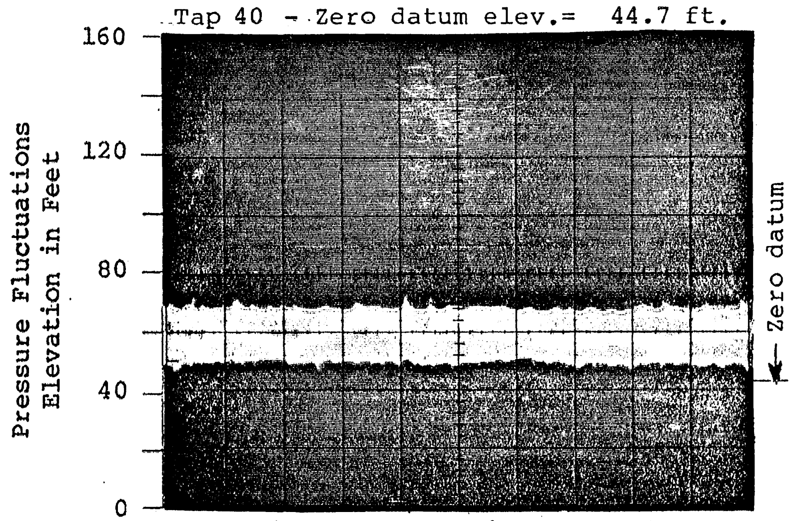
Type L2 R104 Dropshaft Scale 1:8

Typical Pressure Fluctuations

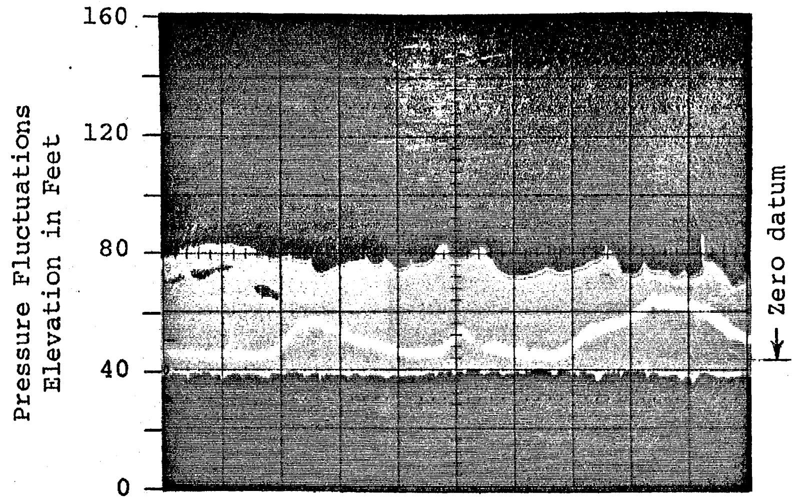
Q = 600 cfs

Model time of record = 1 minute

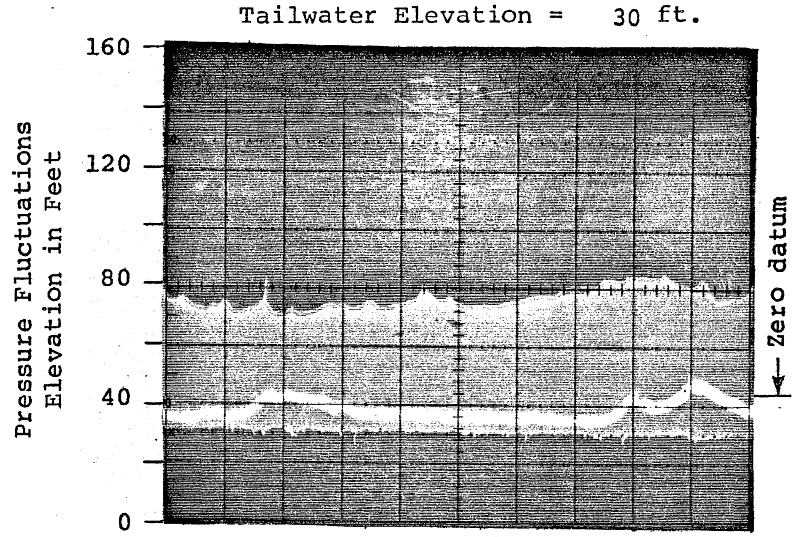
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-76



Tailwater Elevation = 45 ft.



Tailwater Elevation = 30 ft.



Tailwater Elevation = 5.8 ft.

ROCHESTER DROPSHAFTS MODEL STUDIES

Type L2 R104 Dropshaft Scale 1:8

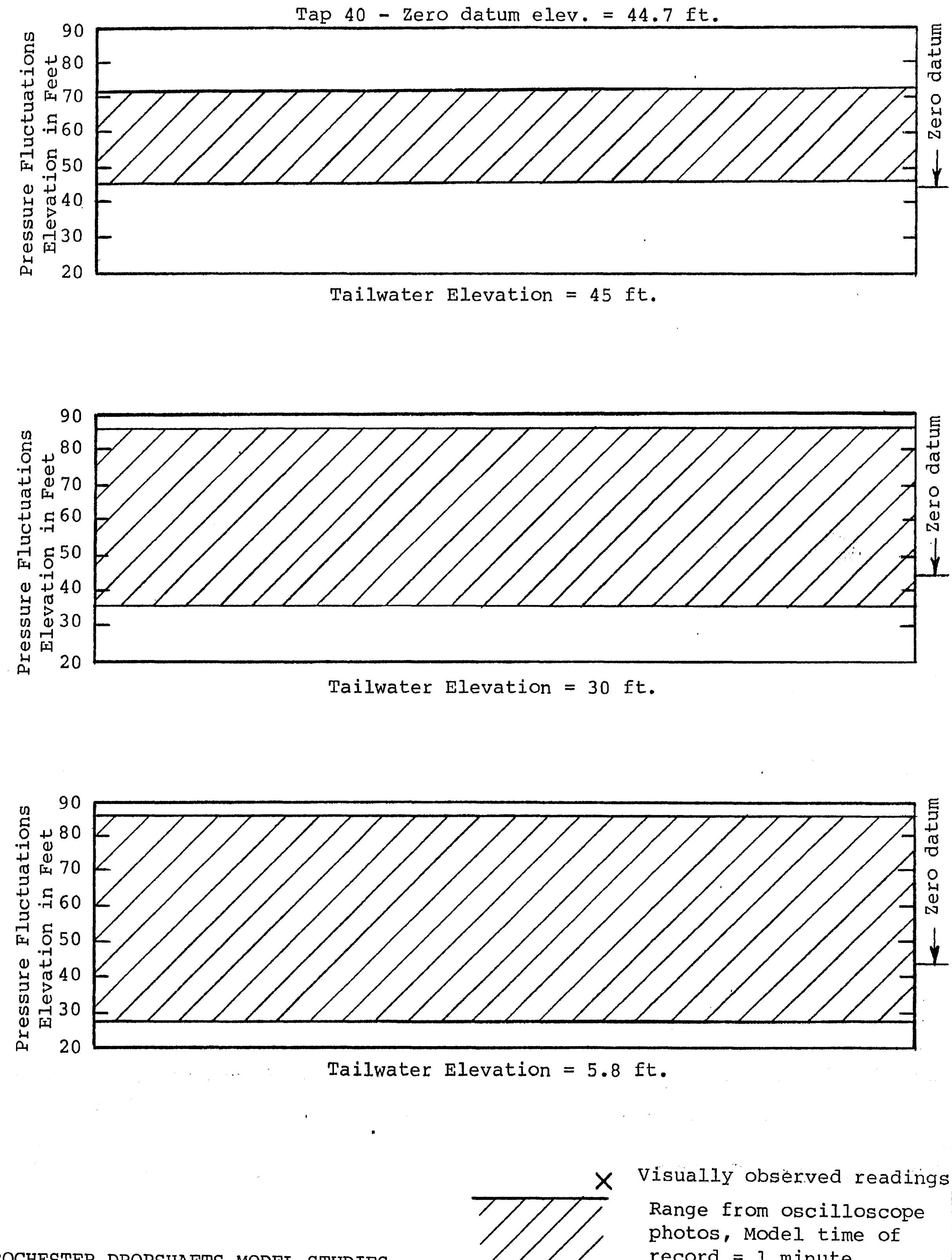
Typical Pressure Fluctuations

Q = 400 cfs

Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

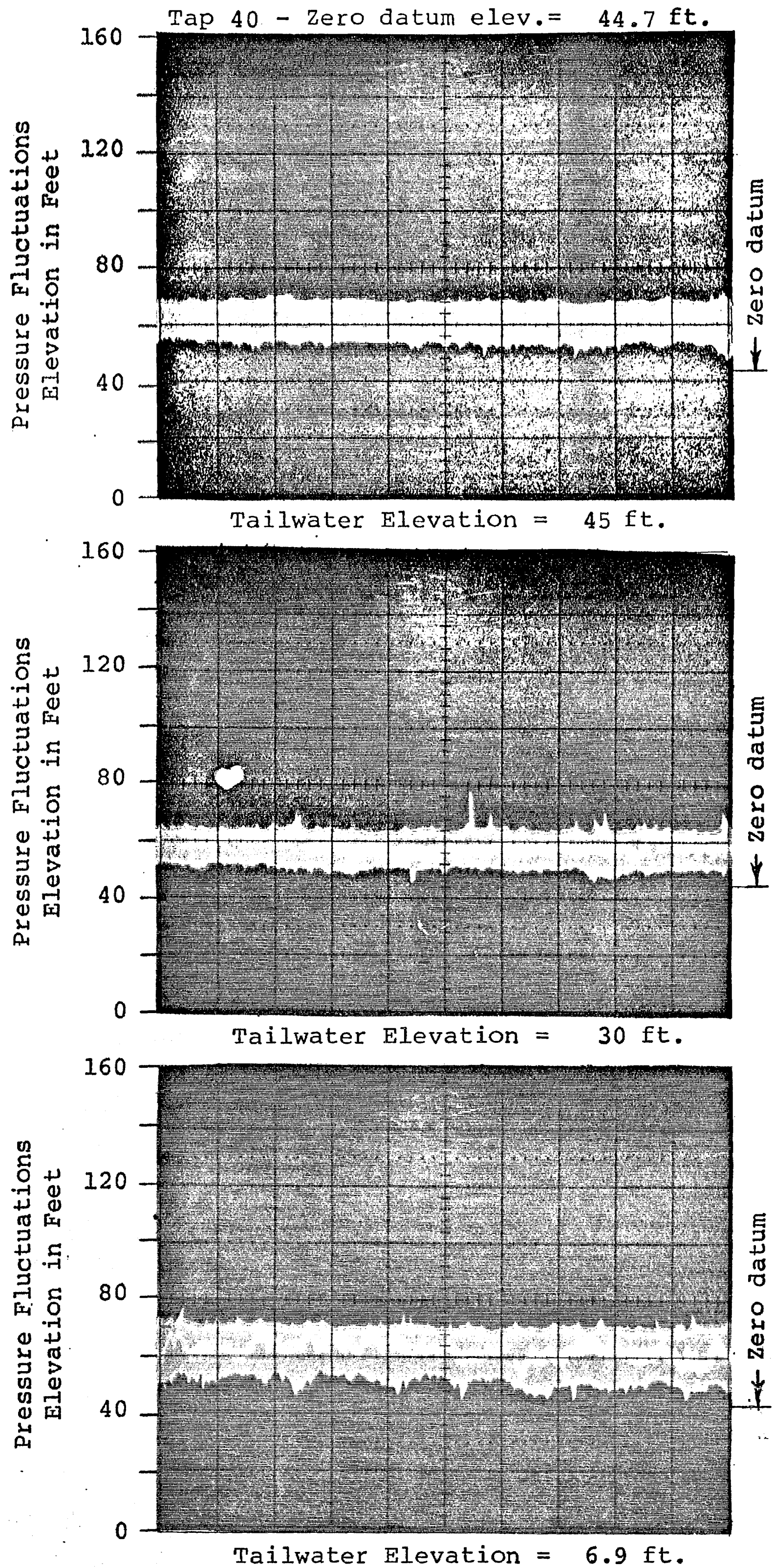
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-78



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 400 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 12/15/81	NO. 302A2321-85



ROCHESTER DROPSHAFTS MODEL STUDIES

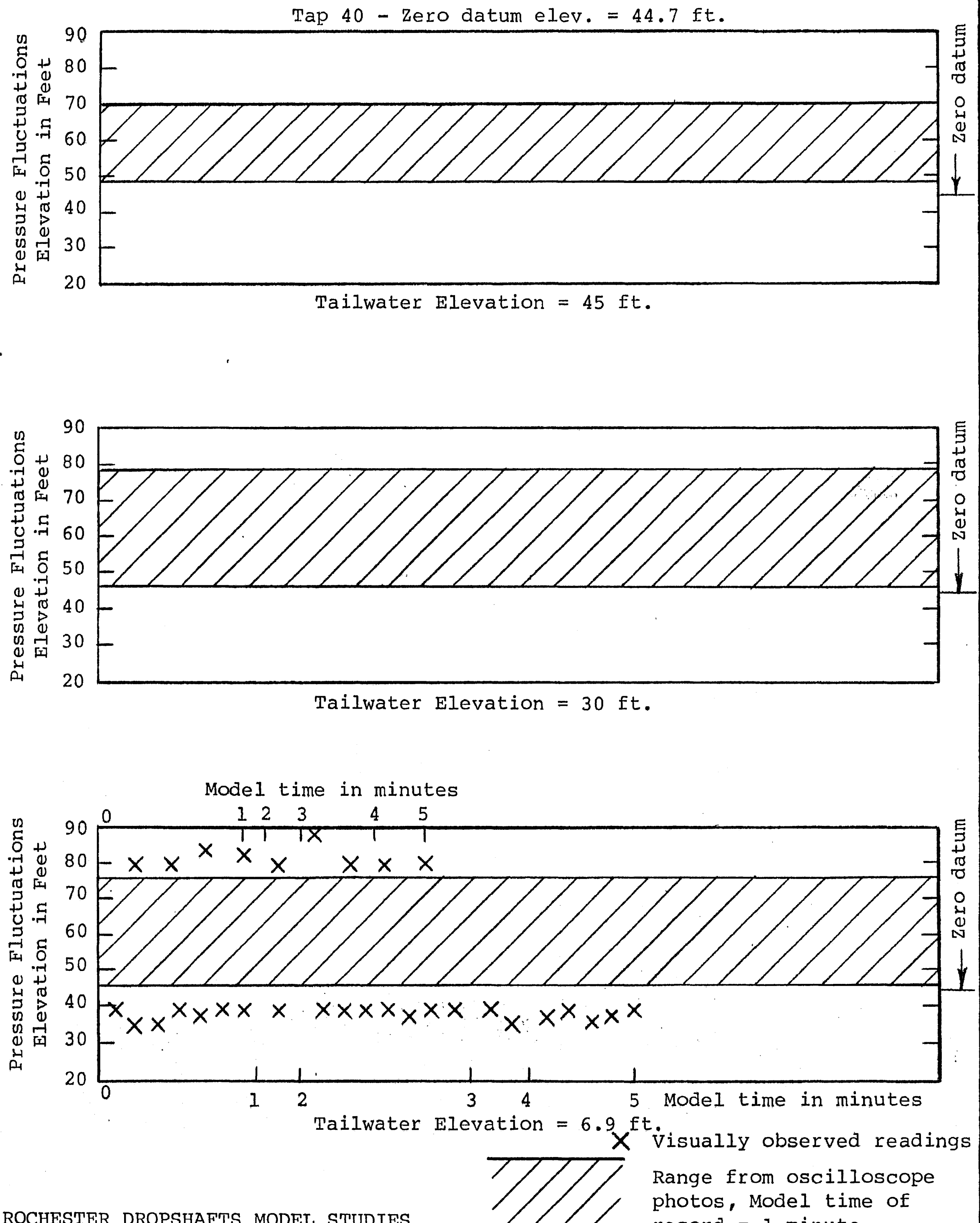
Type L2 R104 Dropshaft Scale 1:8

Typical Pressure Fluctuations

Q = 600 cfs

Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 10/26/81	NO. 302.A2321- 79



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

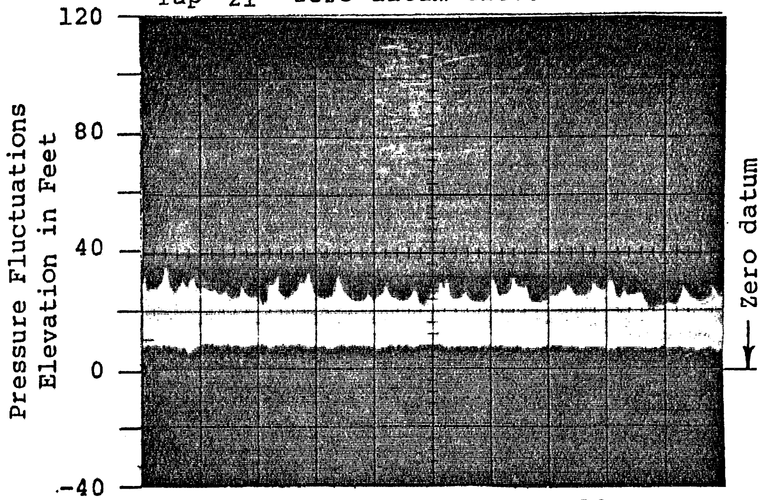
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [illegible]	APPROVED
SCALE	DATE 12/15/81	NO. 302A2321-86

Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Range from Photos Max.-ft	Range from Photos Min.-ft	Observed Readings Max.-ft	Observed Readings Min.-ft
		Type L2 R100 - Tap 39 Elevation = 40.5 ft				
200	45	47.9	74	42		
400	5.8	41.9	80	30	150	10
400	30	41.9	80	28	150	10
400	45	49.9	62	42		
600	6.9	44.5	80	30	110	20
600	10	44.5	80	34	110	20
600	22	44.5	78	34	120	20
600	30	44.5	84	32	120	20
600	45	52.7	70	44		
800	7.5	45.0	72	36	100	24
800	30	45.0	64	38	90	30
800	45	53.5	72	44		
		Type L2 R104 - Tap 39 Elevation = 40.5 ft				
330	5.4	44.0	102	28	120	20
330	30	44.0	68	34		
330	45	51.0	64	46		
400	5.8	44.6	56	34		
400	30	44.6	54	40		
400	45	51.1	64	44		
600	6.9	43.5	52	38		
600	30	43.5	54	40		
600	45	49.3	58	40		
800	7.5	43.9	54	38		
800	30	43.9	52	38		
800	45	49.5	64	44		
		Type L2 R104 - Tap 40 Elevation = 44.67 ft				
400	5.8	44.7	86	28		
400	30	45.1	86	36		
400	45	55.3	72	46		
600	6.9	59.5	76	46	88	36
600	30	57.1	78	46		
600	45	58.7	70	48		
800	7.5	58.0	72	38		
800	30	55.3	68	46		
800	45	57.1	70	46		

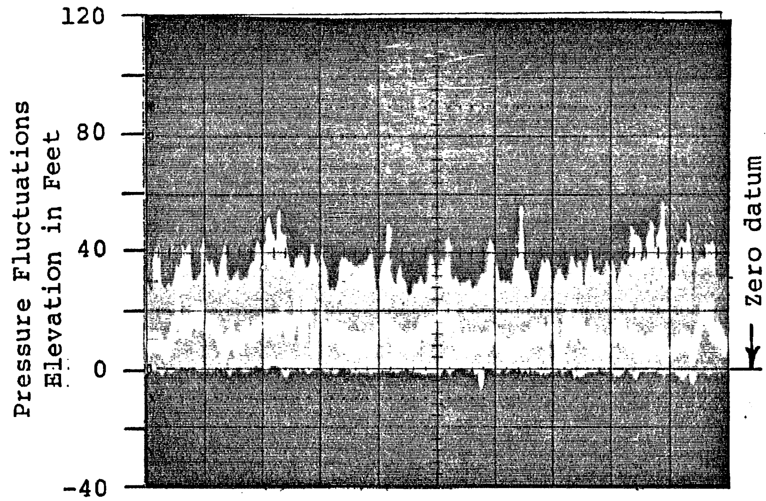
ROCHESTER DROPSHAFT MODEL STUDIES
Model Scale 1:8
Summary of Typical
Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 9/24/81	NO. 302A2321-233

Tap 21 - Zero datum elev.= 0 ft.



Tailwater Elevation = 10 ft.

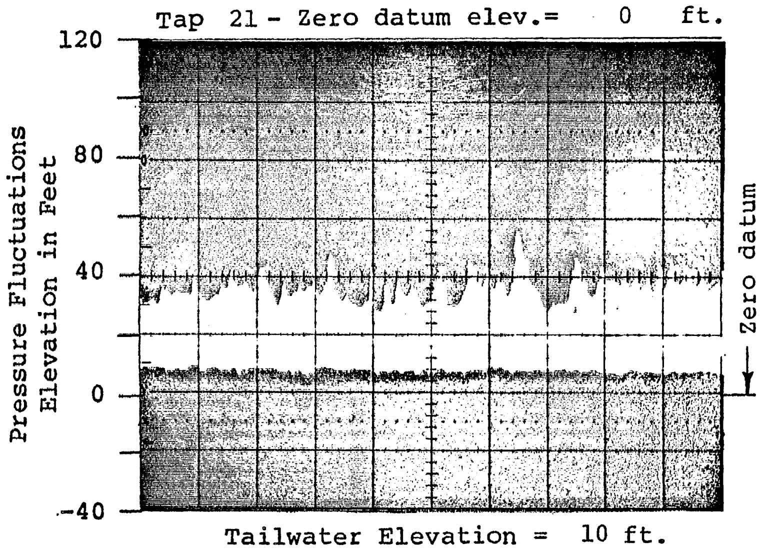


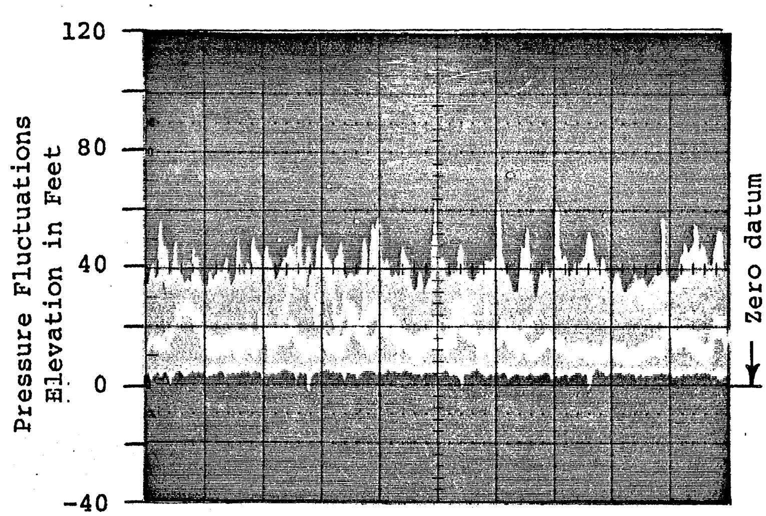
Tailwater Elevation = 4.1 ft.

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Dropshaft Scale 1:8
Typical Pressure Fluctuations
Q = 200 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-14

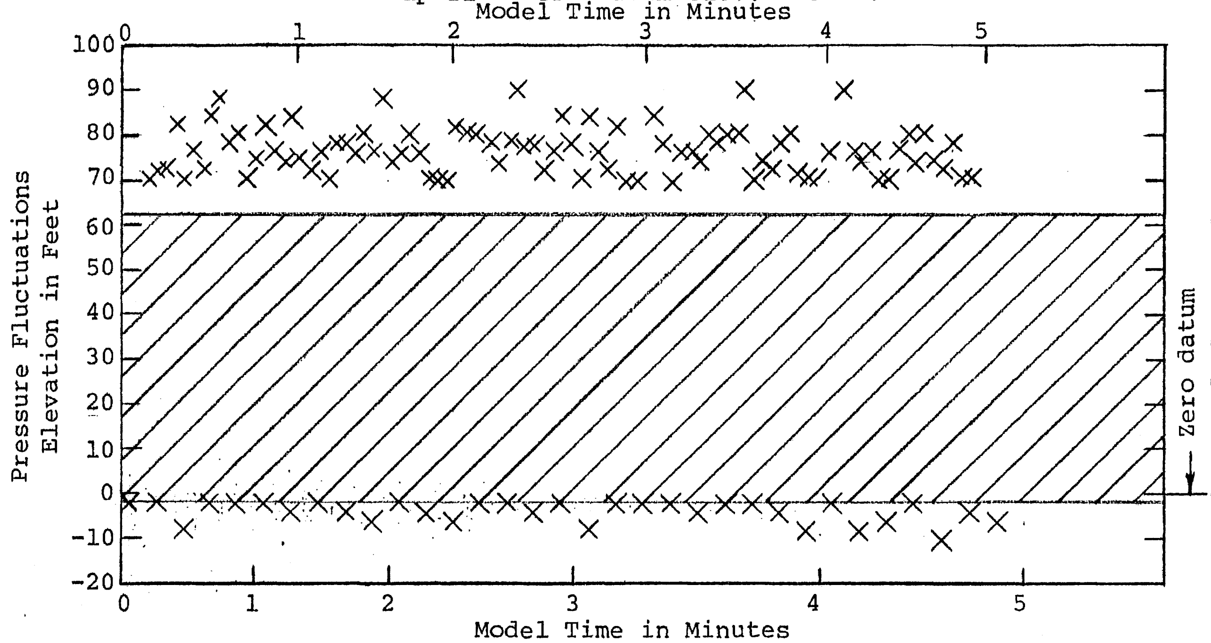




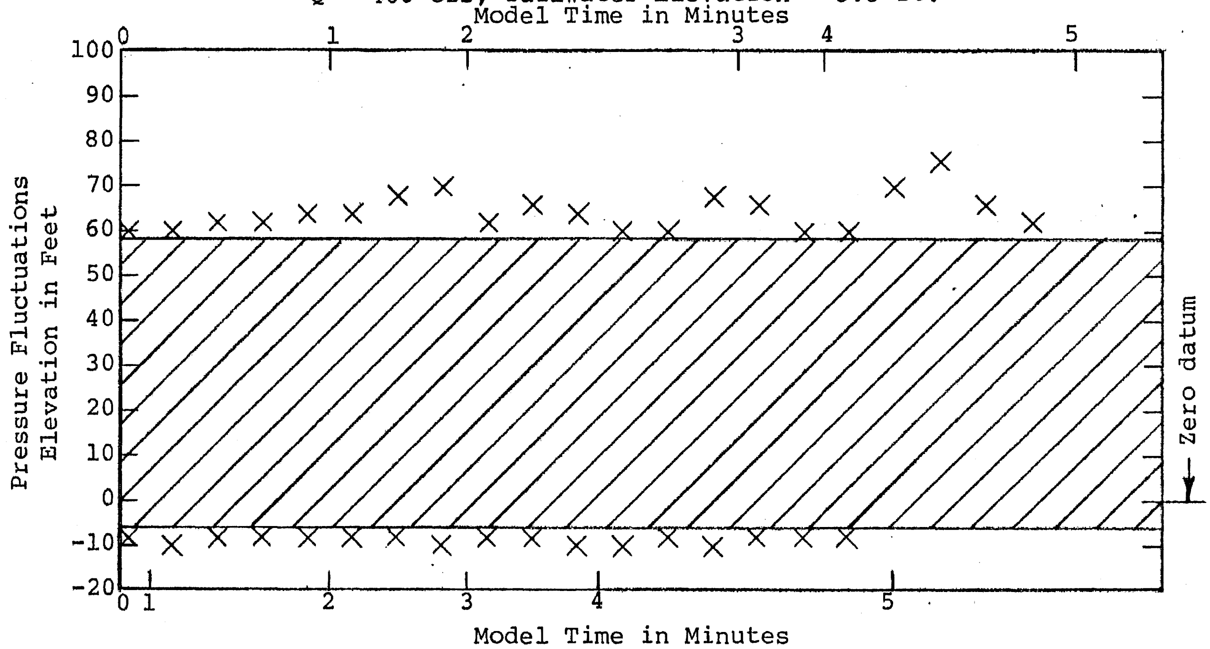
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Dropshaft Scale 1:8
Typical Pressure Fluctuations
Q = 400 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-15

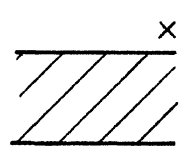
Tap 21 - Zero datum elev. = 0 ft.



Q = 400 cfs, Tailwater Elevation = 5.8 ft.

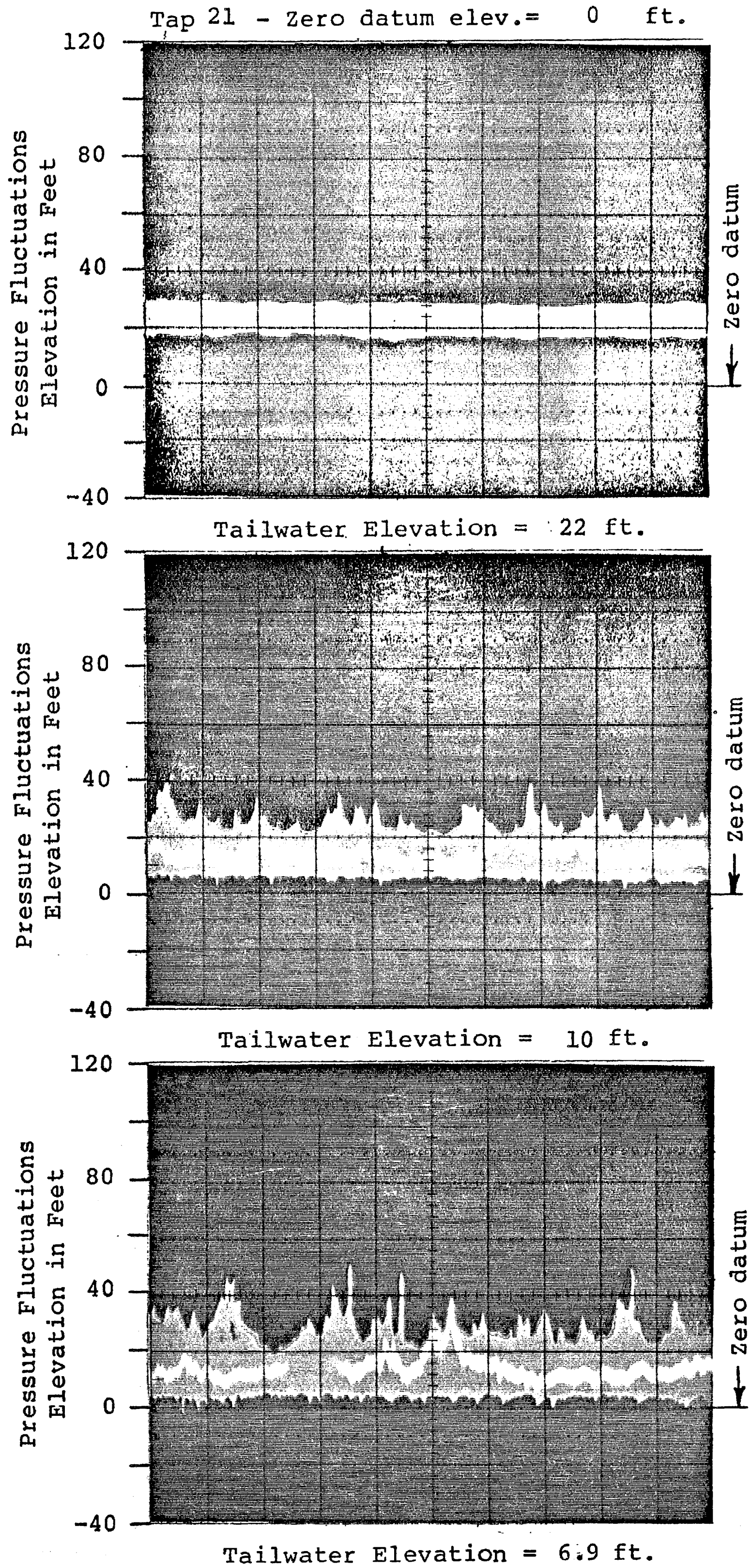


Q = 200 cfs, Tailwater Elevation = 4.1 ft.



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Typical Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN TO	CHECKED [signature]	APPROVED
SCALE	DATE 1/6/82	NO. 302A2321-102



ROCHESTER DROPSHAFTS MODEL STUDIES

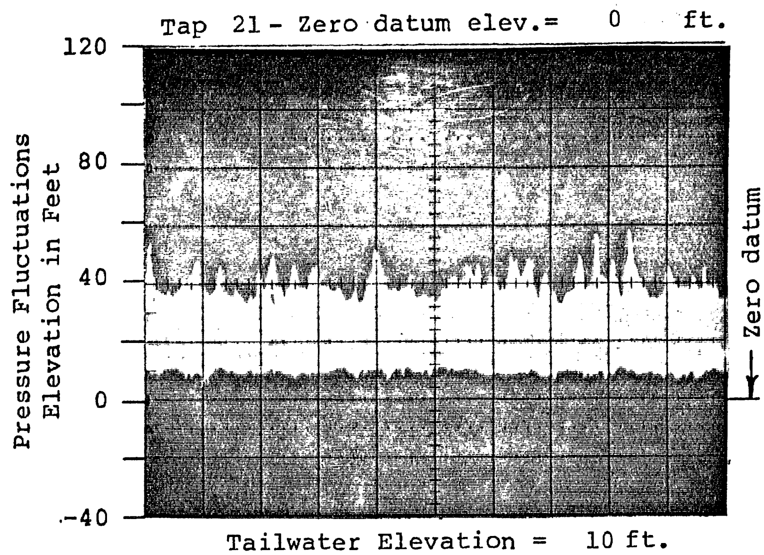
Type L2 R100 Dropshaft Scale 1:8

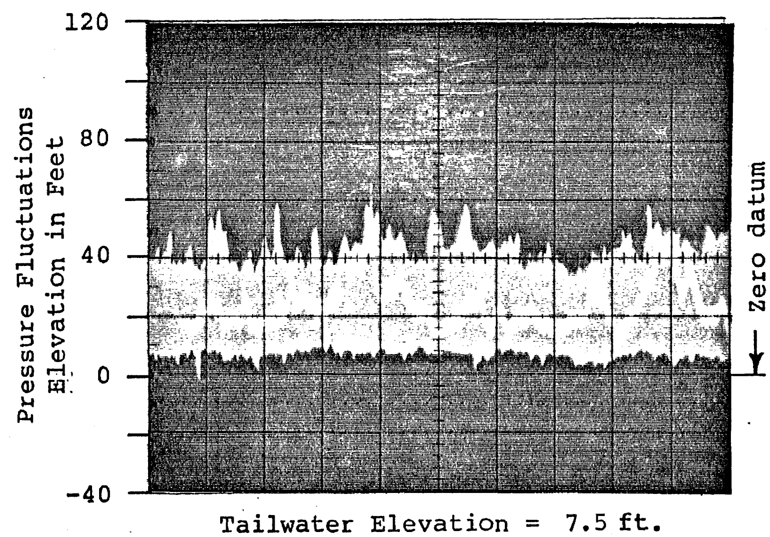
Typical Pressure Fluctuations

Q = 600 cfs

Model time of record = 1 minute

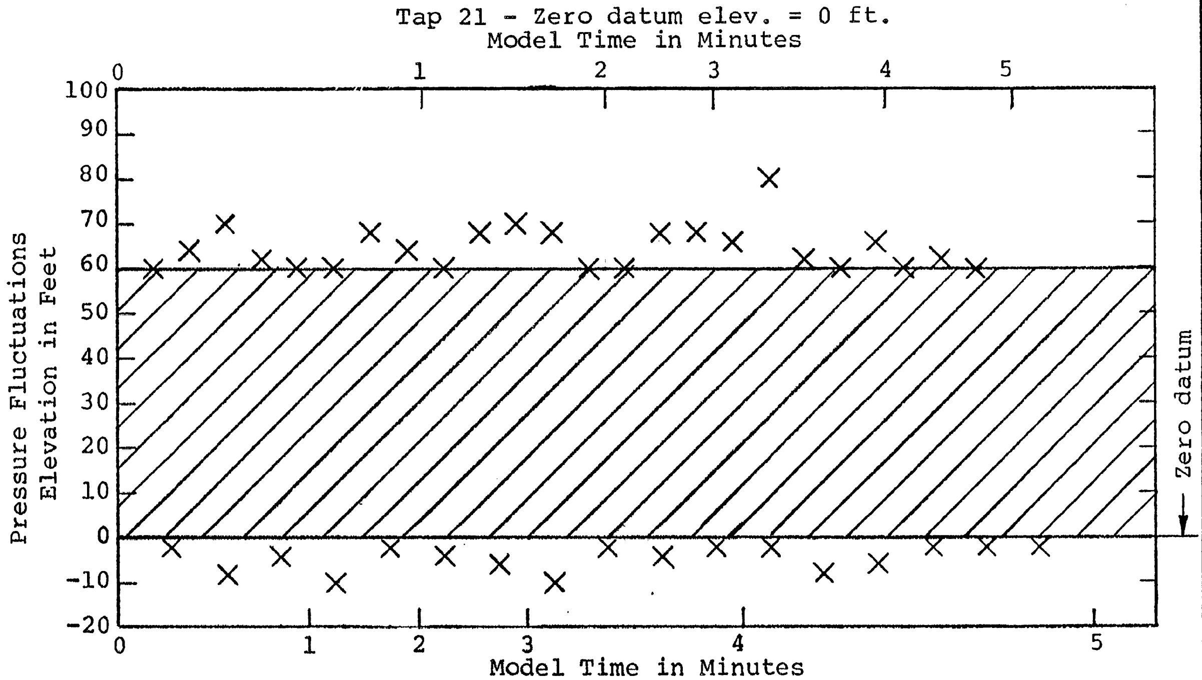
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED MBL	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-13



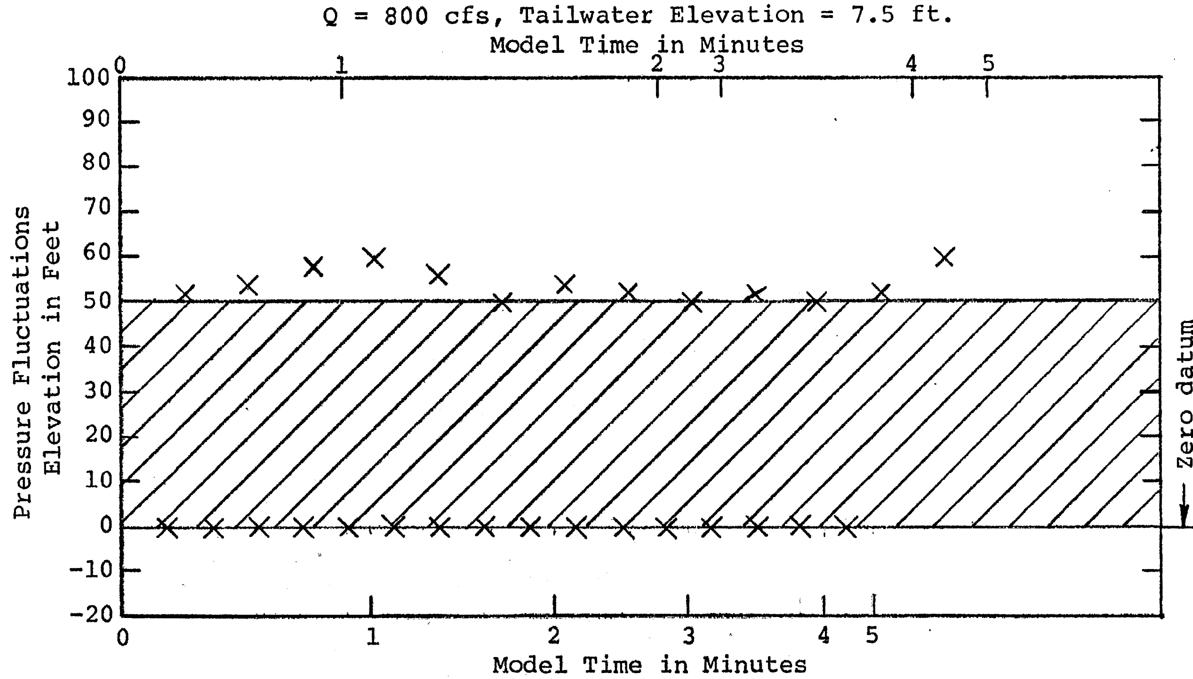


ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Dropshaft Scale 1:8
Typical Pressure Fluctuations
Q = 800 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-16



Q = 800 cfs, Tailwater Elevation = 7.5 ft.



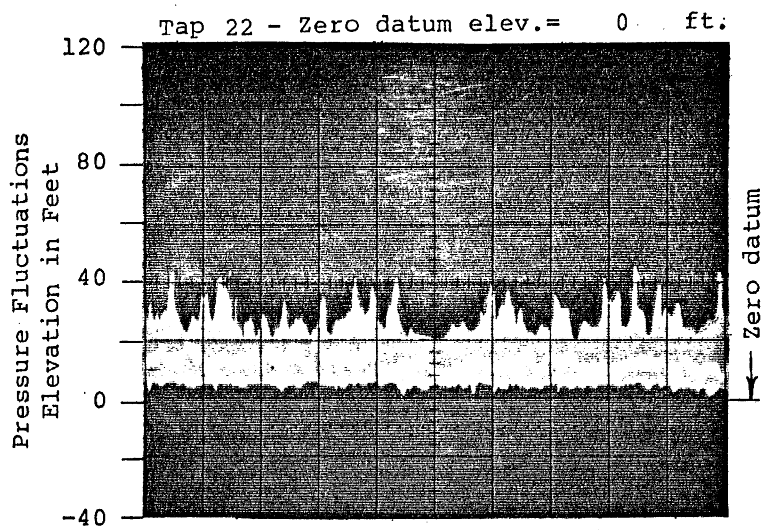
Q = 600 cfs, Tailwater Elevation = 6.9 ft.

× Visually observed readings

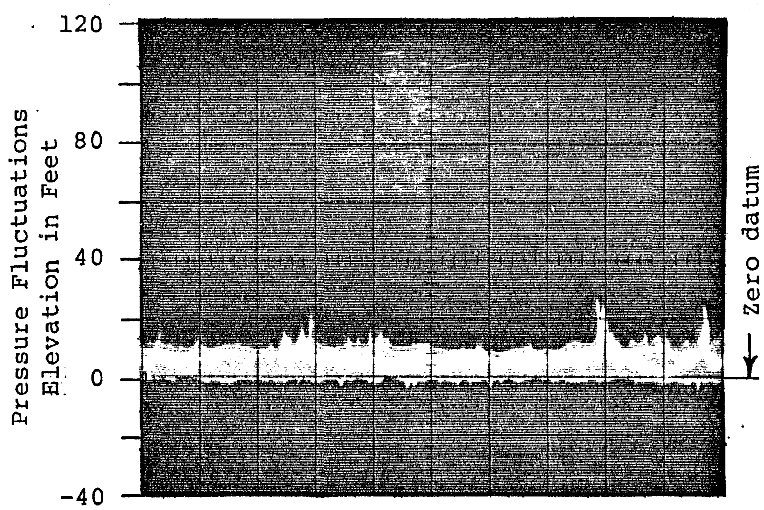
Range from oscilloscope photos, model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Typical Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN TO	CHECKED [signature]	APPROVED
SCALE	DATE 1/6/82	NO. 302A2321-101



Tailwater Elevation = 5.8 ft.
Q = 400 cfs



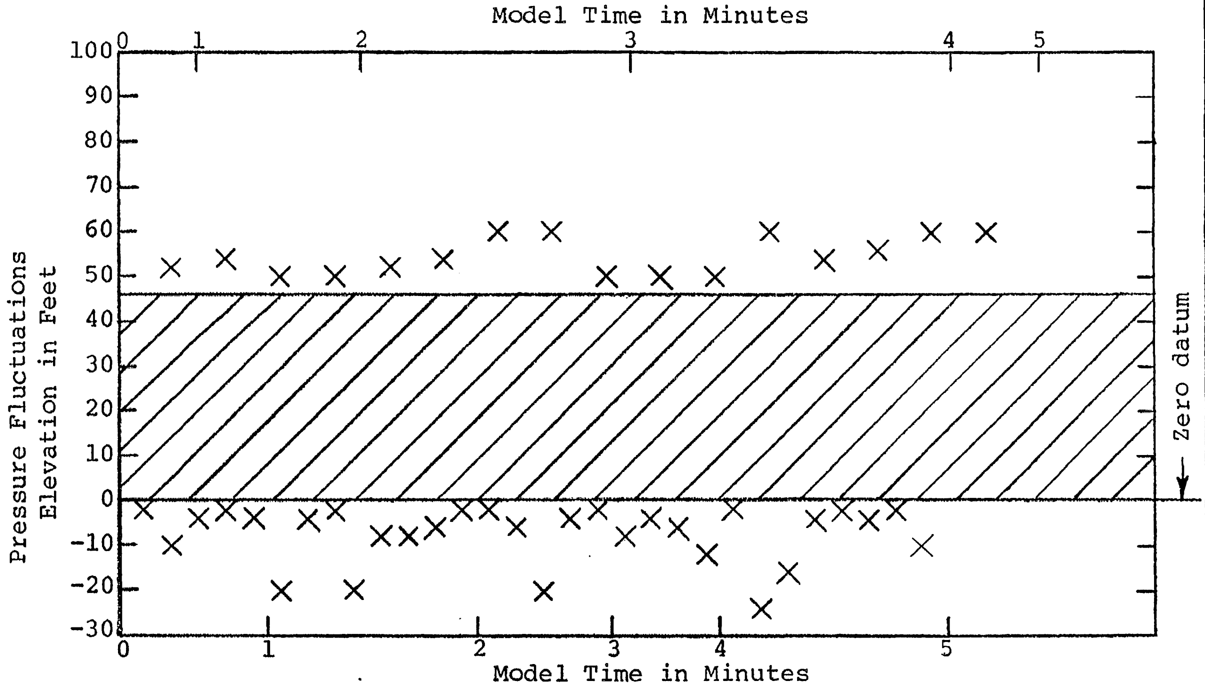
Tailwater Elevation = 4.1 ft.
Q = 200 cfs

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Dropshaft Scale 1:8
Typical Pressure Fluctuations

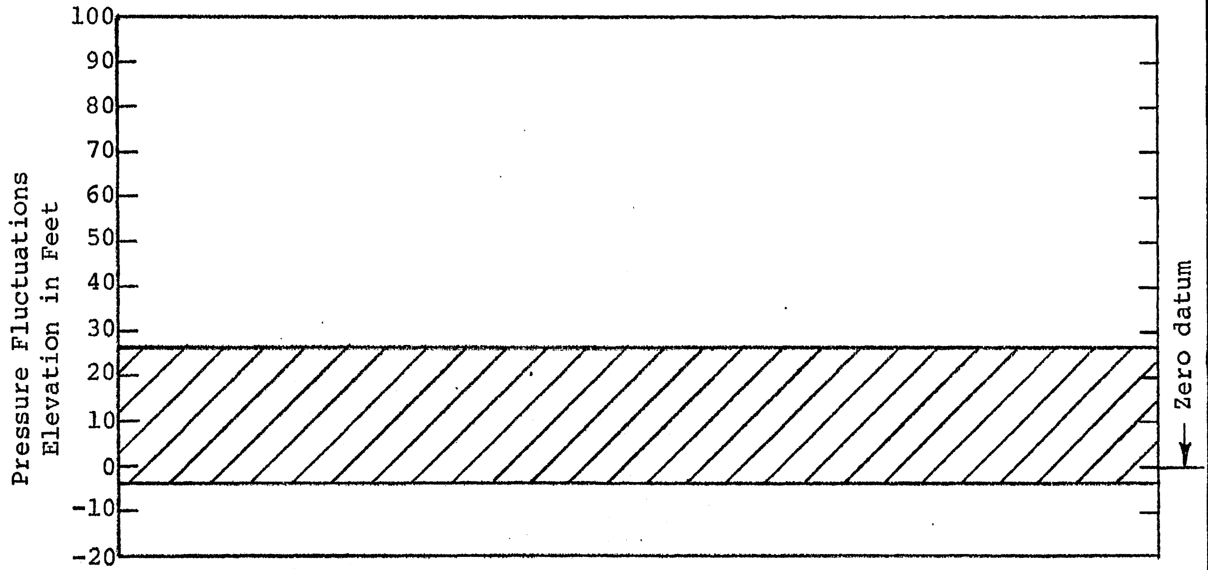
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-17

Tap 22 - Zero datum elev. = 0 ft.



Q = 400 cfs, Tailwater Elevation = 5.8 ft.



Q = 200 cfs, Tailwater Elevation = 4.1 ft.

× Visually observed readings

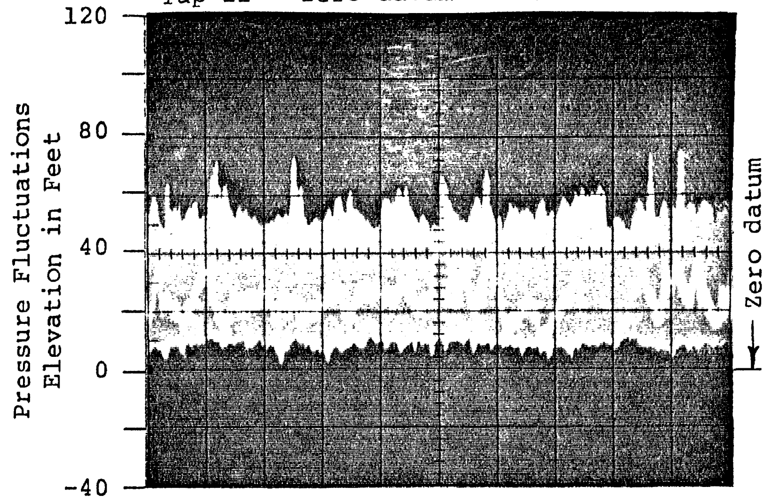
Range from oscilloscope photos, model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Typical Pressure Fluctuations

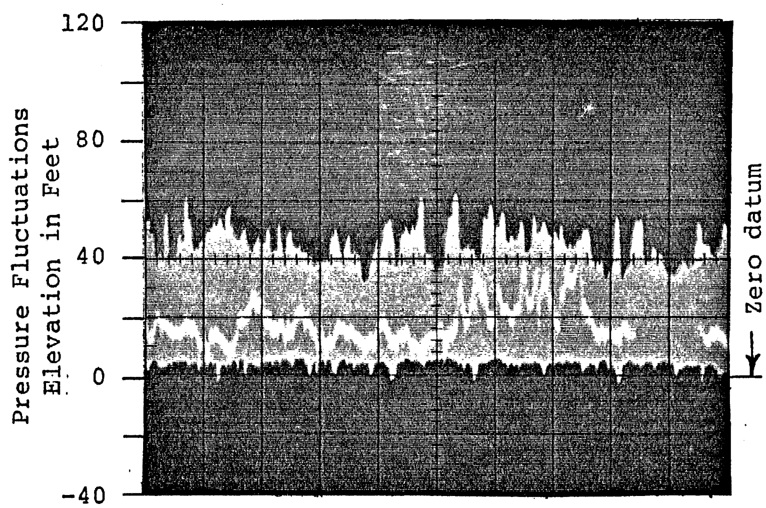
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN TO	CHECKED	APPROVED
SCALE	DATE 1/6/82	NO. 302A-2321-103

Tap 22 - Zero datum elev.= 0 ft.



Tailwater Elevation = 7.5 ft.
Q = 800 cfs

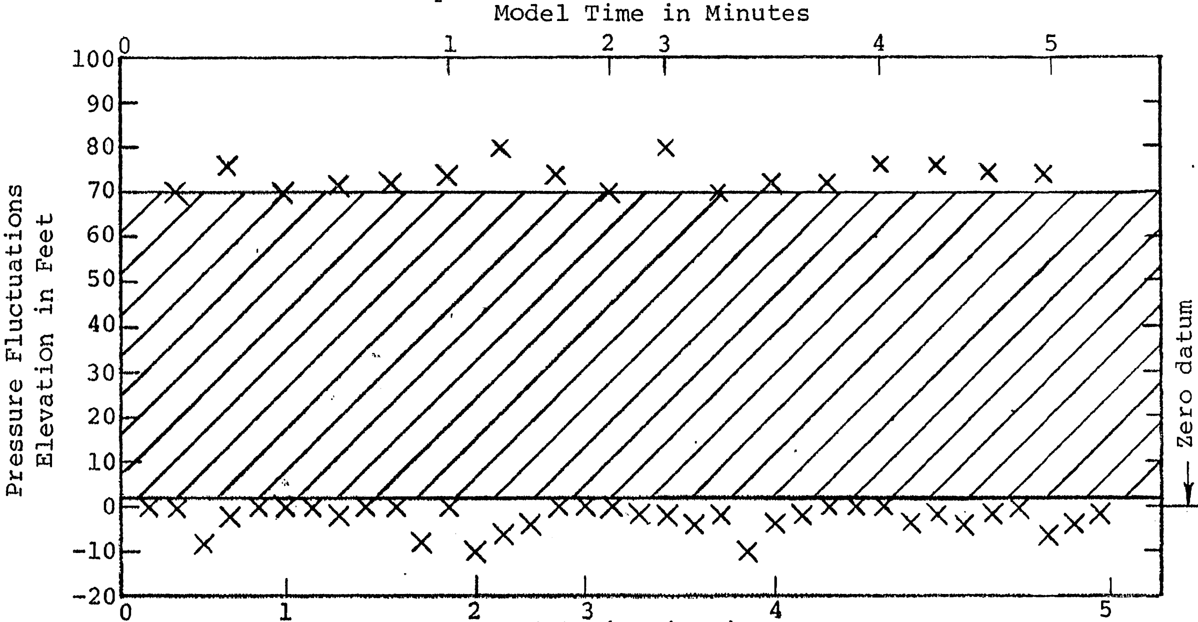


Tailwater Elevation = 6.9 ft.
Q = 600 cfs

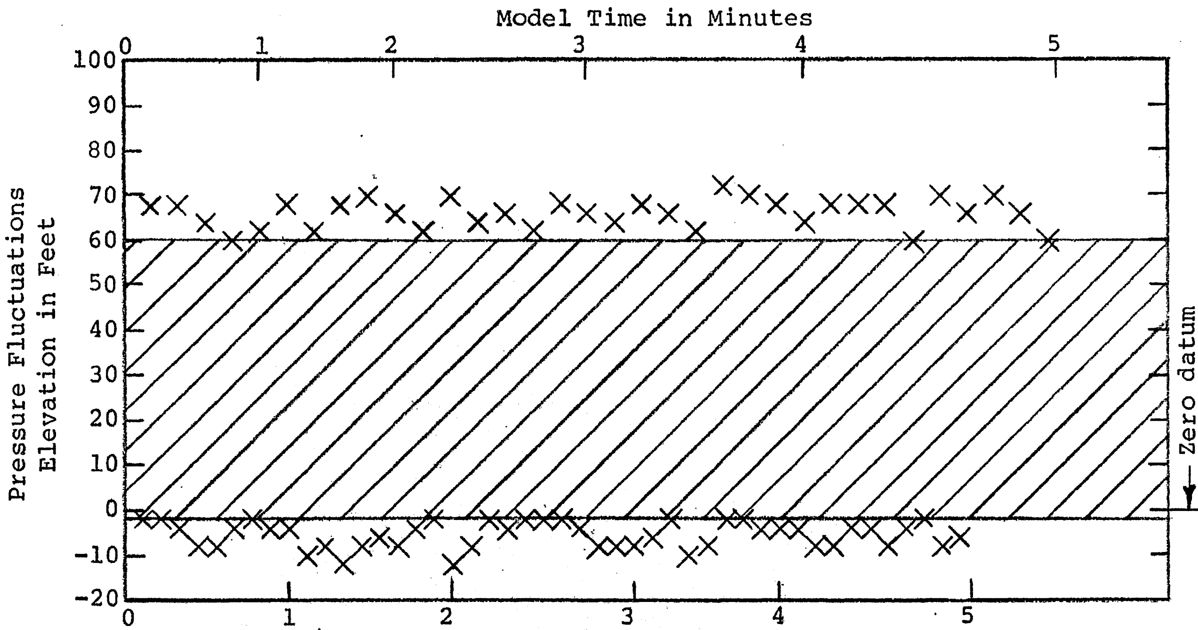
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Dropshaft Scale 1:8
Typical Pressure Fluctuations

Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321- 18



Q = 800 cfs, Tailwater Elevation = 7.5 ft.



Q = 600 cfs, Tailwater Elevation = 6.9 ft.

× Visually observed readings

Range from oscilloscope photos, model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Typical Pressure Fluctuations

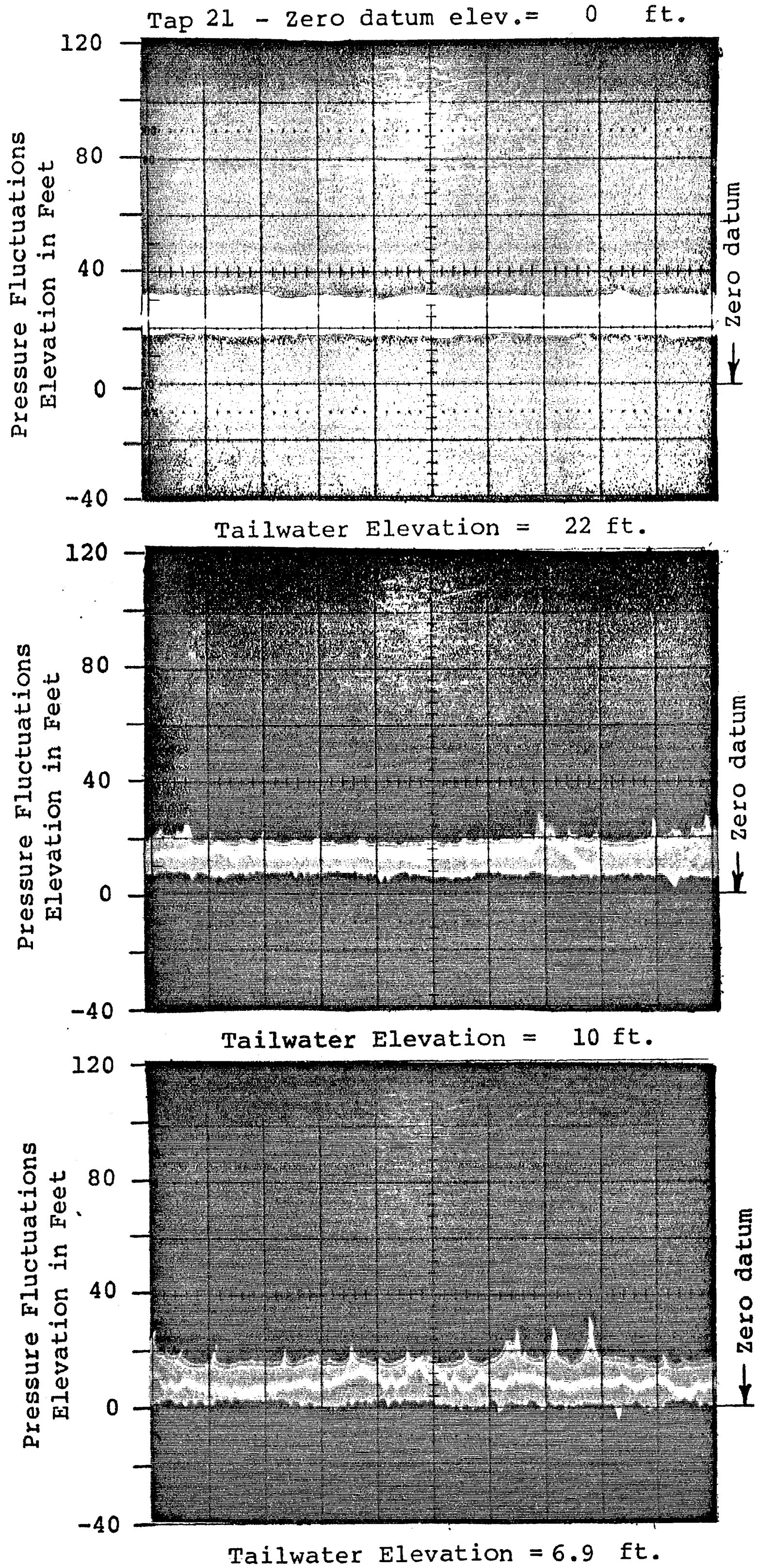
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN TO	CHECKED [signature]	APPROVED
SCALE	DATE 1/6/82	NO. 302A2321-104

Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Range from Photos Max.-ft	Range from Photos Min.-ft	Observed Readings Max.-ft	Observed Readings Min.-ft
			Type L2 R100 - Tap 21 Elevation = 0 ft			
200	4.1	9.1	58	-6	76	-10
200	10	11.2	34	6		
400	5.8	13.3	62	-2	90	-10
400	10	14.8	56	6	80	6
600	6.9	9.1	50	0	60	0
600	10	11.7	40	2	50	0
600	22	21.7	30	16		
800	7.5	17.2	60	0	80	-10
800	10	17.3	58	8	70	-8
			Type L2 R100 - Tap 22 Elevation = 0 ft			
200	4.1	4.6	26	-4		
400	5.8	12.1	46	0	60	-24
600	6.9	15.0	60	-2	72	-12
800	7.5	21.7	70	2	80	-10

ROCHESTER DROPSHAFT MODEL STUDIES
Model Scale 1:8
Summary of Typical
Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

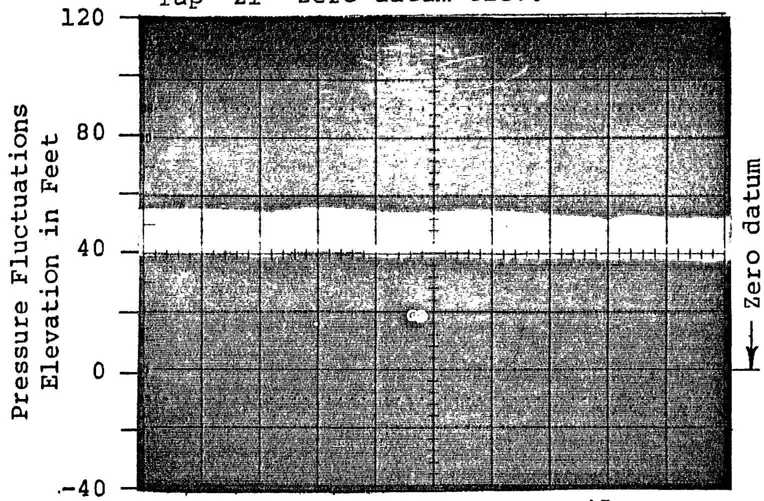
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 9/28/81	NO. 302A2321-234



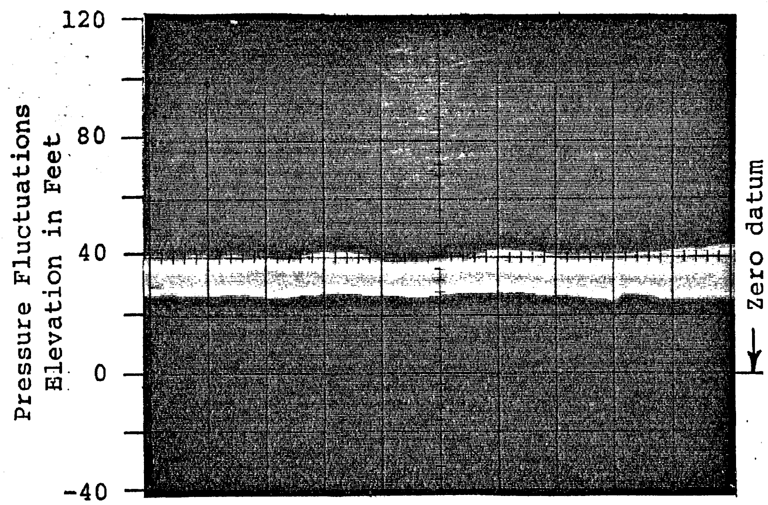
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R101 Dropshaft Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED MQB	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-31

Tap 21 - Zero datum elev.= 0 ft.



Tailwater Elevation = 45 ft.

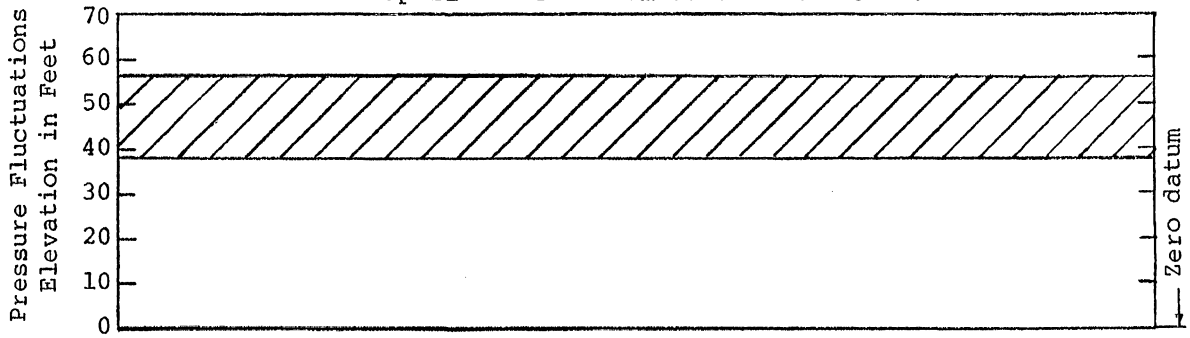


Tailwater Elevation = 30 ft.

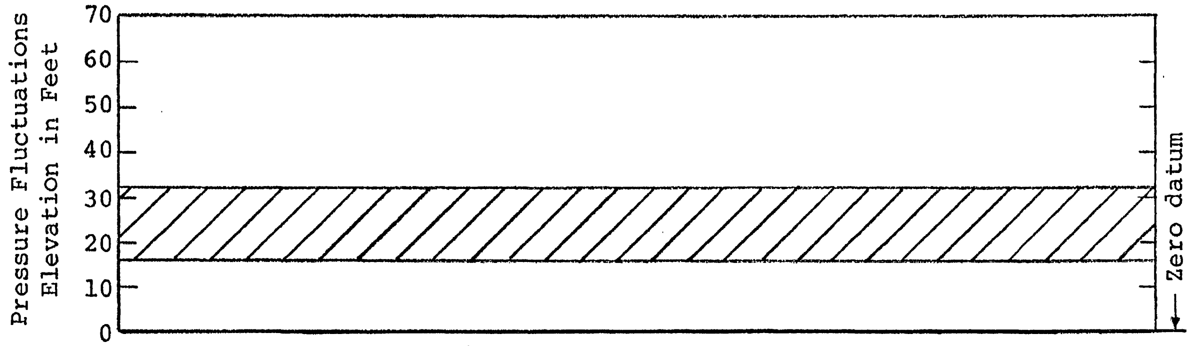
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R101 Dropshaft Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-32

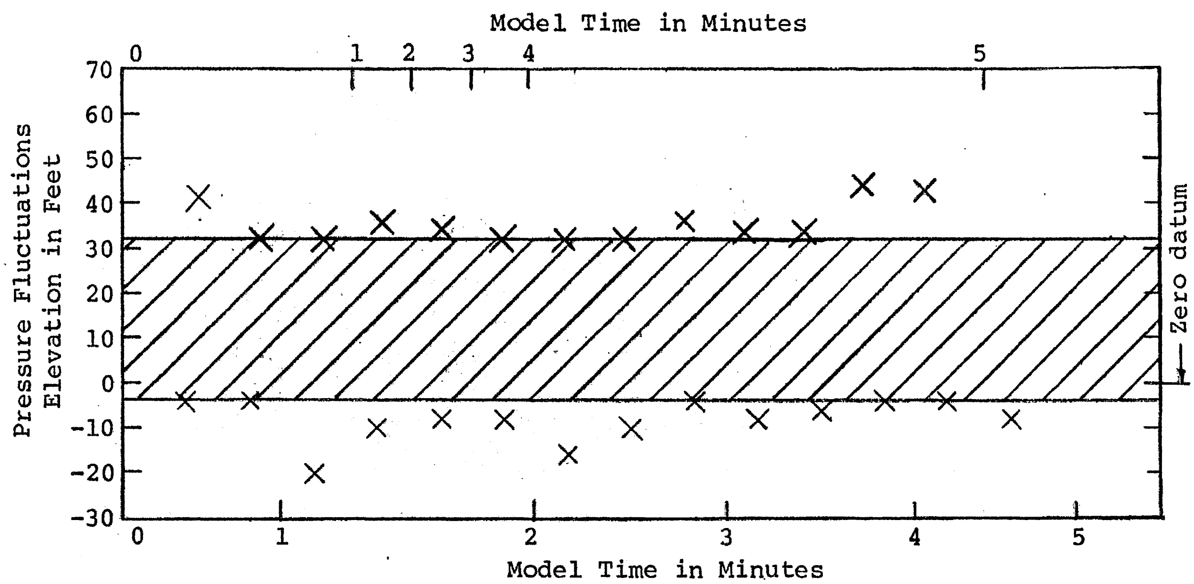
Tap 21 - Zero datum elevation = 0 ft.



Tailwater Elevation = 45 ft.



Tailwater Elevation = 22 ft.



Tailwater Elevation = 6.9 ft.

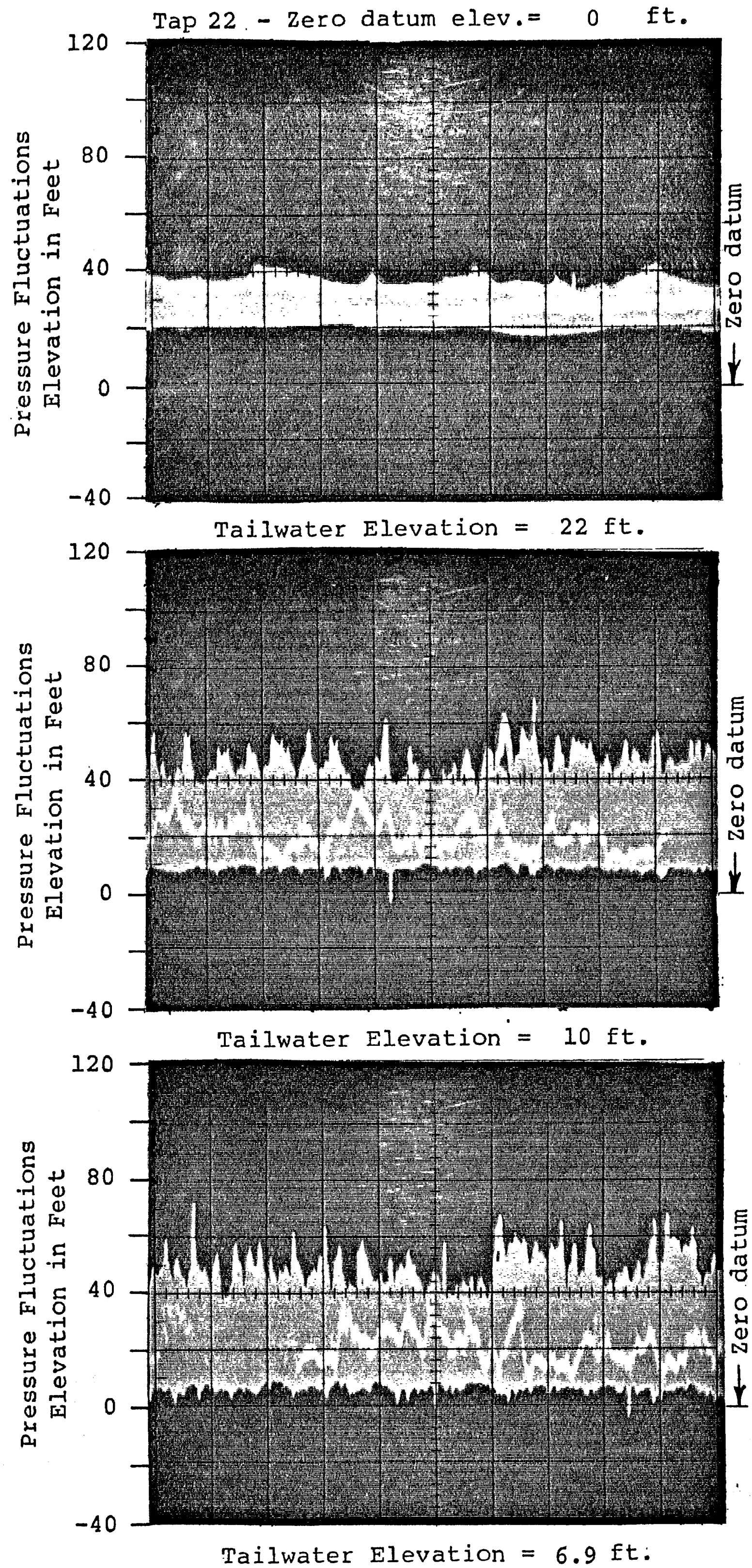
X Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R101 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

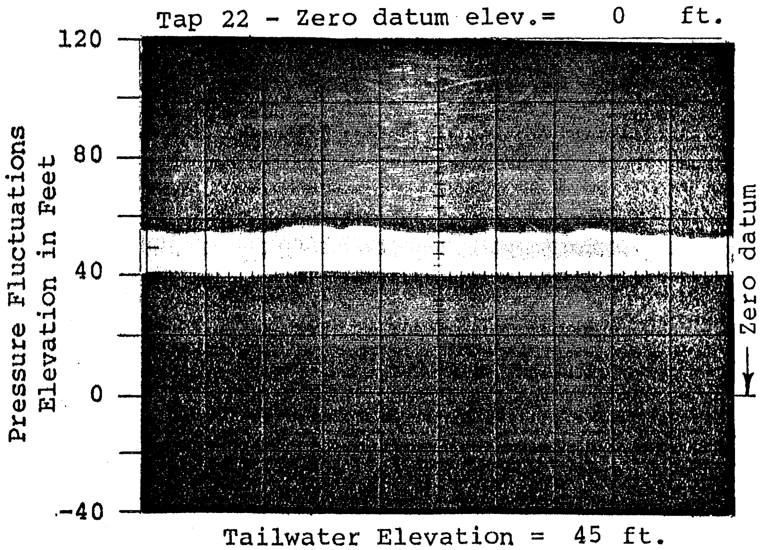
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

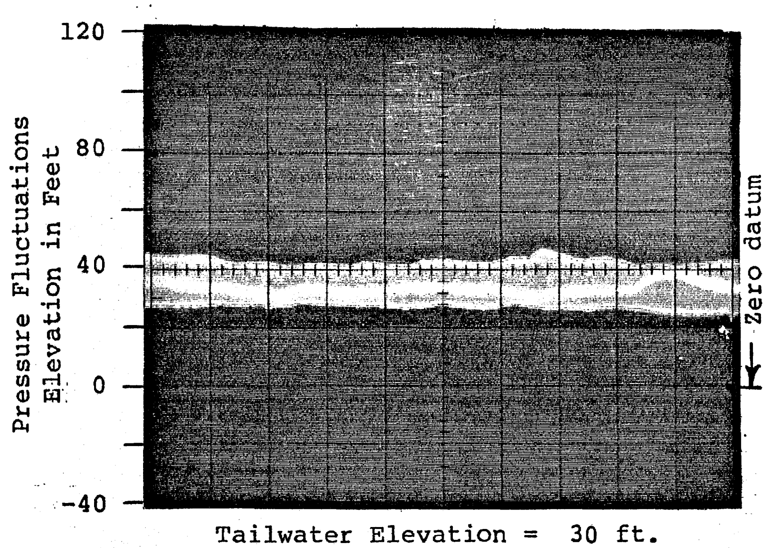
DRAWN BB	CHECKED	APPROVED
SCALE	DATE 1/12/82	NO. 302A 2321-123



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R101 Dropshaft Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-39





ROCHESTER DROPSHAFTS MODEL STUDIES

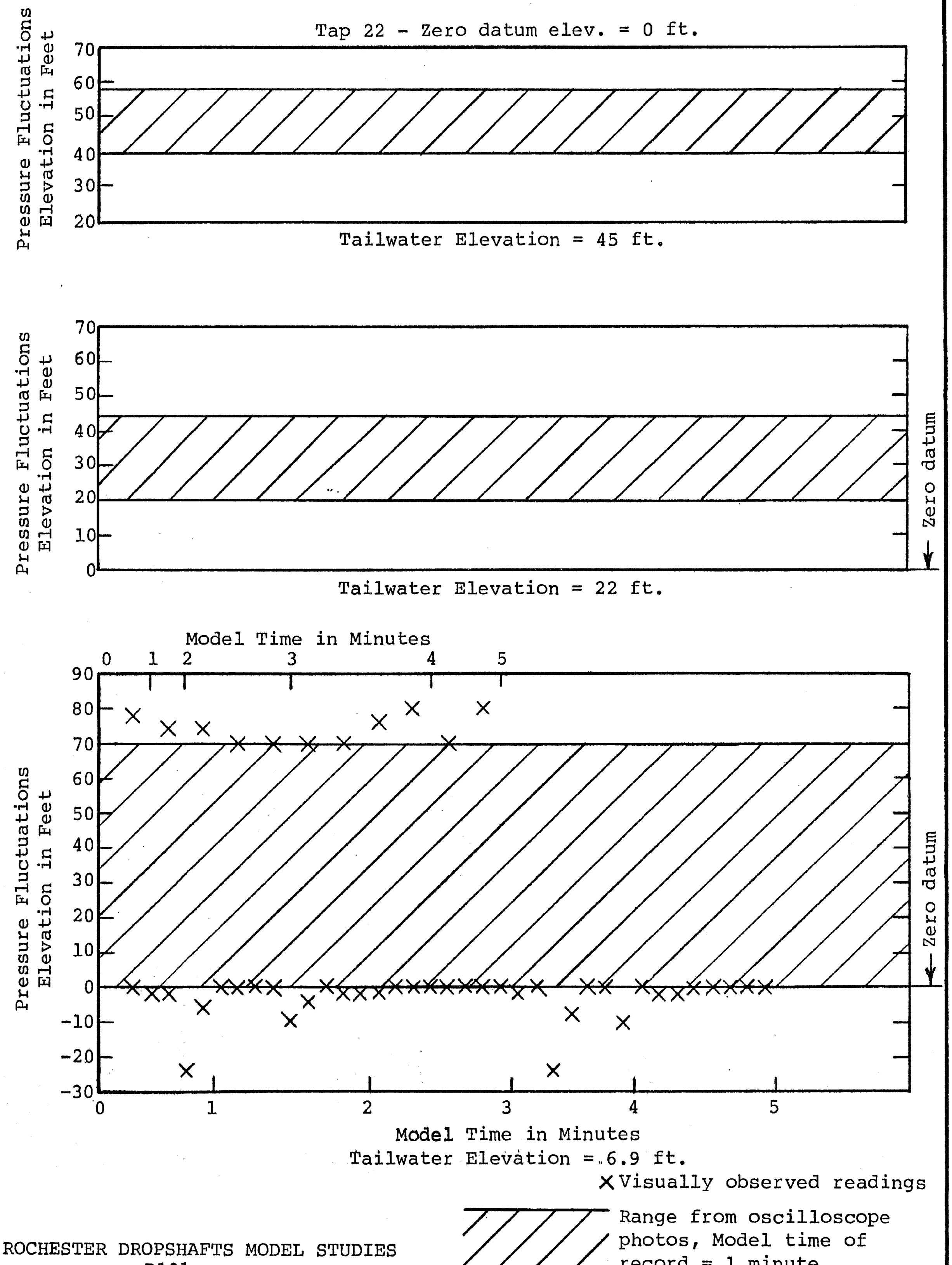
Type L2 R101 Dropshaft Scale 1:8

Typical Pressure Fluctuations

Q = 600 cfs

Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-40



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R101 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 1/12/82	NO. 302A2321-109

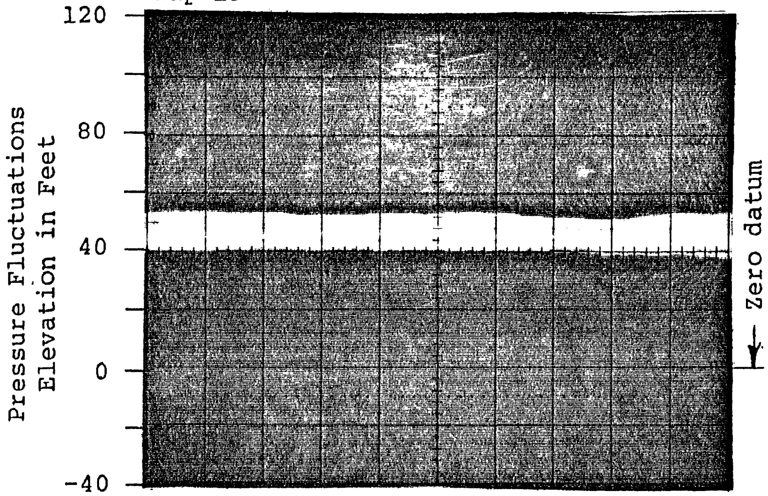
Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Range from Photos Max.-ft	Range from Photos Min.-ft	Observed Readings Max.-ft	Observed Readings Min.-ft
		Type L2 R101 - Tap 21 Elevation = 0 ft				
200	4.1	7.9	40	0	70	-20
200	10	10.7	30	2		
200	22	21.7	32	10		
200	30	29.8	42	20		
200	45	44.9	52	36		
400	5.8	5.4	18	-2		
400	10	9.1	20	2		
400	22	21.9	36	14		
400	30	29.8	42	16		
400	45	44.9	56	32		
600	6.9	7.7	32	-4	44	-20
600	10	10.4	28	2	44	-10
600	22	22.5	32	16		
600	30	30.1	44	26		
600	45	45.4	56	38		
800	7.5	12.5	44	-2	60	-12
800	10	13.5	40	2	58	-20
800	22	24.7	38	18		
800	30	31.0	44	22		
800	45	46.6	58	40		
		Type L2 R101 - Tap 22 Elevation = 0 ft				
200	4.1	4.4	14	-4		
200	10	9.5	18	2		
200	22	21.7	32	12		
200	30	29.8	44	22		
200	45	44.9	54	38		
400	5.8	10.5	60	2	80	-20
400	10	11.5	40	4	70	4
400	22	21.9	34	12		
400	30	29.8	48	20		
400	45	44.9	56	34		
600	6.9	17.8	70	0	80	-24
600	10	18.3	60	4	72	0
600	22	23.2	44	20		
600	30	31.6	48	24		
600	45	46.1	58	40		
800	7.5	24.0	70	8	88	-20
800	10	22.5	68	8	84	-20
800	22	24.9	48	18		
800	30	31.9	48	24		
800	45	46.3	58	34		

ROCHESTER DROPSHAFT MODEL STUDIES
Model Scale 1:8
Summary of Typical
Pressure Fluctuations

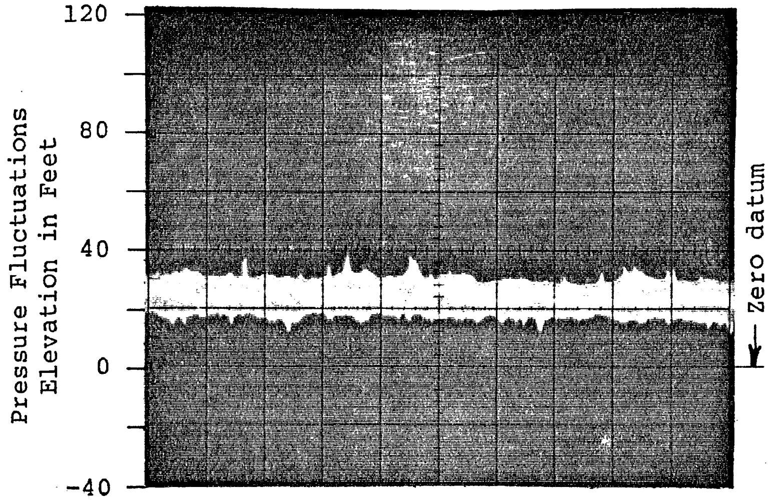
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 9/12/81	NO. 302A2321-235

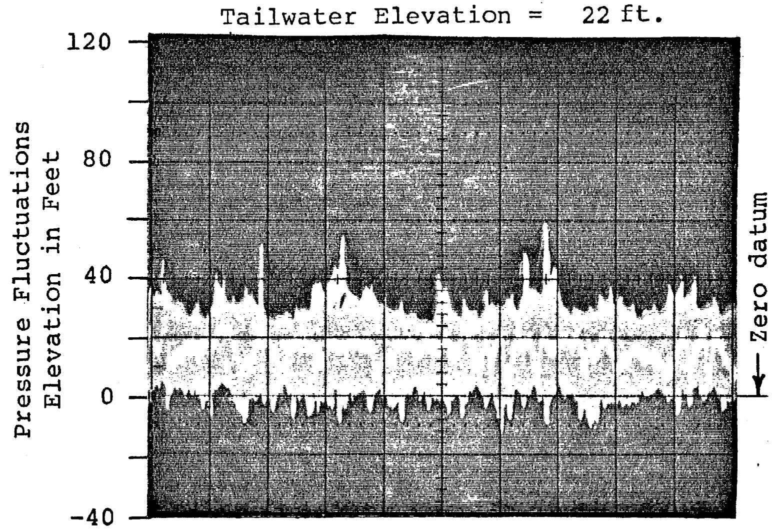
Tap 18 - Zero datum elev.= 0 ft.



Tailwater Elevation = 45 ft.



Tailwater Elevation = 22 ft.



Tailwater Elevation = 6.9 ft.

ROCHESTER DROPSHAFTS MODEL STUDIES

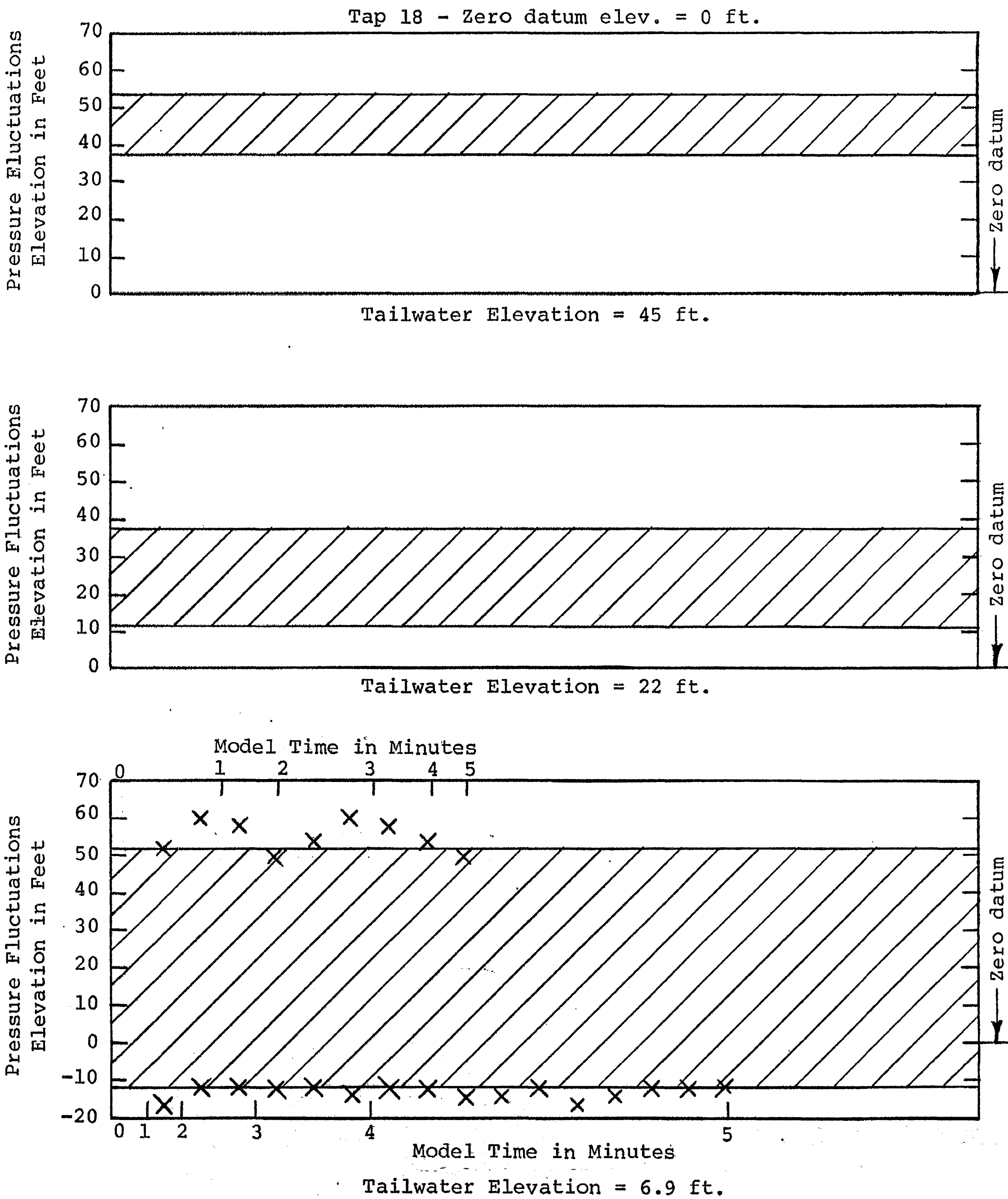
Type L2 R104 Dropshaft Scale 1:8

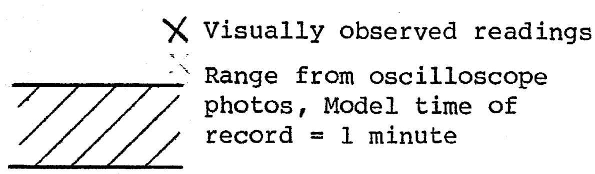
Typical Pressure Fluctuations

Q = 600 cfs

Model time of record = 1 minute

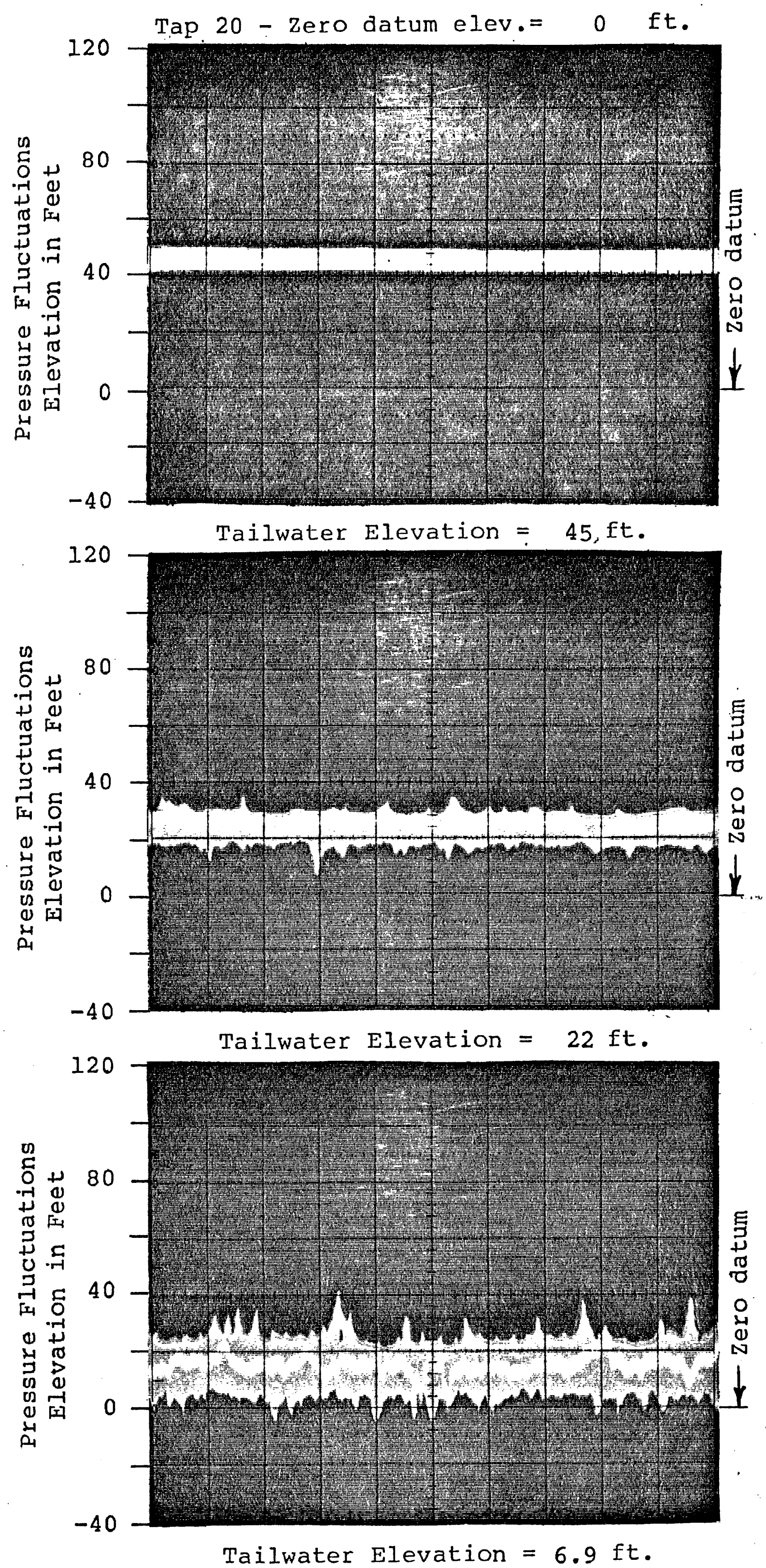
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-70





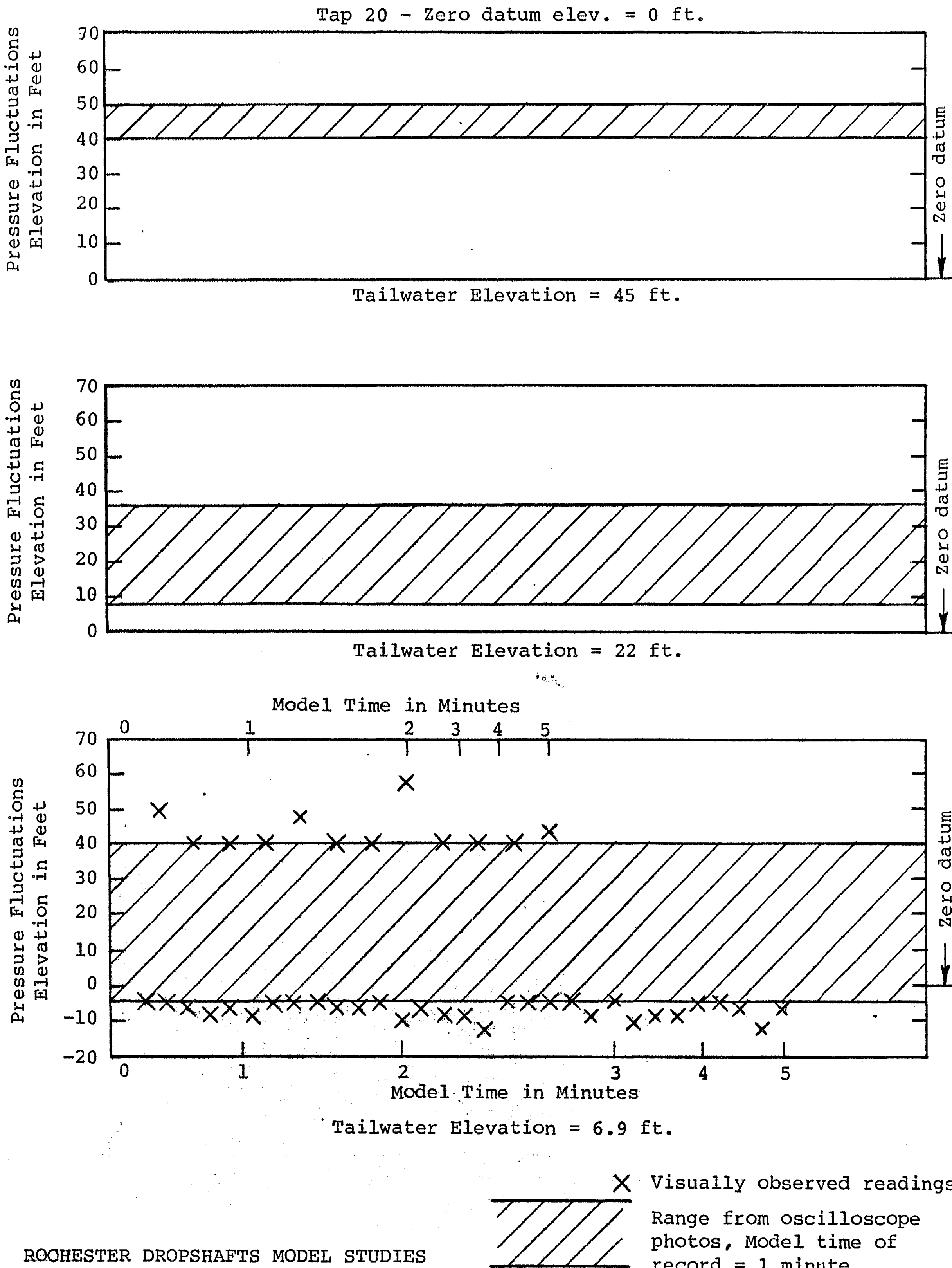
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [handwritten initials]	APPROVED
SCALE	DATE 12/15/81	NO. 302A2321-88



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Dropshaft Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

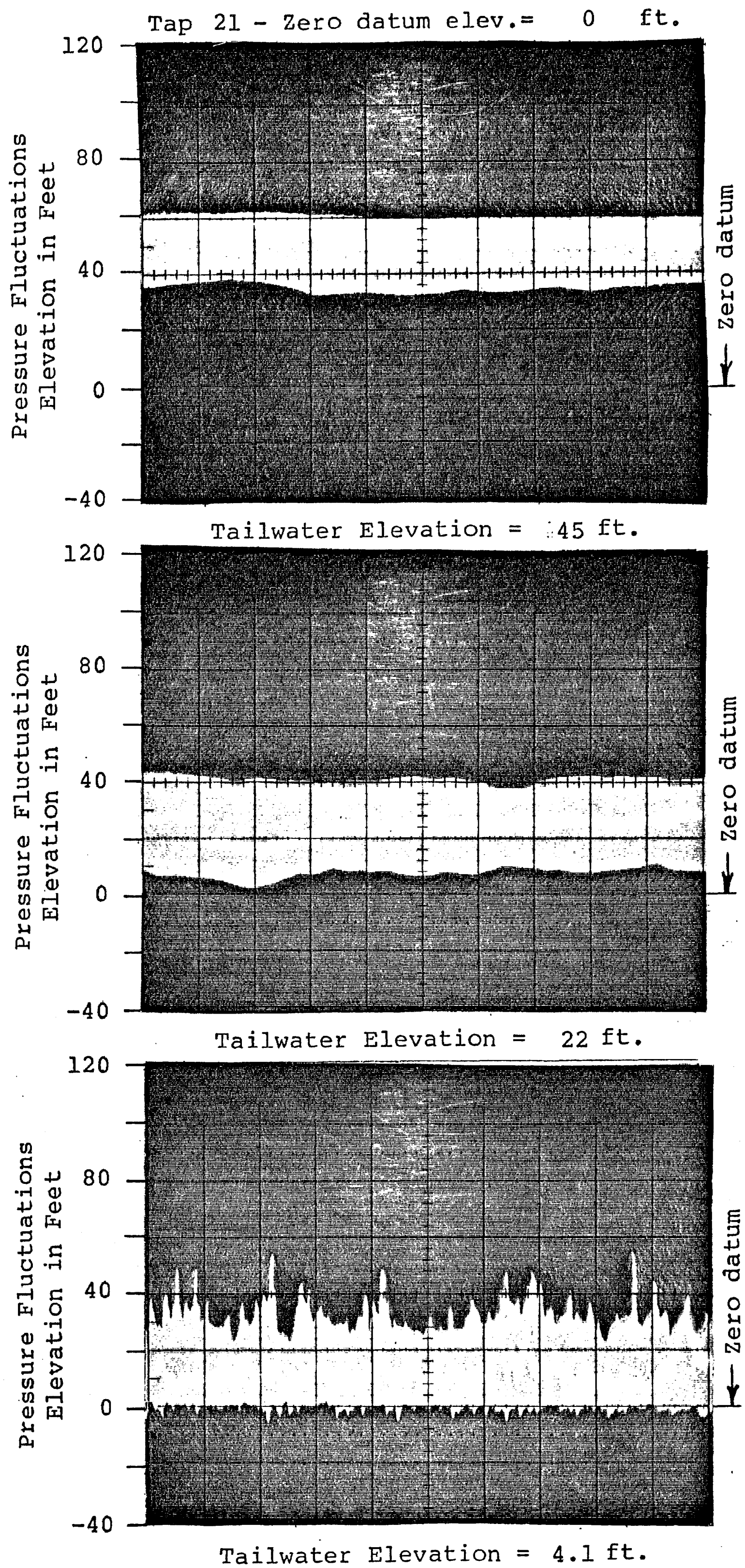
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-71



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

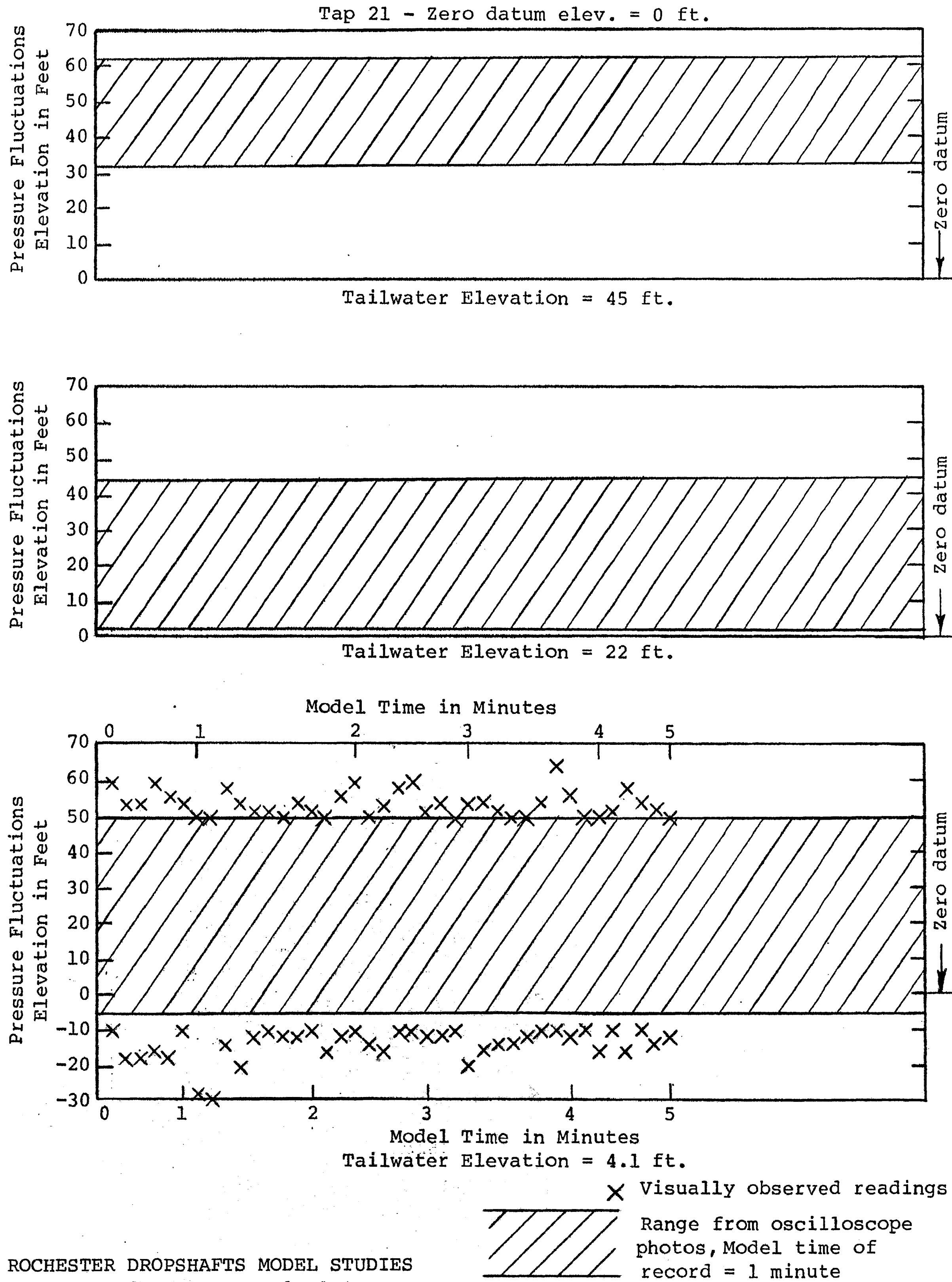
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/15/81	NO. 302A2321-89



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Dropshaft Scale 1:8
Typical Pressure Fluctuations
Q = 200 cfs
Model time of record = 1 minute

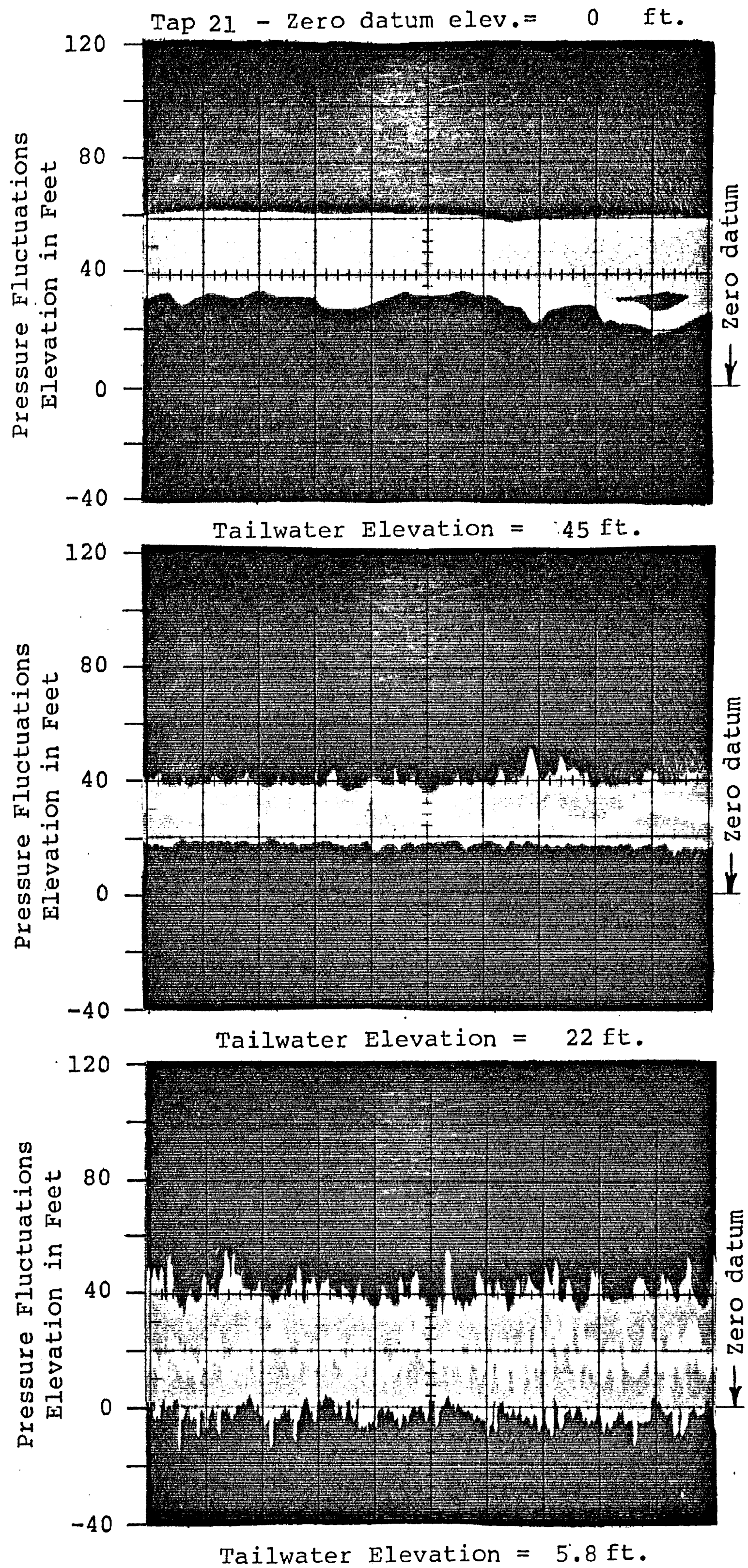
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-66



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 200 cfs

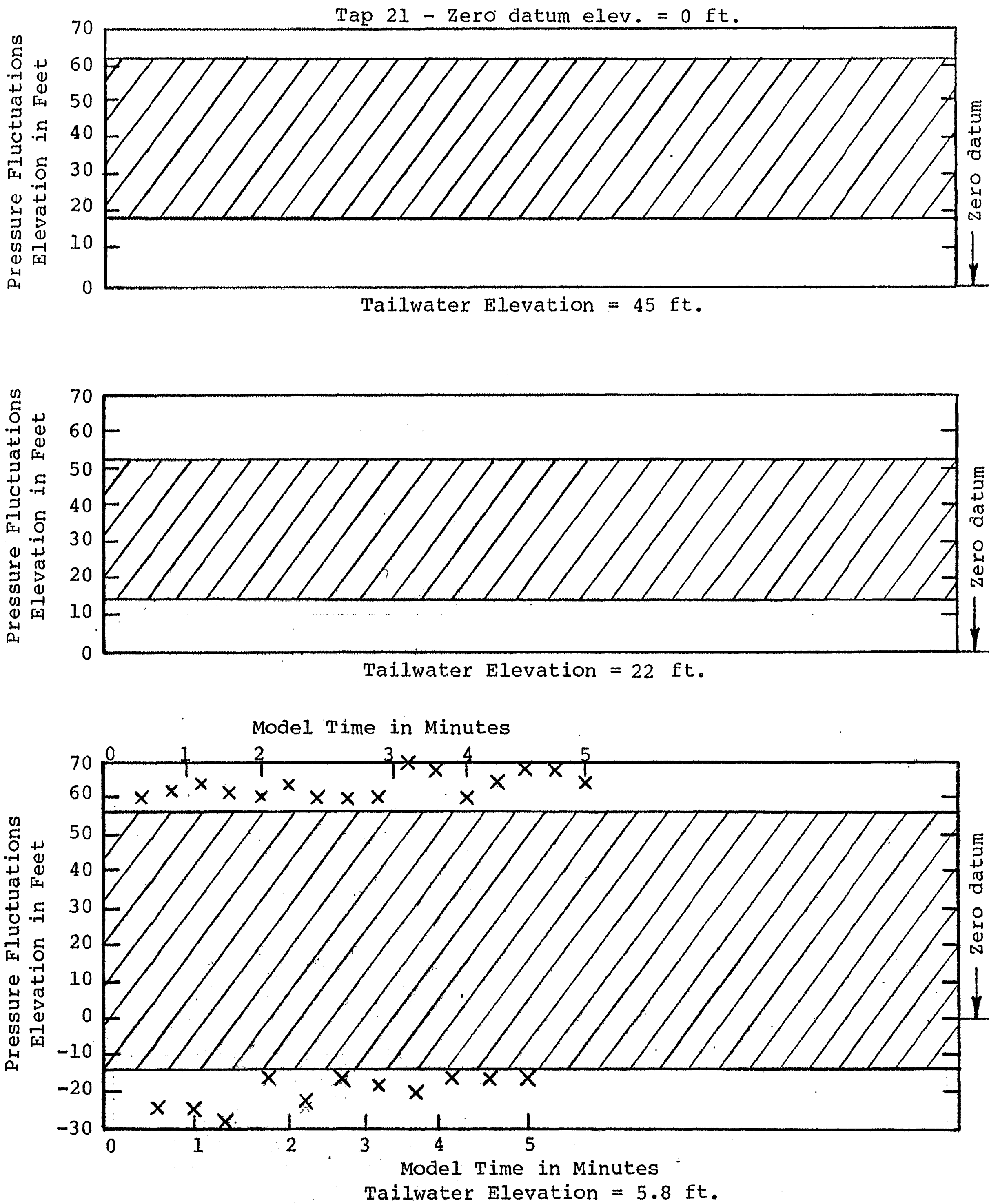
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 12/15/81	NO. 302A2321-92



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Dropshaft Scale 1:8
Typical Pressure Fluctuations
Q = 400 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-67

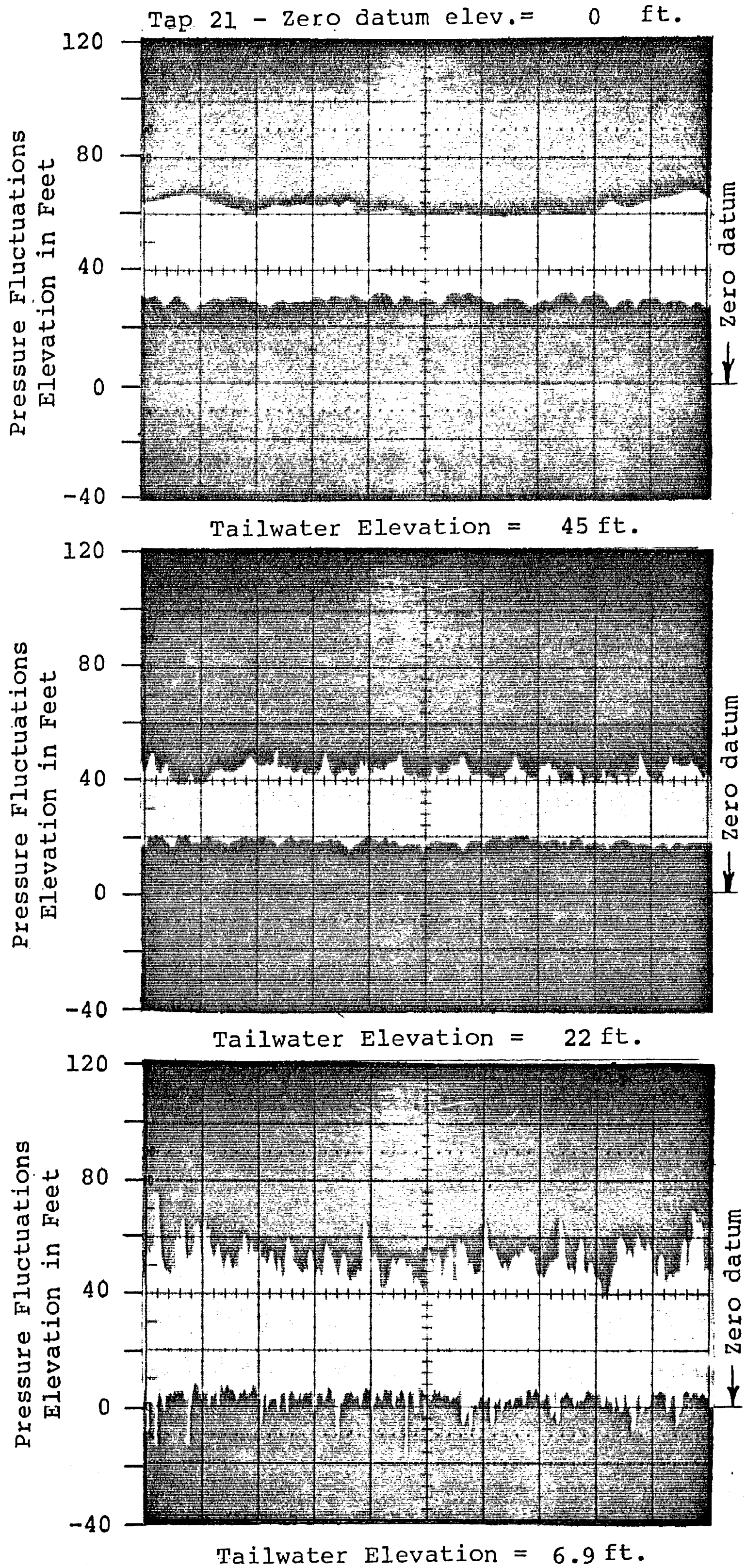


X Visually observed readings

Range from oscilloscope photos, Model time of record = 1 minute

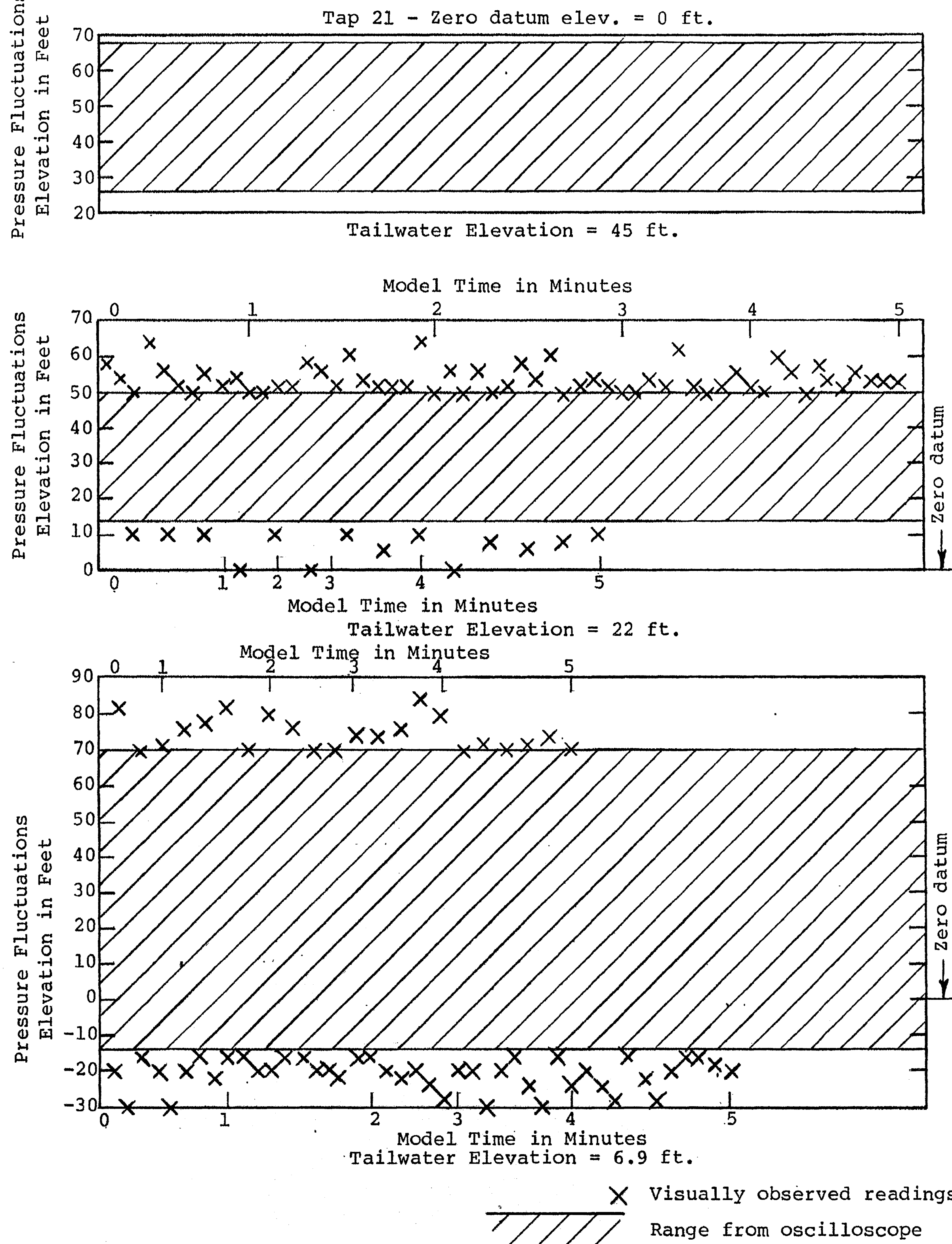
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 400 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 12/15/81	NO. 302A2321-93



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Dropshaft Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs
Model time of record = 1 minute

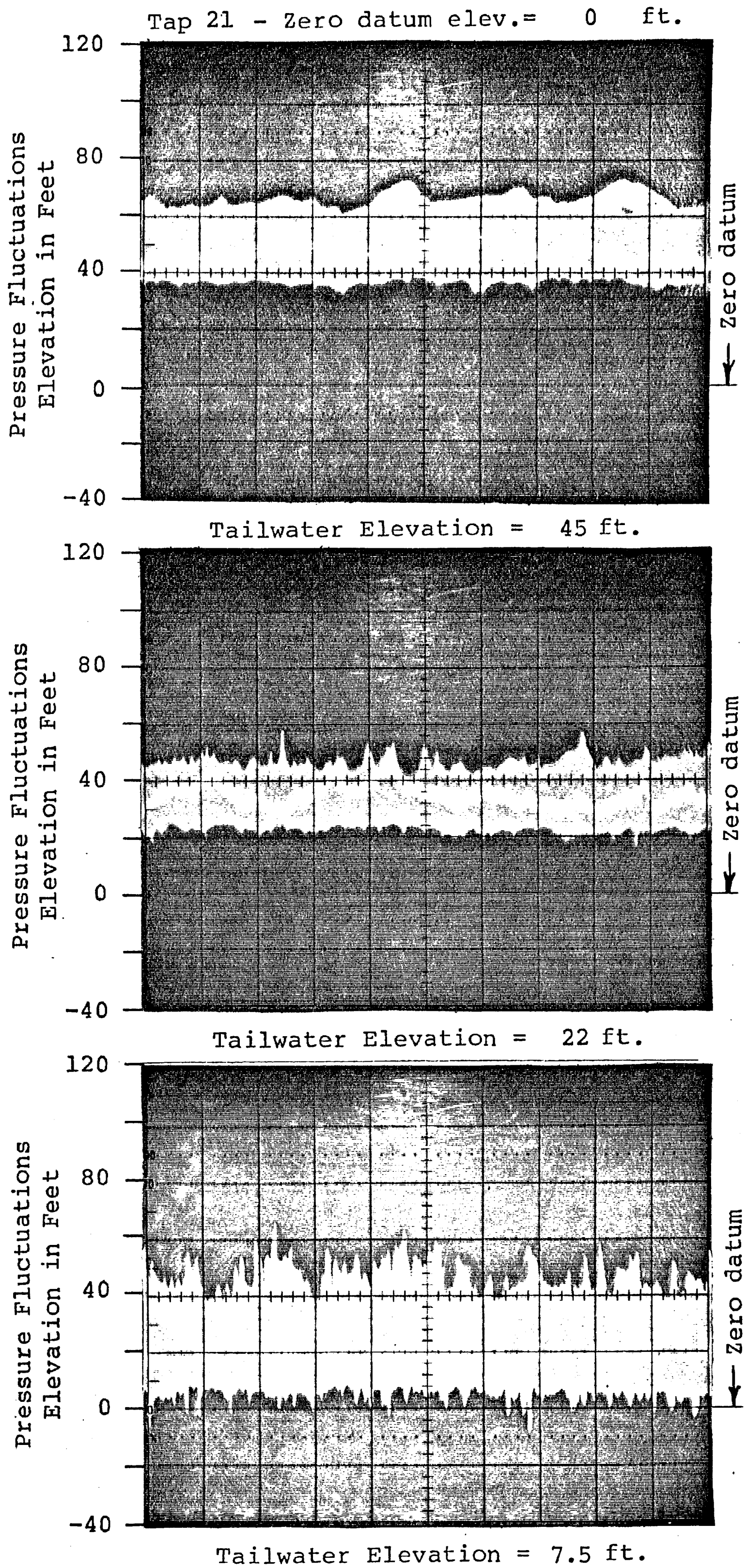
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-68



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

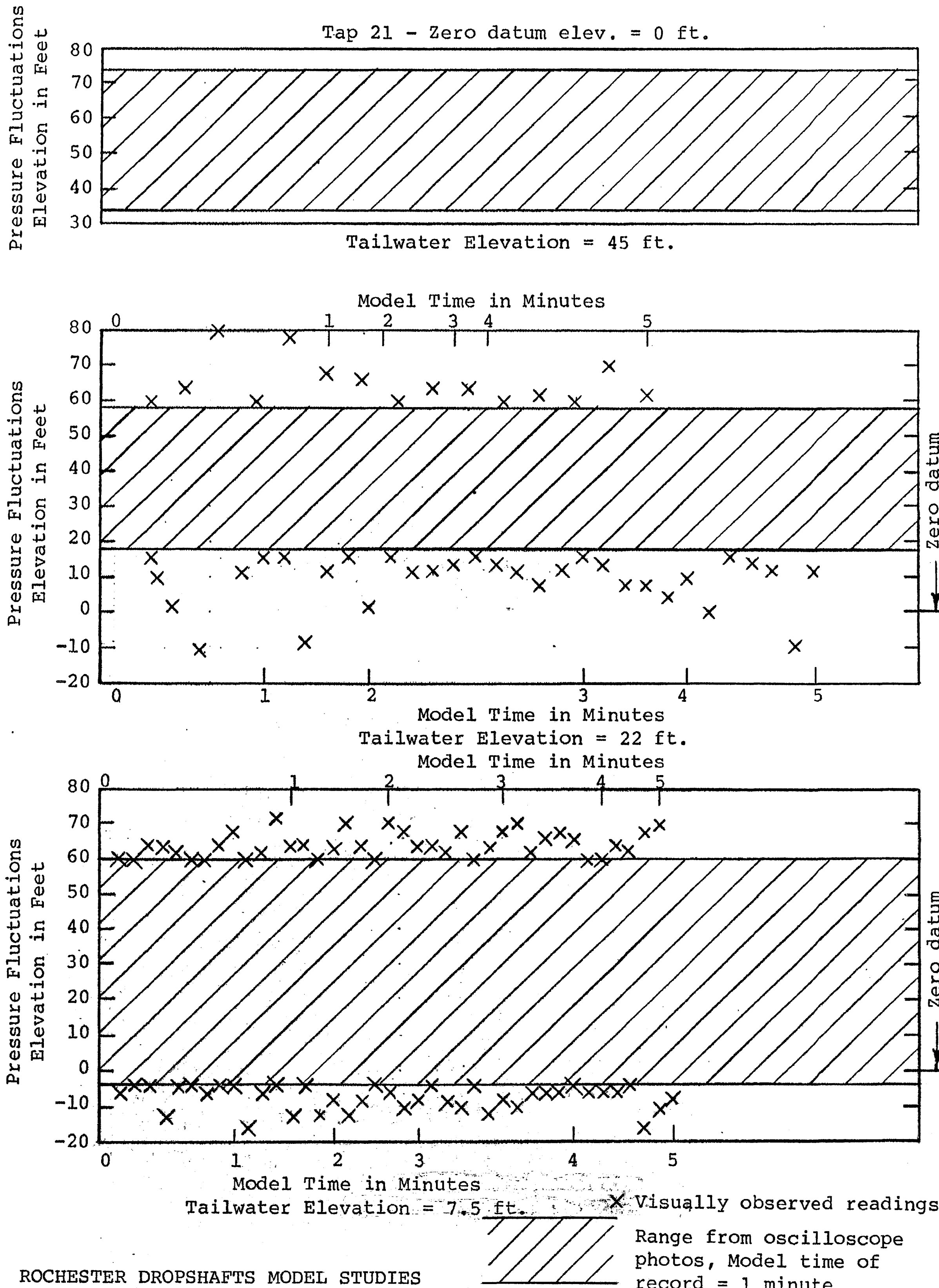
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN BB	CHECKED	APPROVED
SCALE	DATE 12/15/81	NO. 302A2321-94



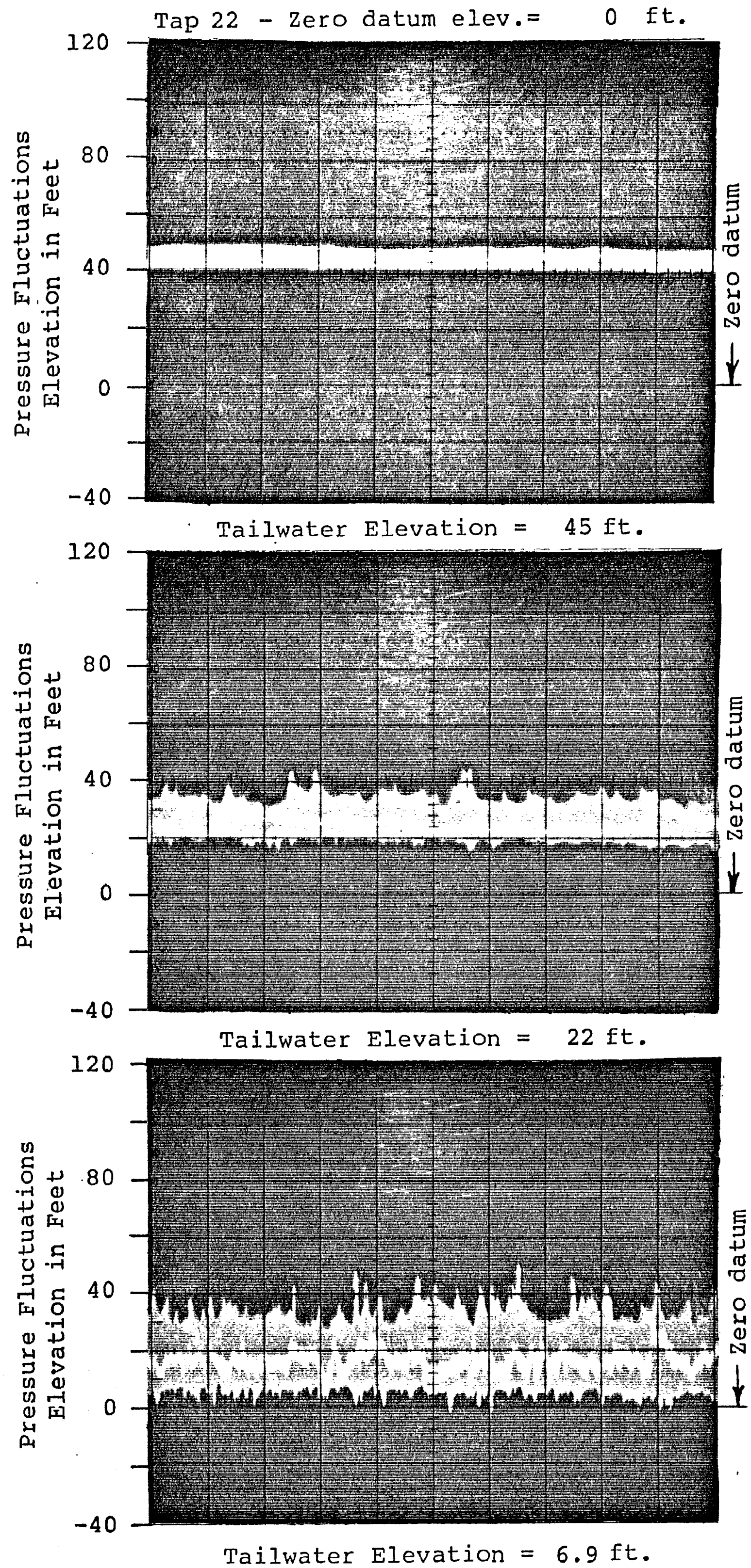
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Dropshaft Scale 1:8
Typical Pressure Fluctuations
Q = 800 cfs
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-69



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 800 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 12/15/81	NO. 302A2321-95



ROCHESTER DROPSHAFTS MODEL STUDIES

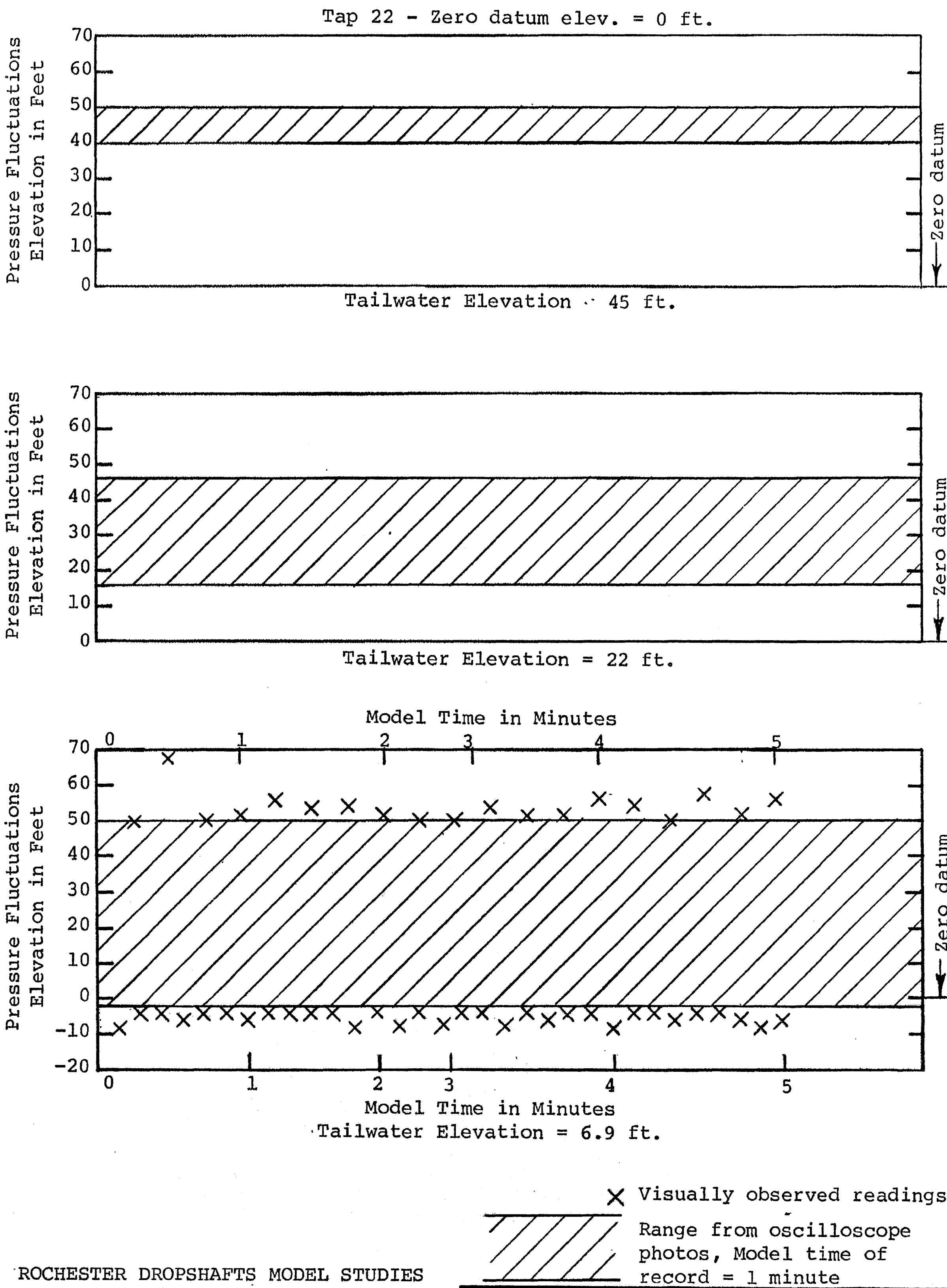
Type L2 R104 Dropshaft Scale 1:8

Typical Pressure Fluctuations

Q = 600 cfs

Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 10/26/81	NO. 302A2321-72



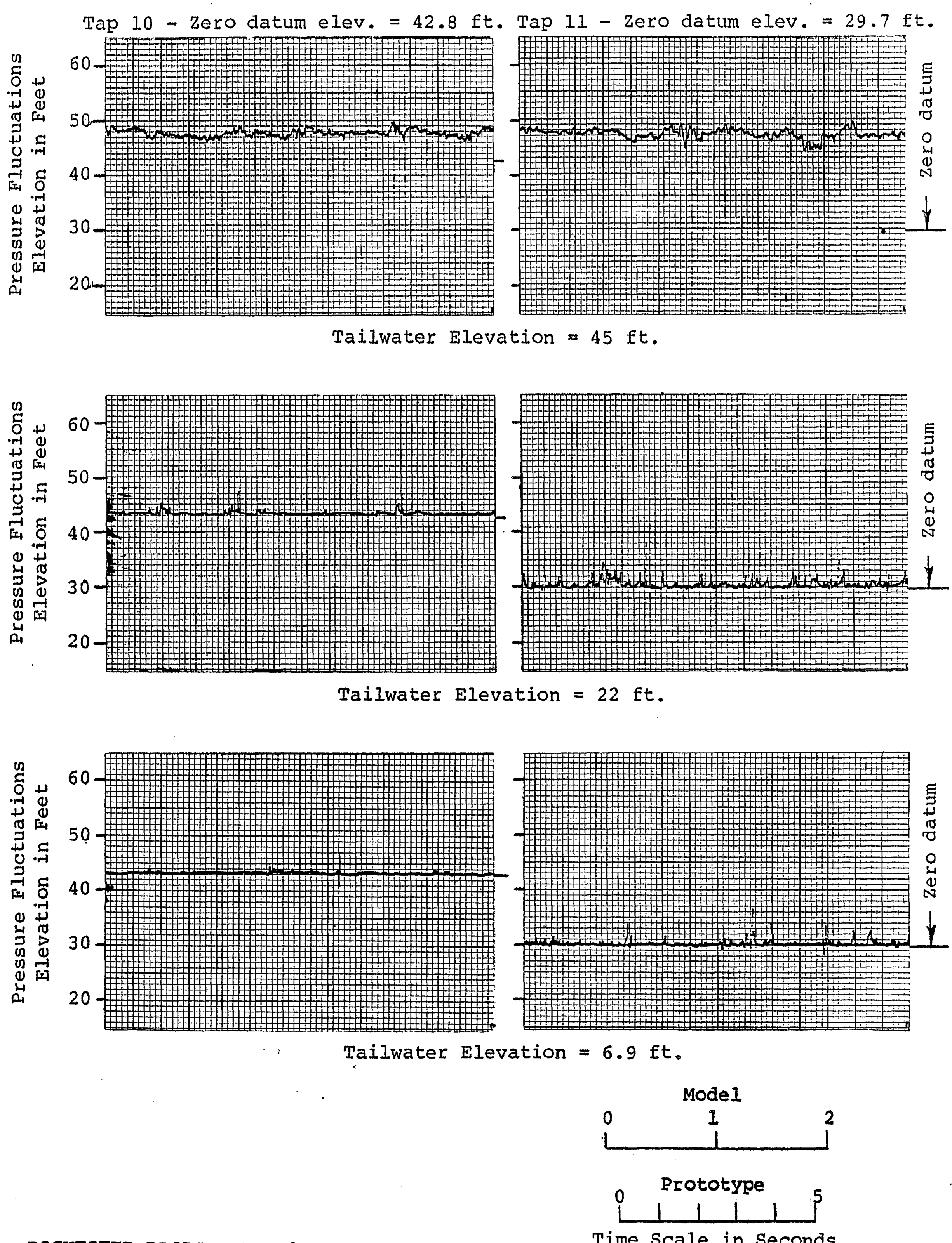
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN BB	CHECKED [signature]	APPROVED
SCALE	DATE 12/15/81	NO. 302A2321-90

Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Range from Photos Max.-ft	Range from Photos Min.-ft	Observed Readings Max.-ft	Observed Readings Min.-ft
		Type L2 R104 - Tap 18 Elevation = 0 ft				
600	6.9	13.8	52	-12	60	-16
600	22	22.9	38	12		
600	45	45.4	54	38		
		Type L2 R104 - Tap 20 Elevation = 0 ft				
600	6.9	12.0	40	-4	58	-12
600	22	22.3	36	8		
600	45	45.5	50	40		
		Type L2 R104 - Tap 21 Elevation = 0 ft				
200	4.1	10.1	50	-6	64	-30
200	22	21.9	44	2		
200	45	44.9	62	32		
400	5.8	15.7	56	-14	70	-24
400	22	23.2	52	14		
400	45	44.9	62	18		
600	6.9	19.5	70	-14	84	-30
600	22	25.4	50	14	64	0
600	45	45.3	68	26		
800	7.5	20.2	60	-4	72	-16
800	22	29.7	58	18	80	-10
800	45	46.4	74	34		
		Type L2 R104 - Tap 22 Elevation = 0 ft				
600	6.9	14.9	50	-2	68	-8
600	22	22.9	46	16		
600	45	45.1	50	40		

ROCHESTER DROPSHAFT MODEL STUDIES
Model Scale 1:8
Summary of Typical
Pressure Fluctuations

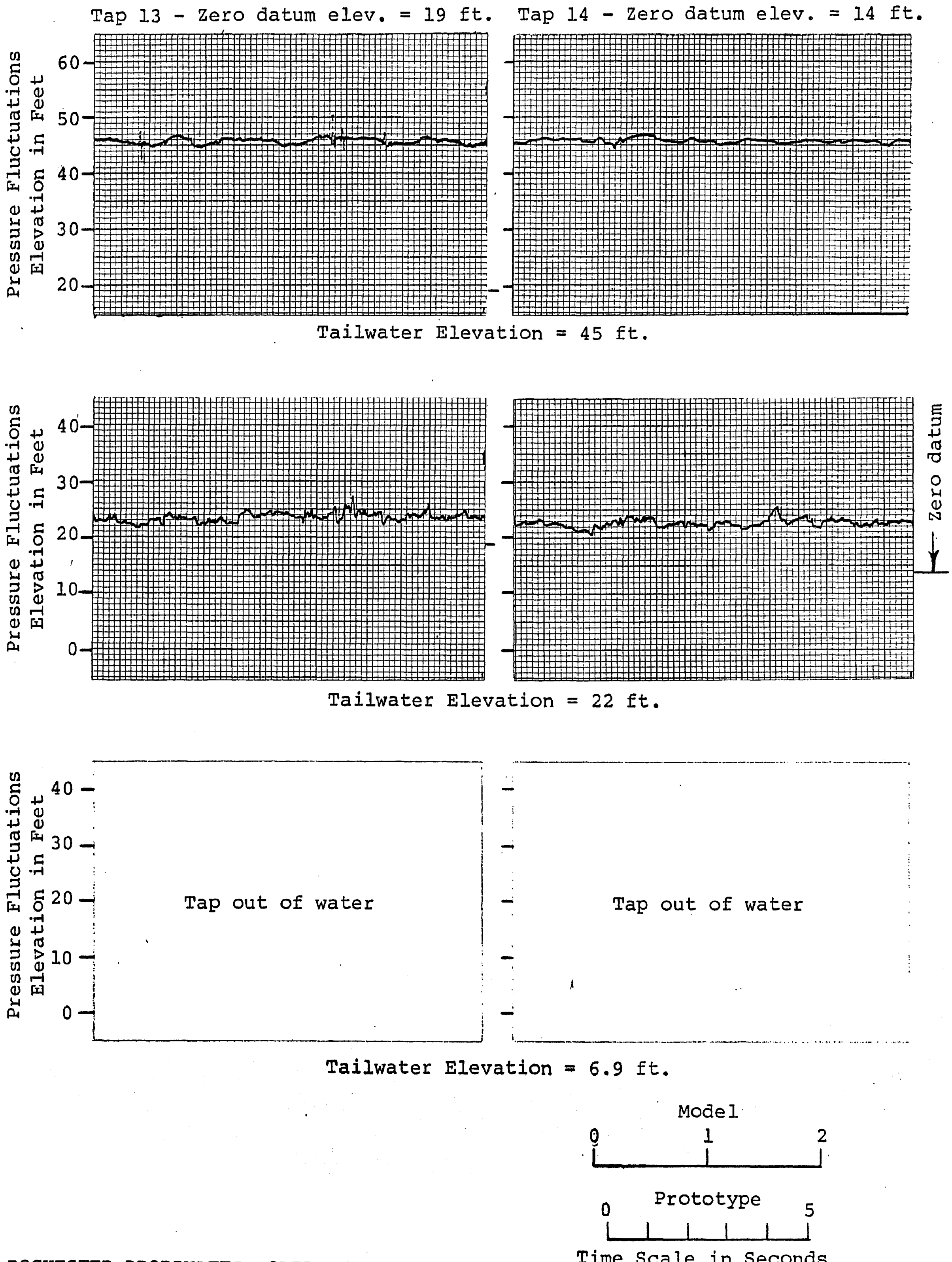
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED BB	APPROVED
SCALE	DATE 11/16/81	NO. 302A2321-236



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 12/4/81	NO. 302A2321-59

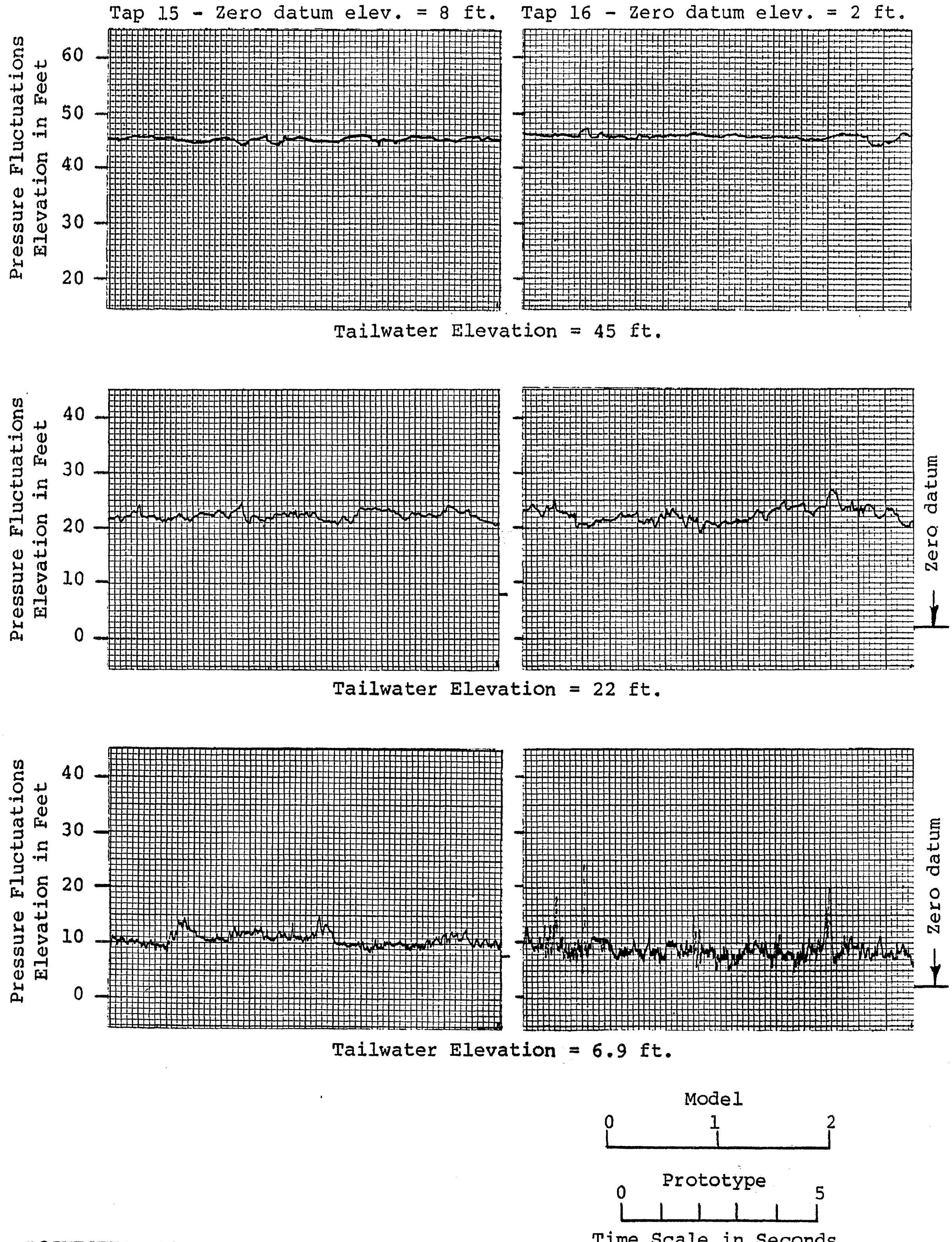


ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104   Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 12/4/81	NO. 302A2321-60

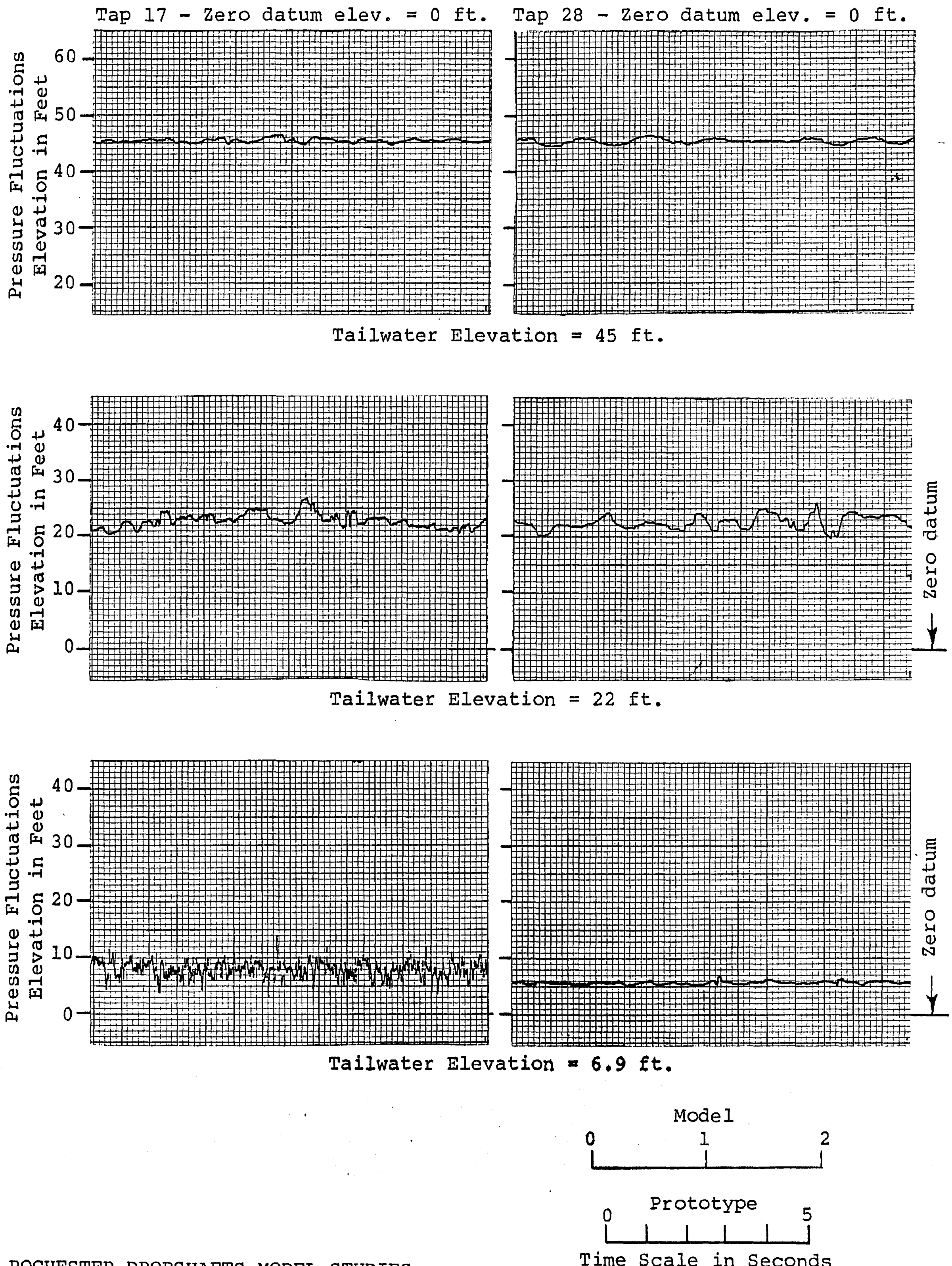
CHART 146



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

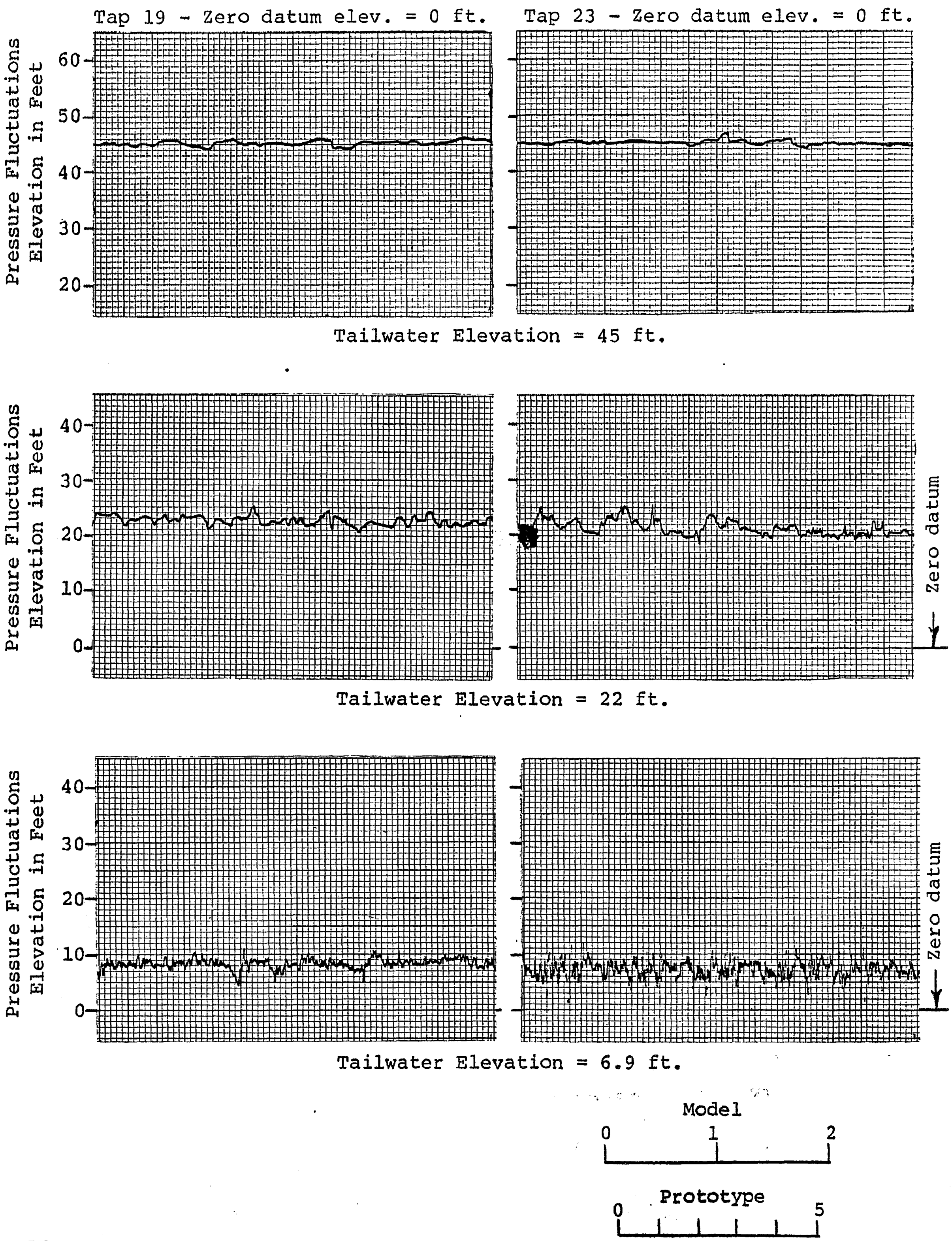
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 12/4/81	NO. 302A2321-61



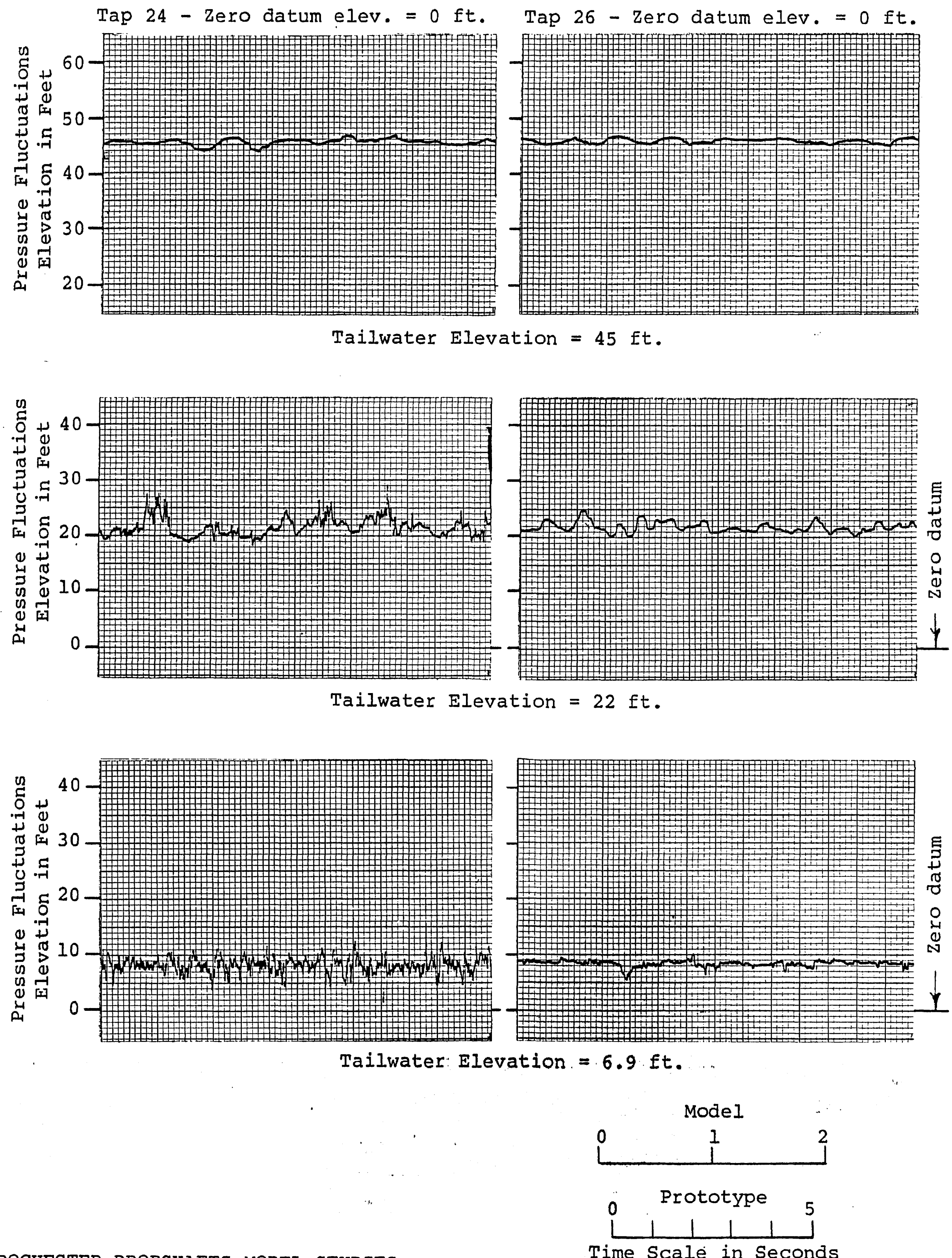
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 12/4/81	NO. 302A 2321-62



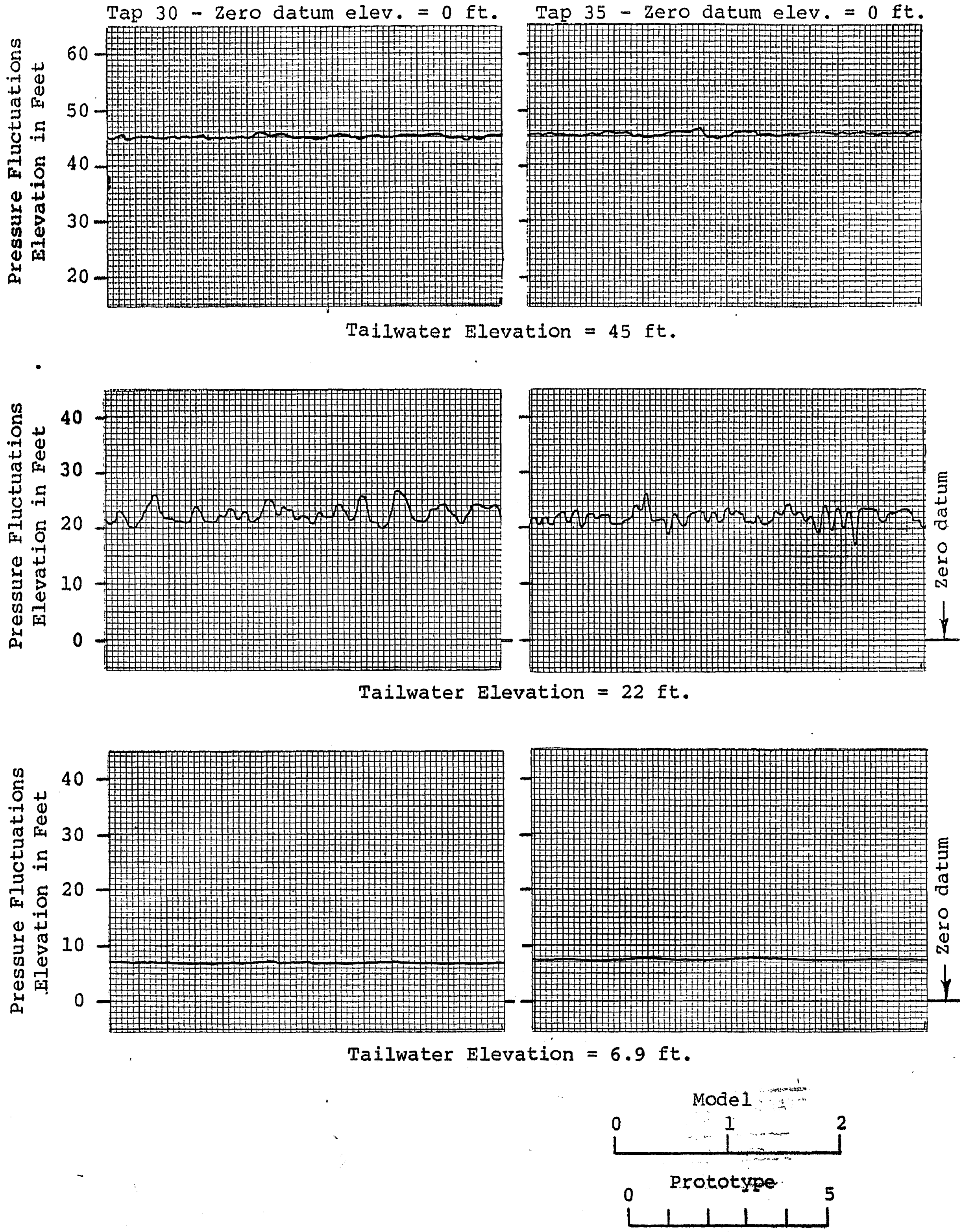
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 12/4/81	NO. 302A2321-63



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 12/4/81	NO. 302A2321-64



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Typical Pressure Fluctuations
Q = 600 cfs

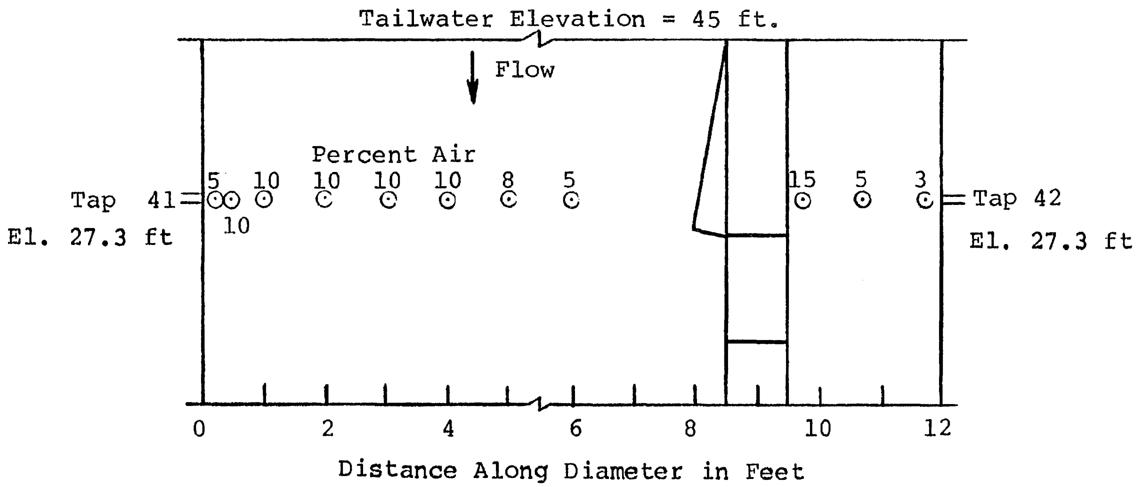
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 12/4/81	NO. 302A2321-65

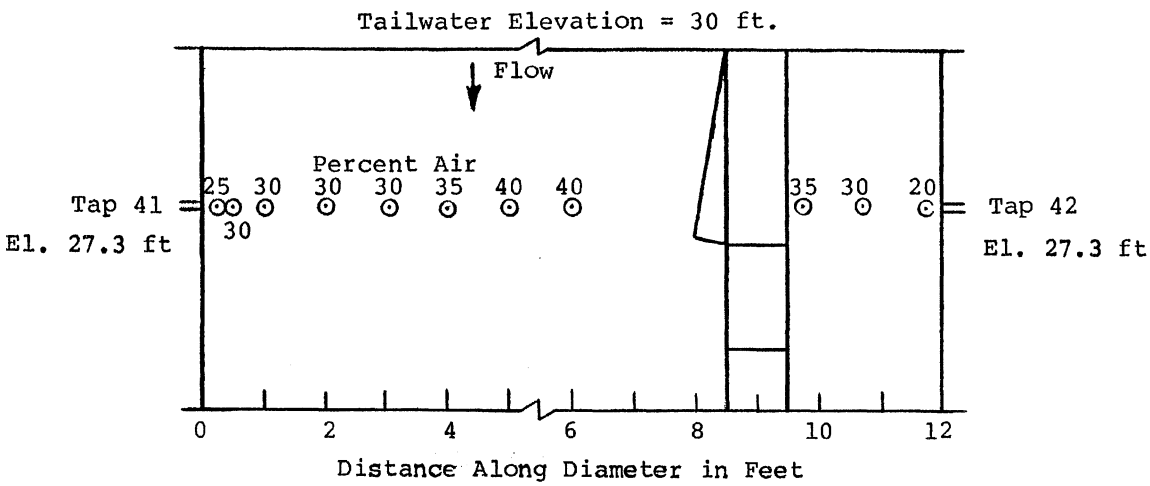
Tap No.	Tap El. ft	Q cfs	T.W. El. ft	Av. Piez. Press.-ft	Pressure Fluctuations Max.-ft	Min.-ft
10	42.8	600	6.9	43.4	47.0	41.0
10	42.8	600	22	43.4	47.2	42.0
10	42.8	600	45	47.2	49.9	43.9
11	29.7	600	6.9	30.3	37.8	27.2
11	29.7	600	22	30.3	37.9	28.4
11	29.7	600	45	46.9	49.6	42.5
13	19	600	22	23.7	27.3	21.8
13	19	600	45	45.9	50.3	41.0
14	14	600	22	22.7	25.5	20.5
14	14	600	45	45.6	47.0	44.2
15	8	600	6.9	10.3	15.0	8.0
15	8	600	22	22.1	26.0	19.8
15	8	600	45	45.5	46.2	43.2
16	2	600	6.9	8.7	24.2	1.8
16	2	600	22	21.5	27.0	18.4
16	2	600	45	45.5	47.0	44.0
17	0	600	6.9	8.1	15.0	1.1
17	0	600	22	21.3	26.8	17.0
17	0	600	45	45.5	46.5	43.9
19	0	600	6.9	8.1	11.0	4.5
19	0	600	22	22.1	25.3	19.8
19	9	600	45	45.3	46.2	44.0
23	0	600	6.9	7.2	14.9	-0.9
23	0	600	22	21.5	25.7	16.8
23	0	600	45	45.3	46.0	43.8
24	0	600	6.9	8.0	15.6	0.4
24	0	600	22	21.4	29.1	14.8
24	0	600	45	45.3	47.1	43.6
26	0	600	6.9	8.6	11.0	5.4
26	0	600	22	21.5	25.0	19.8
26	0	600	45	45.3	46.7	44.1
28	0	600	6.9	5.5	6.9	3.6
28	0	600	22	21.6	26.1	18.9
28	0	600	45	45.0	46.9	43.3
30	0	600	6.9	6.9	7.2	6.5
30	0	600	22	21.9	27.0	19.4
30	0	600	45	45.1	46.1	43.6
35	0	600	6.9	6.9	7.8	6.5
35	0	600	22	21.9	26.3	17.0
35	0	600	45	44.9	46.6	43.9

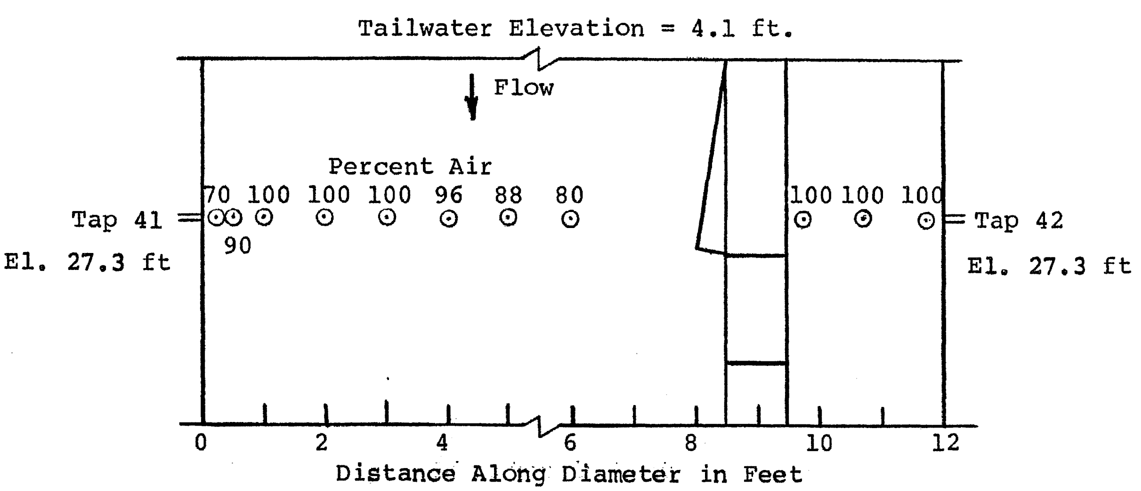
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2. R104 Scale 1:8
Summary of Typical
Pressure Fluctuations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED	APPROVED BB
SCALE	DATE 12/4/81	NO 302A2321-237



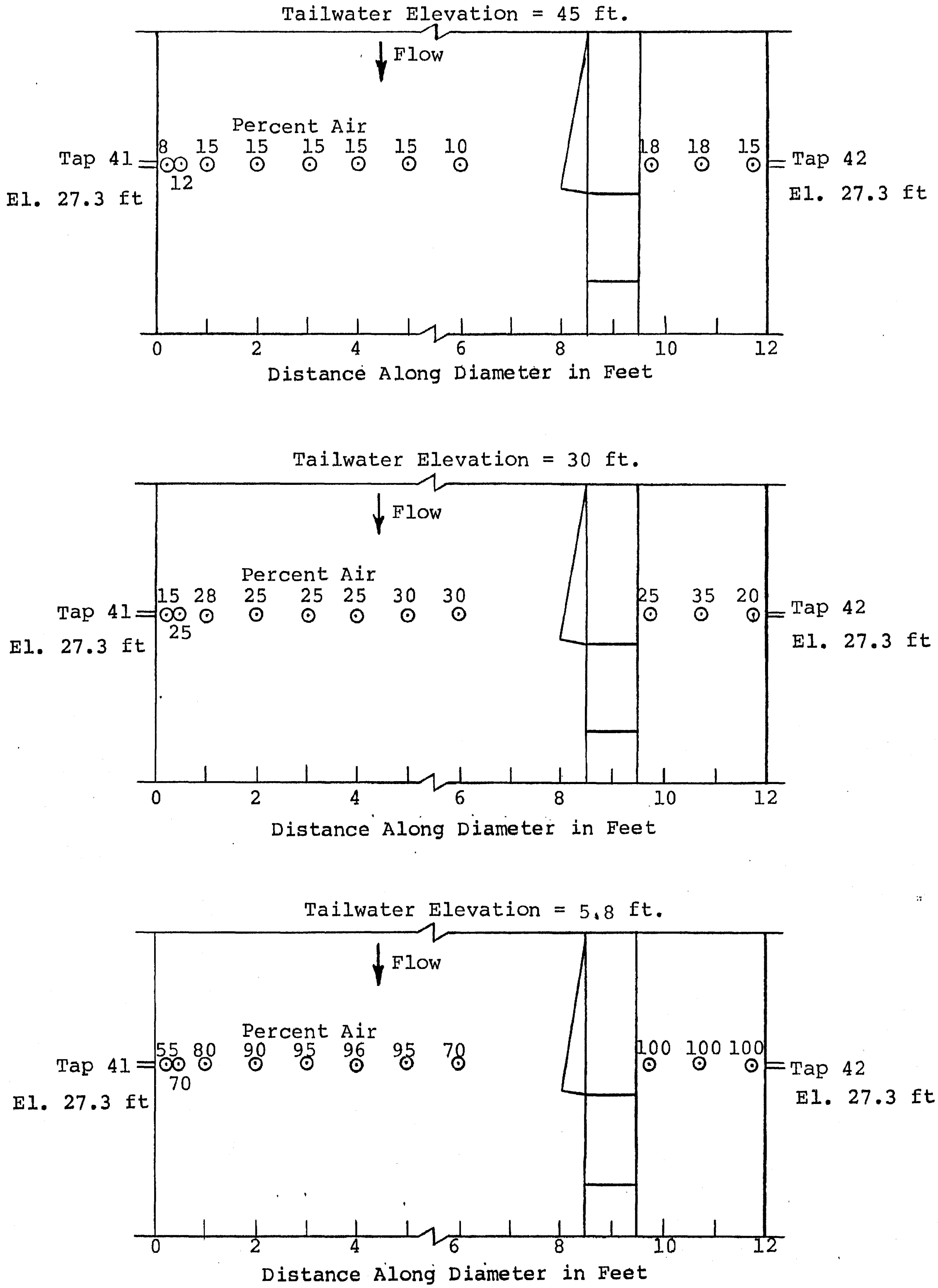




ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Dropshaft Scale 1:8
Air Concentrations in Dropshaft
Q = 200 cfs

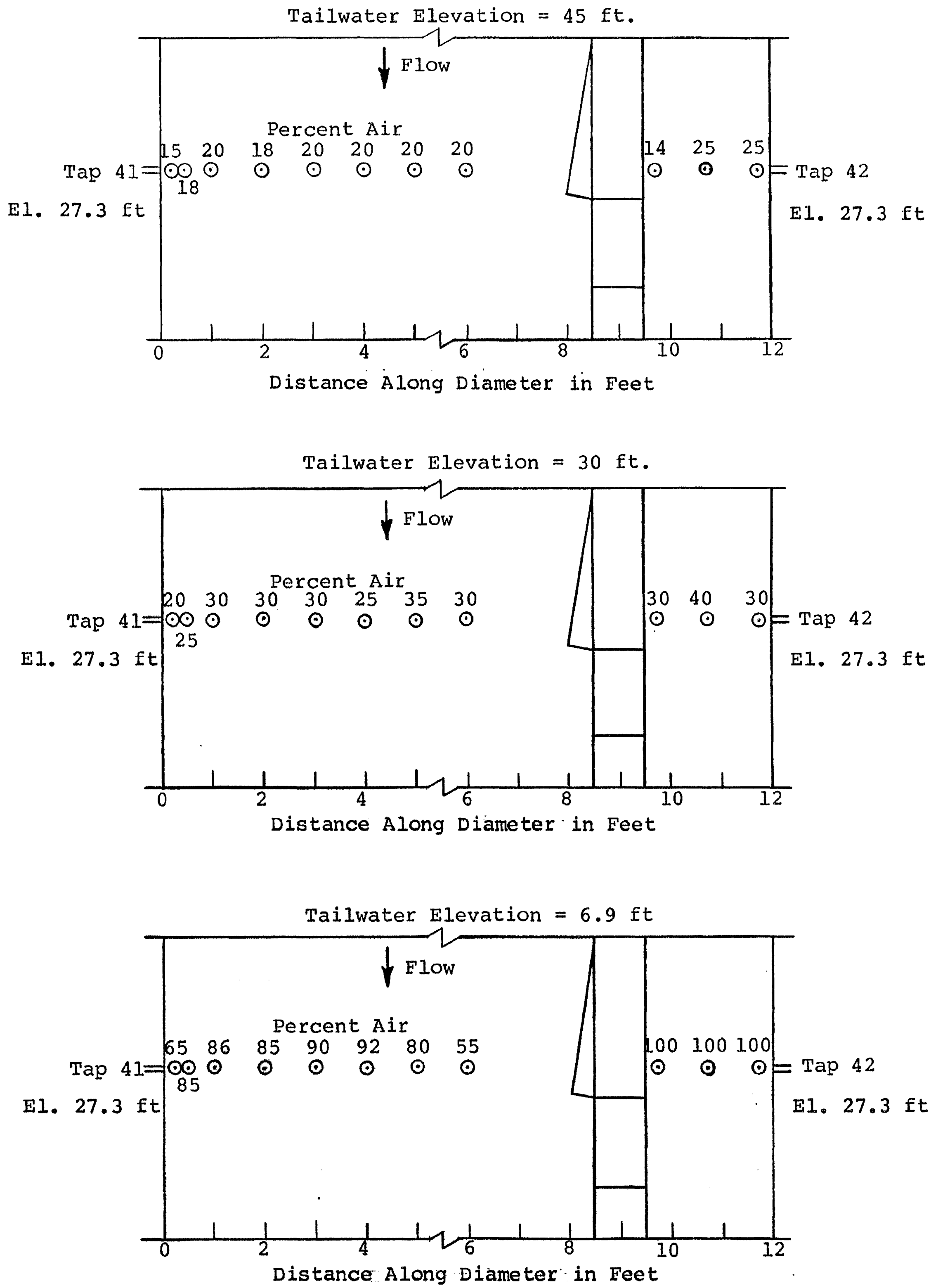
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN B.B.	CHECKED [illegible]	APPROVED
SCALE	DATE 12/21/81	NO. 302A2321-96



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Dropshaft Scale 1:8
Air Concentrations in Dropshaft
Q = 400 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY, UNIVERSITY OF MINNESOTA		
DRAWN B.B.	CHECKED [illegible]	APPROVED
SCALE	DATE 12/21/81	NO. 302A2321-97



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Dropshaft Scale 1:8
Air Concentrations in Dropshaft
Q = 600 cfs

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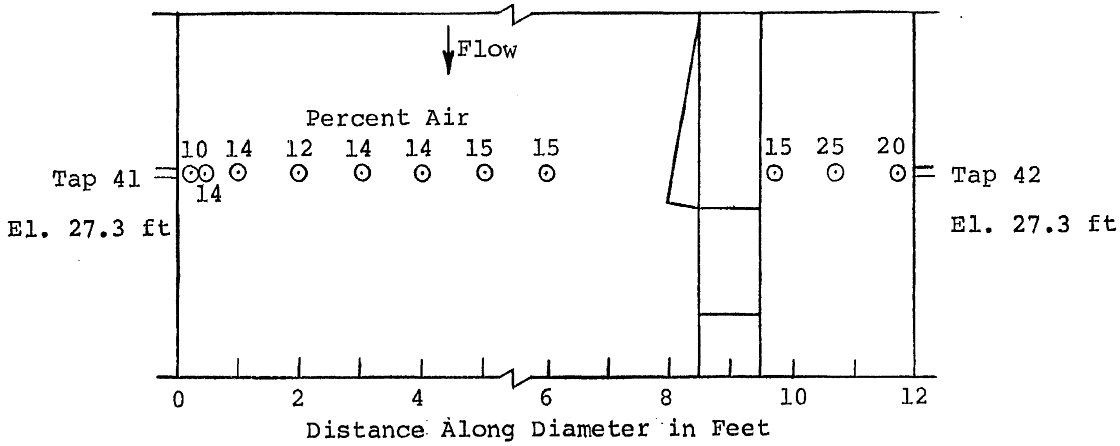
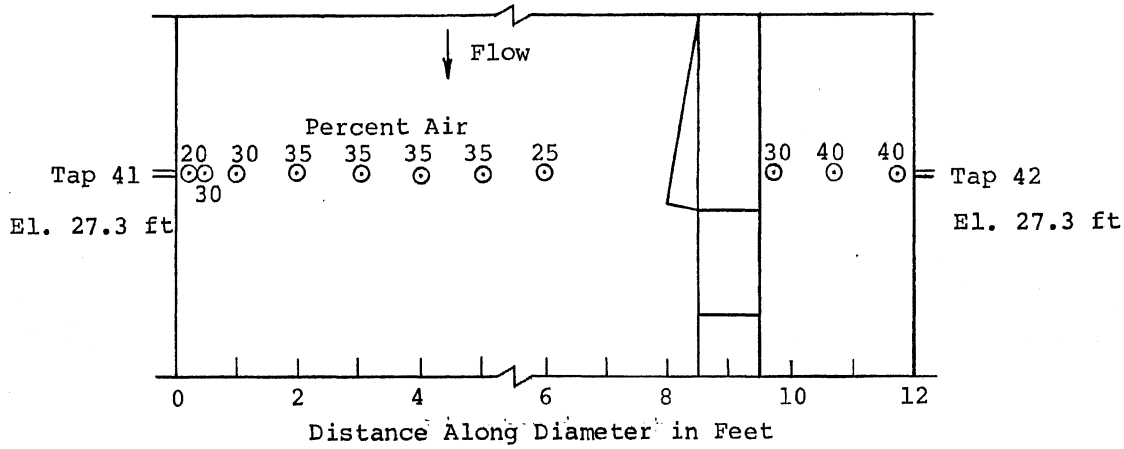
UNIVERSITY OF MINNESOTA

DRAWN B.B.	CHECKED [signature]	APPROVED
SCALE	DATE 12/21/81	NO. 302A2321-98

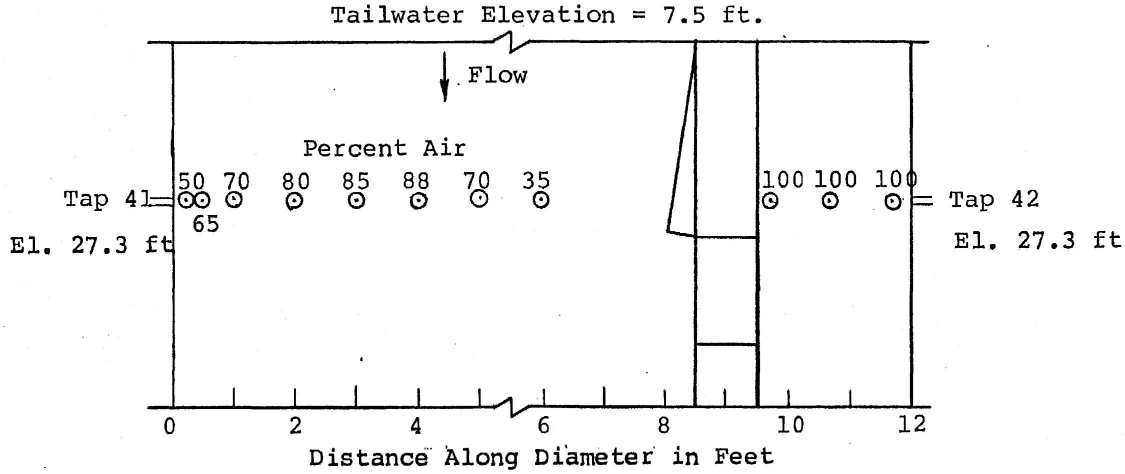
Tailwater Elevation = 45 ft.



Tailwater Elevation = 30 ft.

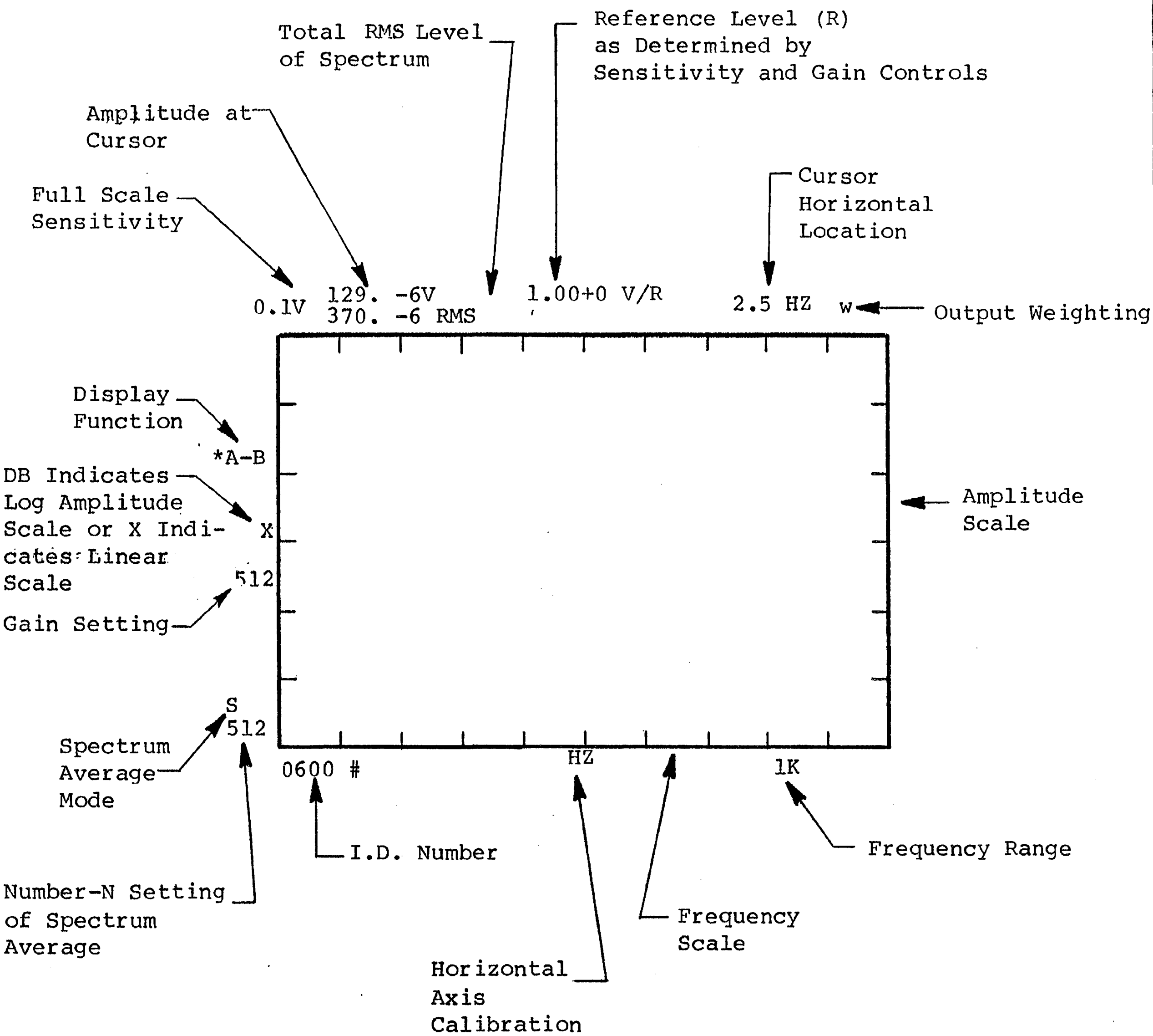


Tailwater Elevation = 7.5 ft.



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Dropshaft Scale 1:8
Air Concentrations in Dropshaft
Q = 800 cfs

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN B.B.	CHECKED [signature]	APPROVED
SCALE	DATE 12/21/81	NO. 302A2321-99



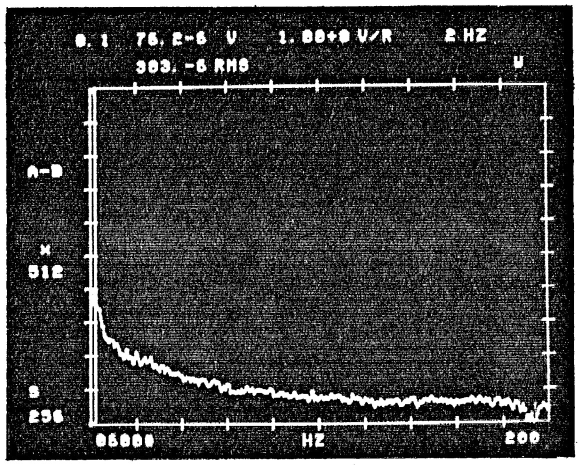
*A-B Indicates Signal (A) Minus the Noise (B) on True Spectrum.

ROCHESTER DROPSHAFTS MODEL STUDIES
Single Spectrum Display

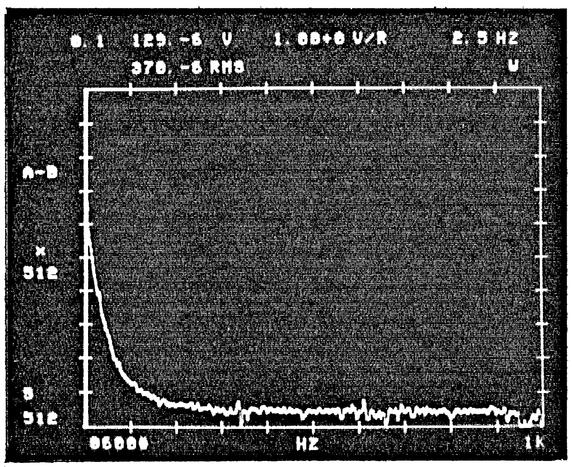
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN B.B.	CHECKED	APPROVED
SCALE	DATE 10/21/81	NO. 302A2321-238

Tap 39 - Elev. = 40.5 ft.



Q = 600 cfs, T. W. Elev. = 6.9 ft.

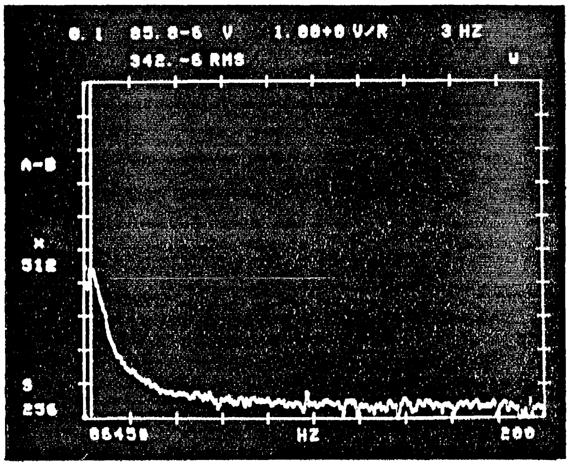


Q = 600 cfs, T. W. Elev. = 6.9 ft.

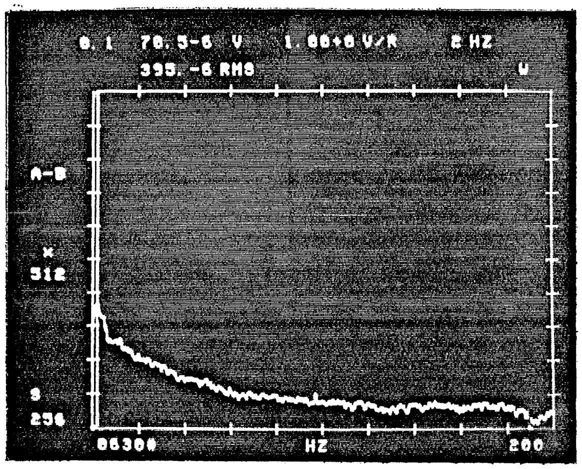
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-212

Tap 39 - Elev. = 40.5 ft.



Q = 600 cfs, T. W. Elev. = 45 ft.

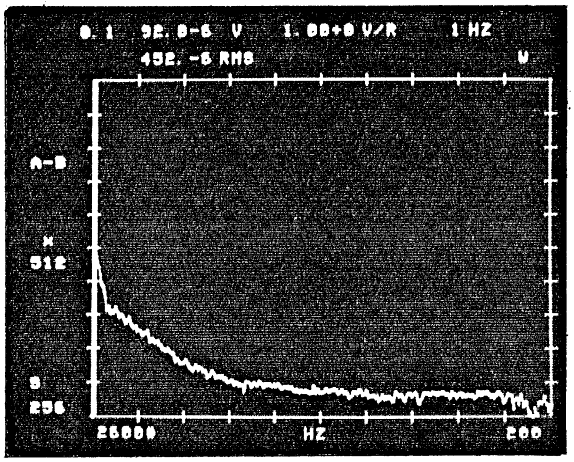


Q = 600 cfs, T. W. Elev. = 30 ft.

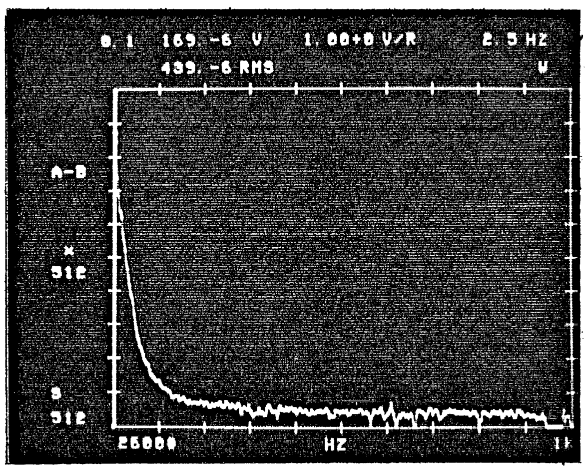
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-213

Tap 39 - Elev. = 40.5 ft.



Q = 600 cfs, T. W. Elev. = 6.9 ft.

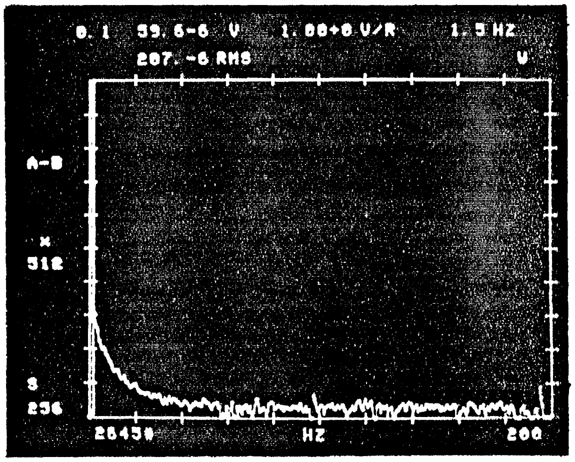


Q = 600 cfs, T. W. Elev. = 6.9 ft.

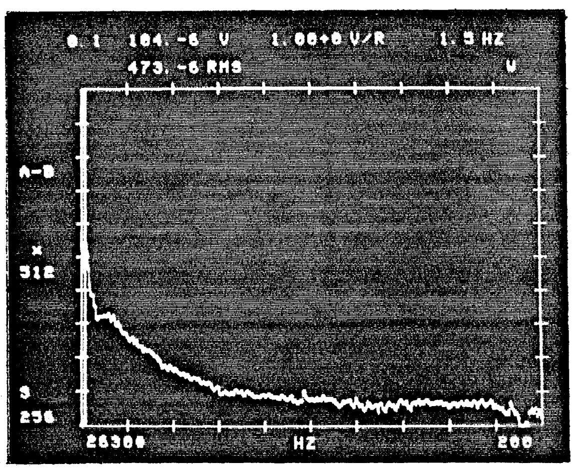
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R101 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-216

Tap 39 - Elev. = 40.5 ft.



Q = 600 cfs, T. W. Elev. = 45 ft.

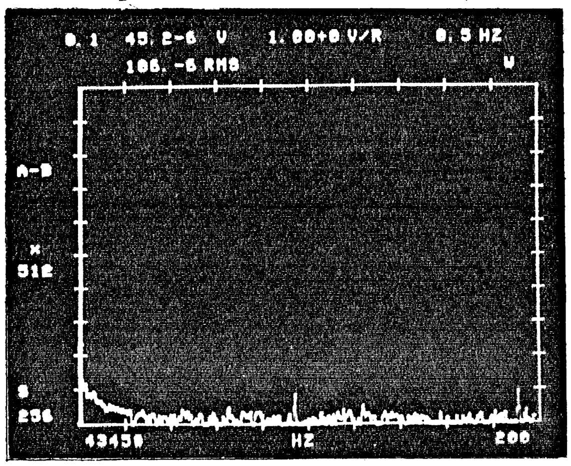


Q = 600 cfs, T. W. Elev. = 30 ft.

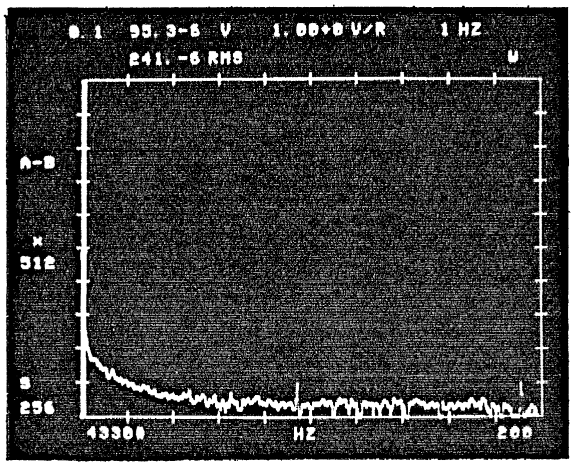
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R101 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED *[signature]*	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-217

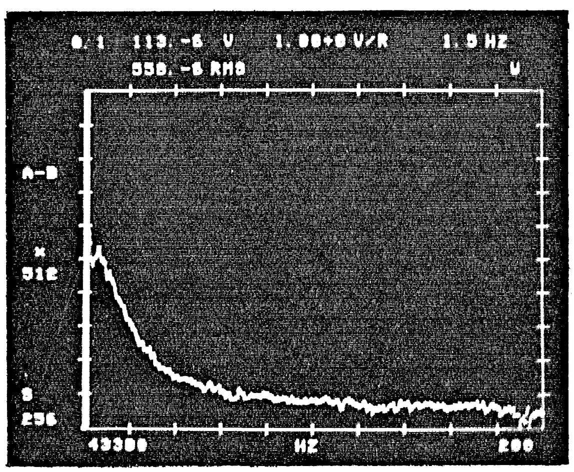
Tap 39 - Elev. = 40.5 ft.



Q = 330 cfs, T. W. Elev. = 45 ft.



Q = 330 cfs, T. W. Elev. = 30 ft.



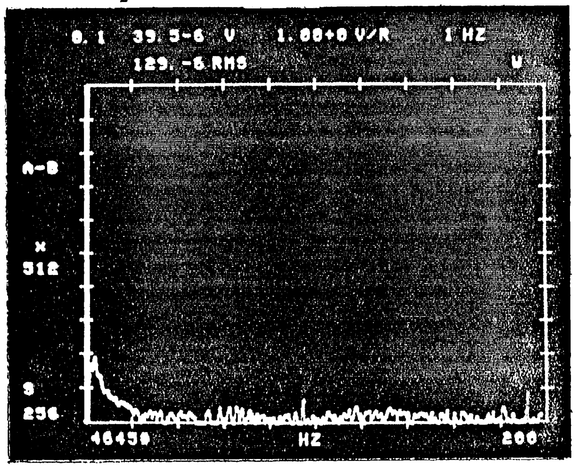
Q = 330 cfs, T. W. Elev. = 5.4 ft.

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Spectrum Displays

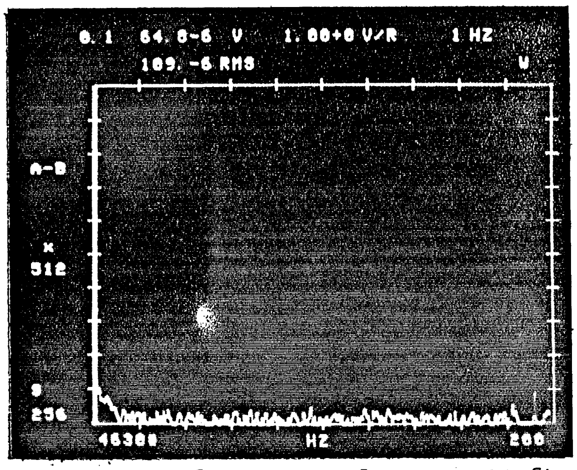
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED JQB	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-220

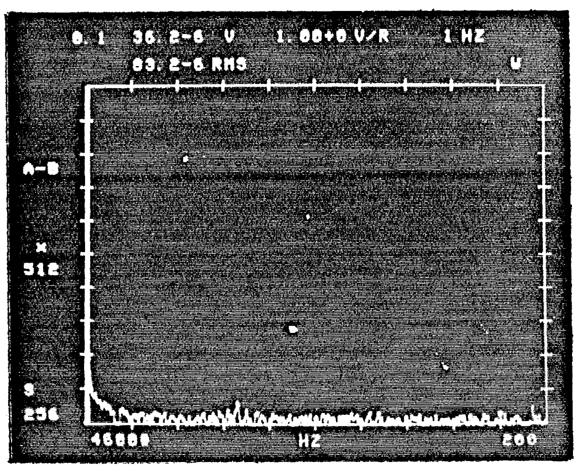
Tap 39 - Elev. = 40.5 ft.



Q = 600 cfs, T. W. Elev. = 45 ft.



Q = 600 cfs, T. W. Elev. = 30 ft.

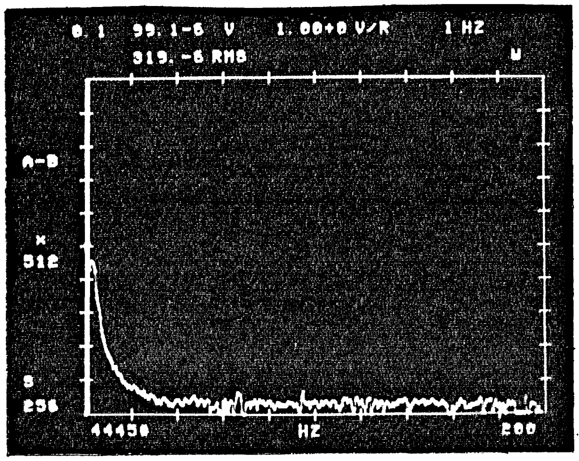


Q = 600 cfs, T. W. Elev. = 6.9 ft.

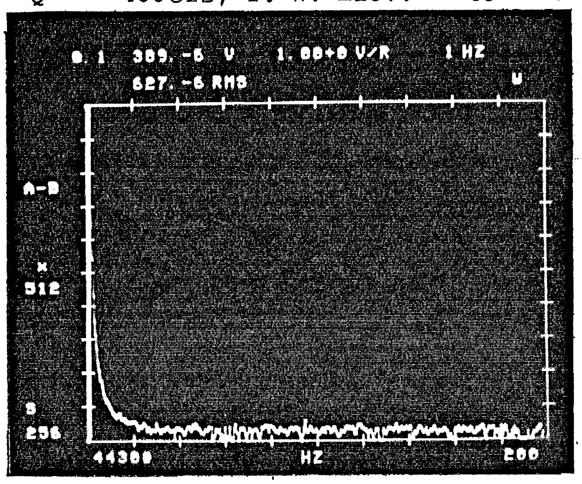
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-219

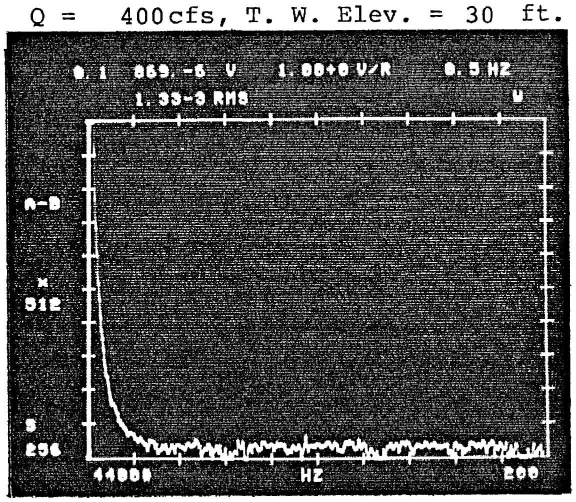
Tap 40 - Elev. = 44.7ft.



Q = 400cfs, T. W. Elev. = 45 ft.



Q = 400cfs, T. W. Elev. = 30 ft.

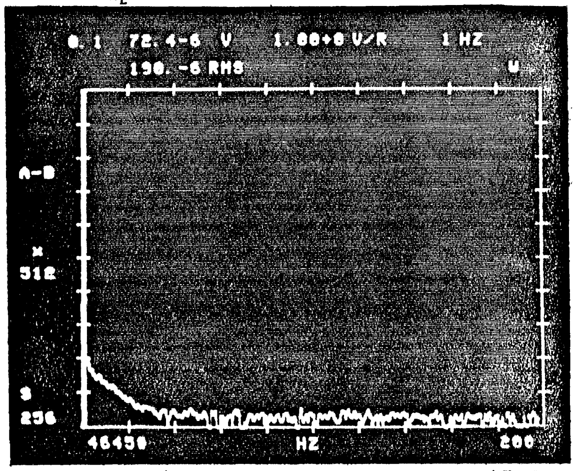


Q = 400cfs, T. W. Elev. = 5.8 ft.

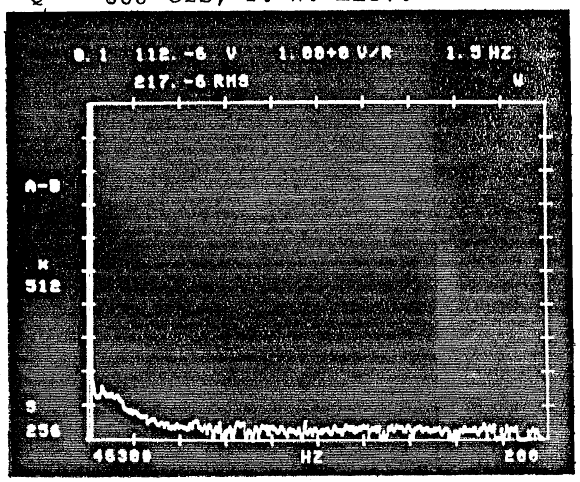
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-222

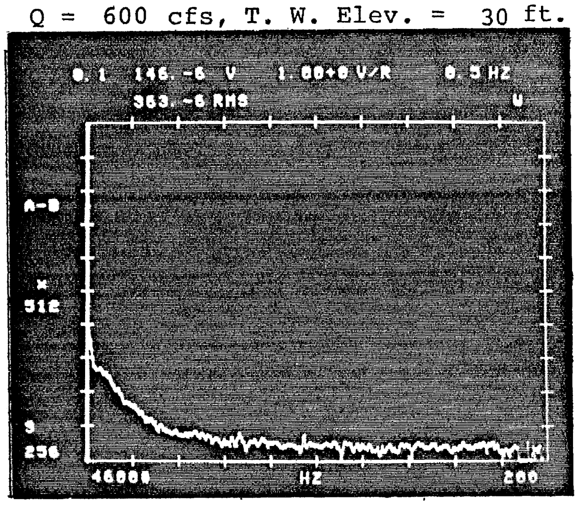
Tap 40 - Elev. = 44.7 ft.



Q = 600 cfs, T. W. Elev. = 45 ft.



Q = 600 cfs, T. W. Elev. = 30 ft.

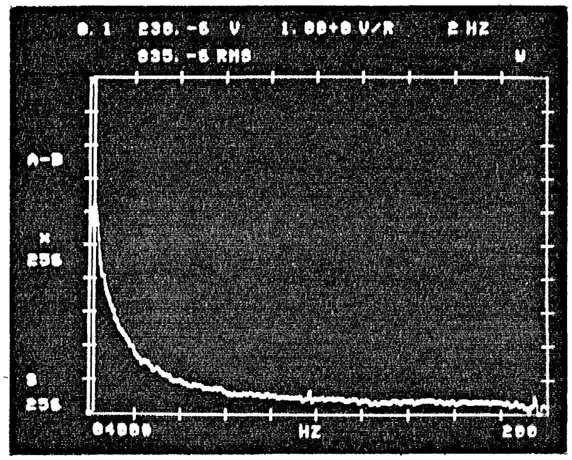


Q = 600 cfs, T. W. Elev. = 6.9 ft.

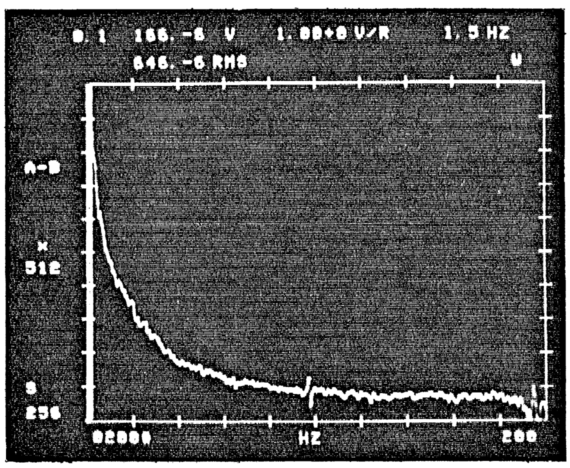
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321- 221

Tap 21 - Elev. = 0 ft.



Q = 400 cfs, T. W. Elev. = 5.8 ft.

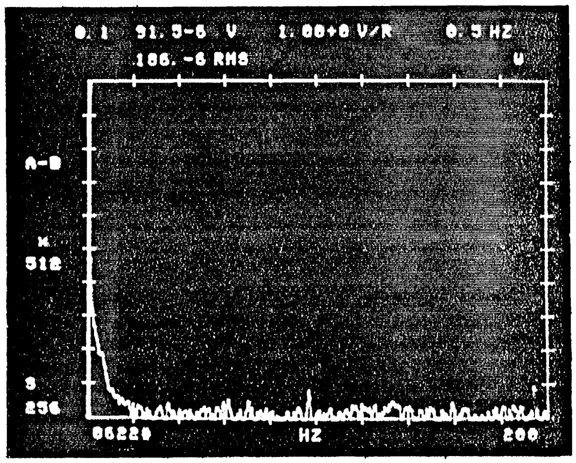


Q = 200 cfs, T. W. Elev. = 4.1 ft.

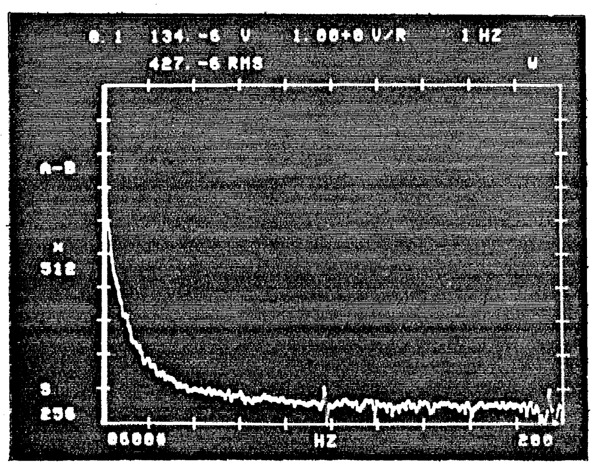
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-215

Tap 21 - Elev. = 0 ft.



Q = 600 cfs, T. W. Elev. = 22 ft.

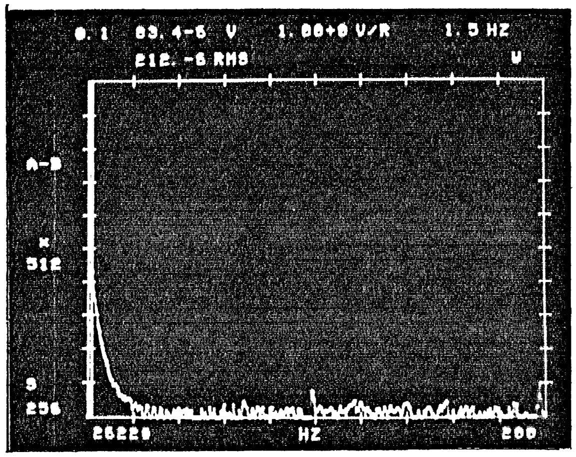


Q = 600 cfs, T. W. Elev. = 6.9 ft.

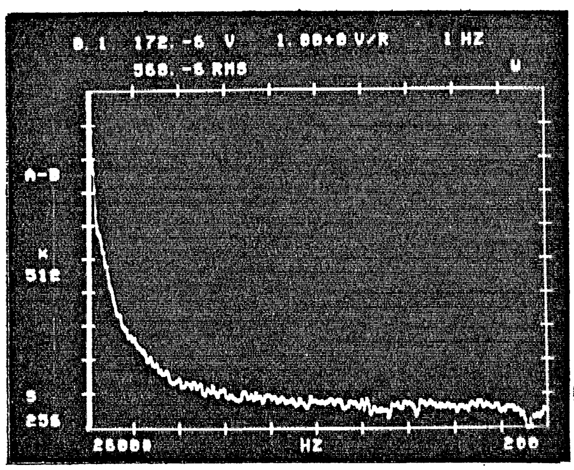
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R100 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-214

Tap 20 - Elev. = 0 ft.



Q = 600cfs, T. W. Elev. = 22 ft.

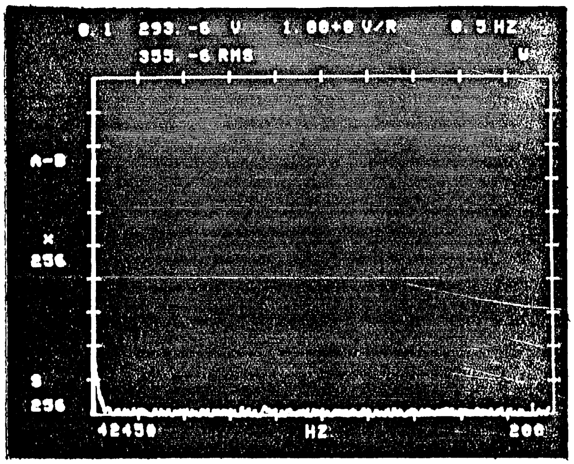


Q = 600 cfs, T. W. Elev. = 6.9 ft.

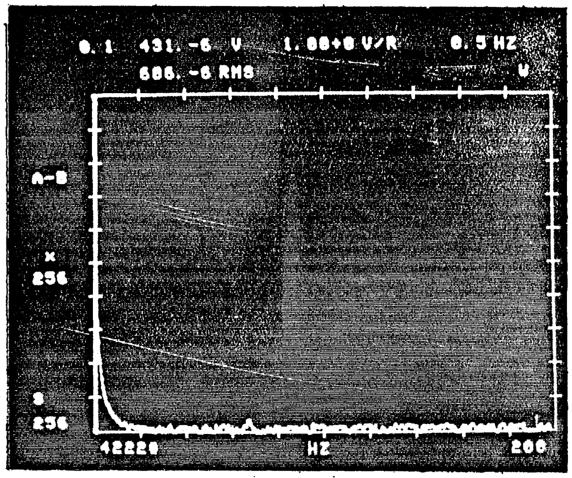
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R101 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-218

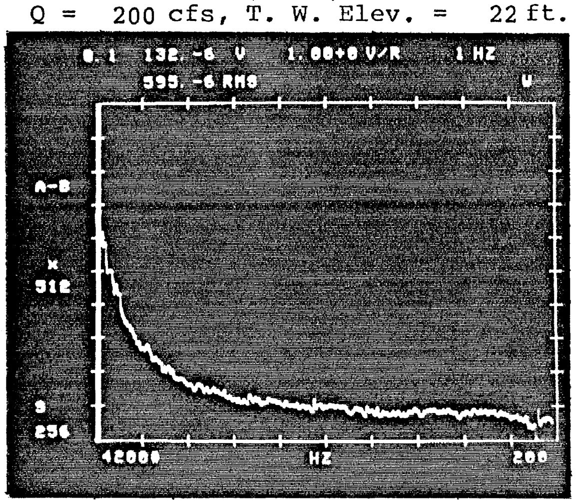
Tap 21 - Elev. = 0 ft.



Q = 200 cfs, T. W. Elev. = 45 ft.



Q = 200 cfs, T. W. Elev. = 22 ft.

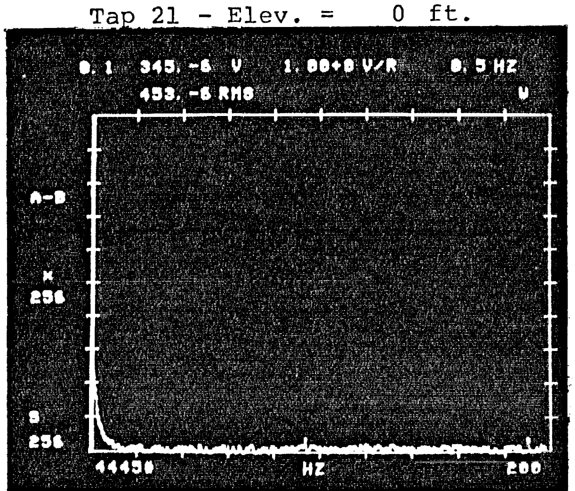


Q = 200 cfs, T. W. Elev. = 4.1 ft.

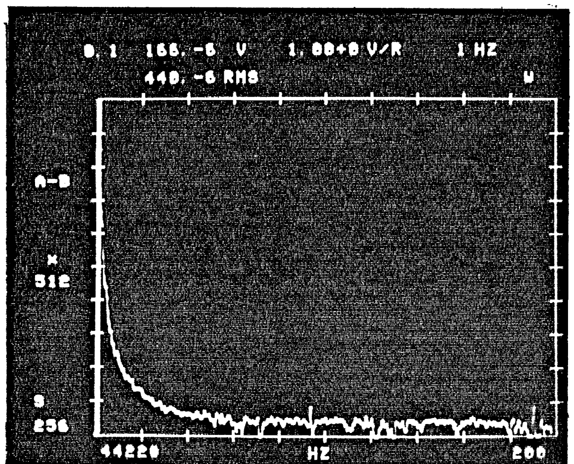
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-226

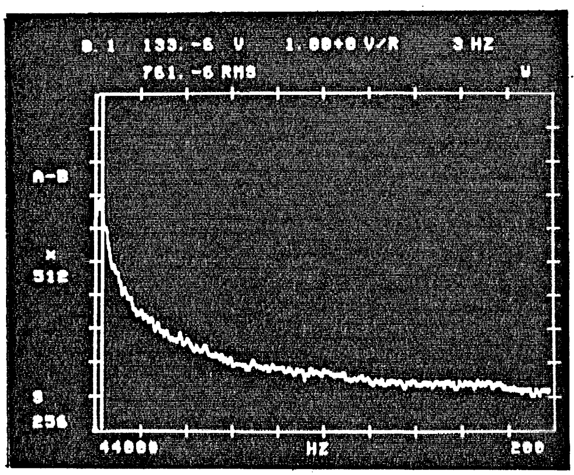
Tap 21 - Elev. = 0 ft.



Q = 400 cfs, T. W. Elev. = 45 ft.



Q = 400 cfs, T. W. Elev. = 22 ft.

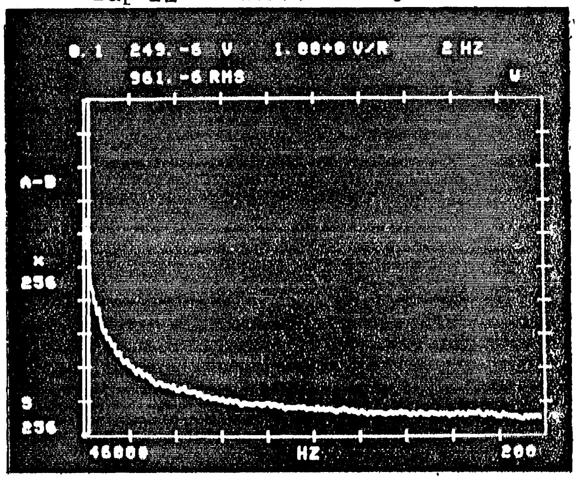


Q = 400 cfs, T. W. Elev. = 5.8 ft.

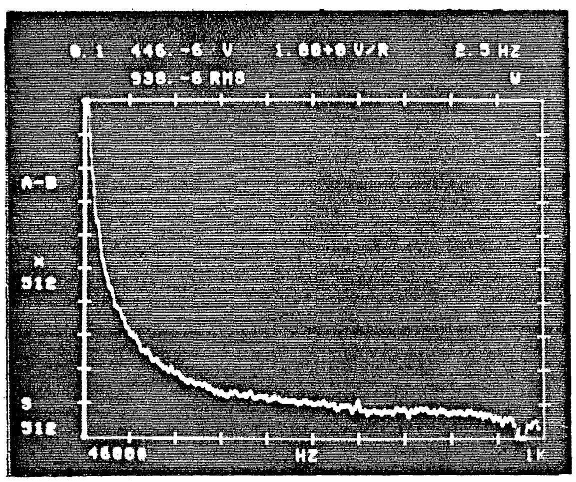
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-225

Tap 21 - Elev. = 0 ft.



Q = 600 cfs, T. W. Elev. = 6.9 ft.

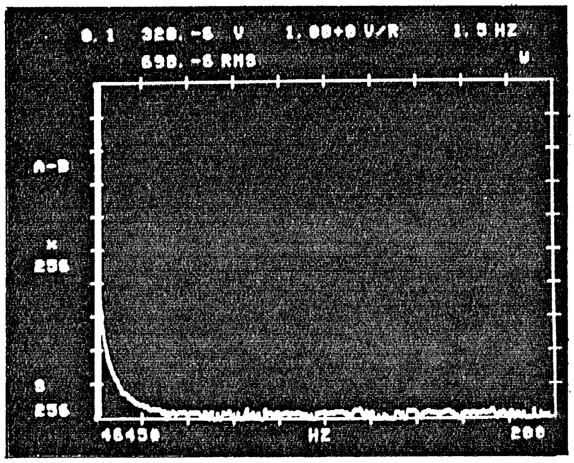


Q = 600 cfs, T. W. Elev. = 6.9 ft.

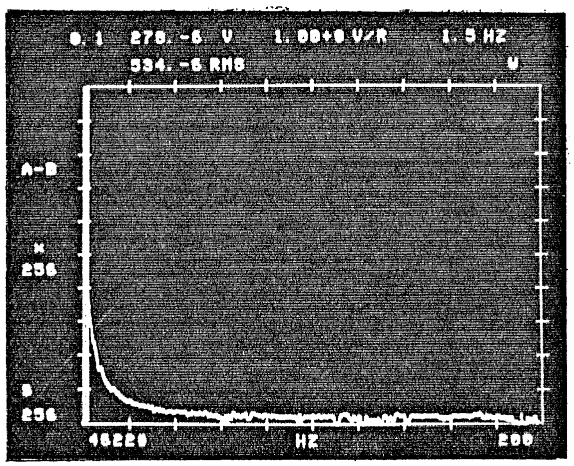
ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-223

Tap 21 - Elev. = 0 ft.



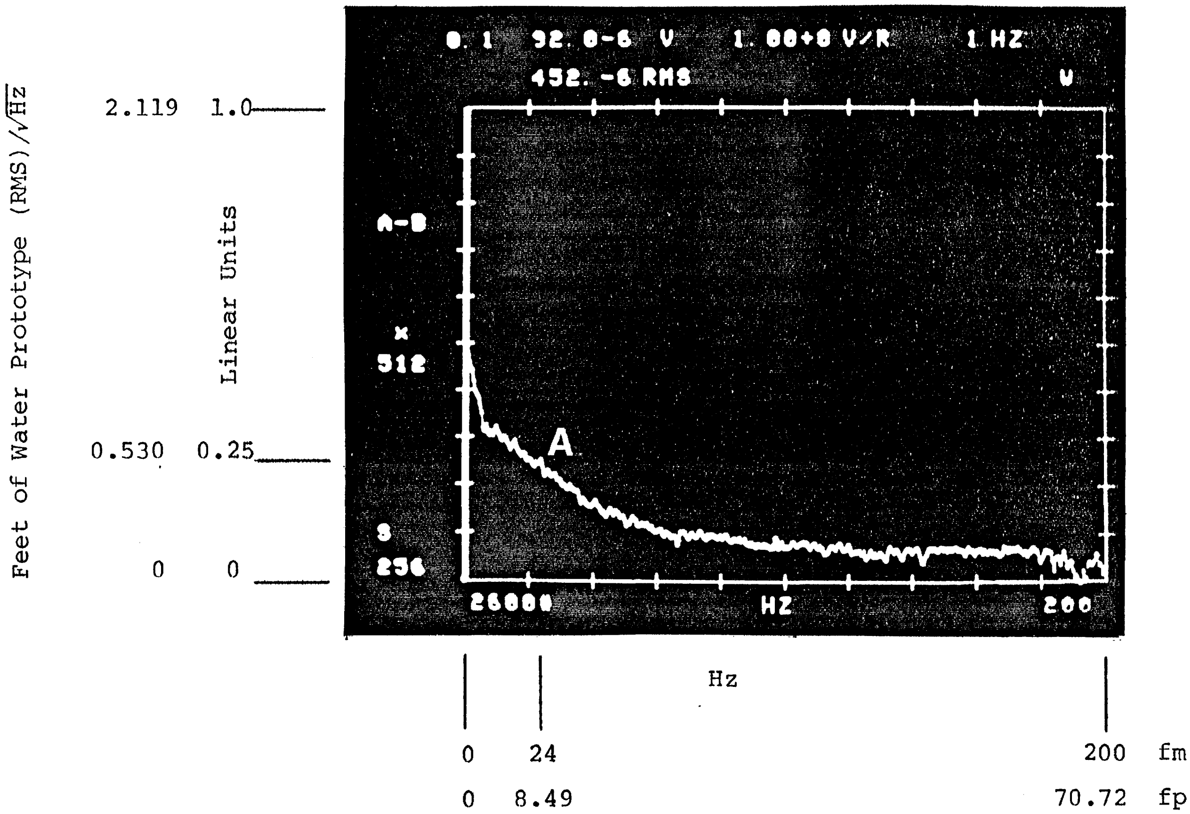
Q = 600 cfs, T. W. Elev. = 45 ft.



Q = 600 cfs, T. W. Elev. = 22 ft.

ROCHESTER DROPSHAFTS MODEL STUDIES
Type L2 R104 Scale 1:8
Spectrum Displays

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 12/10/81	NO. 302A2321-224



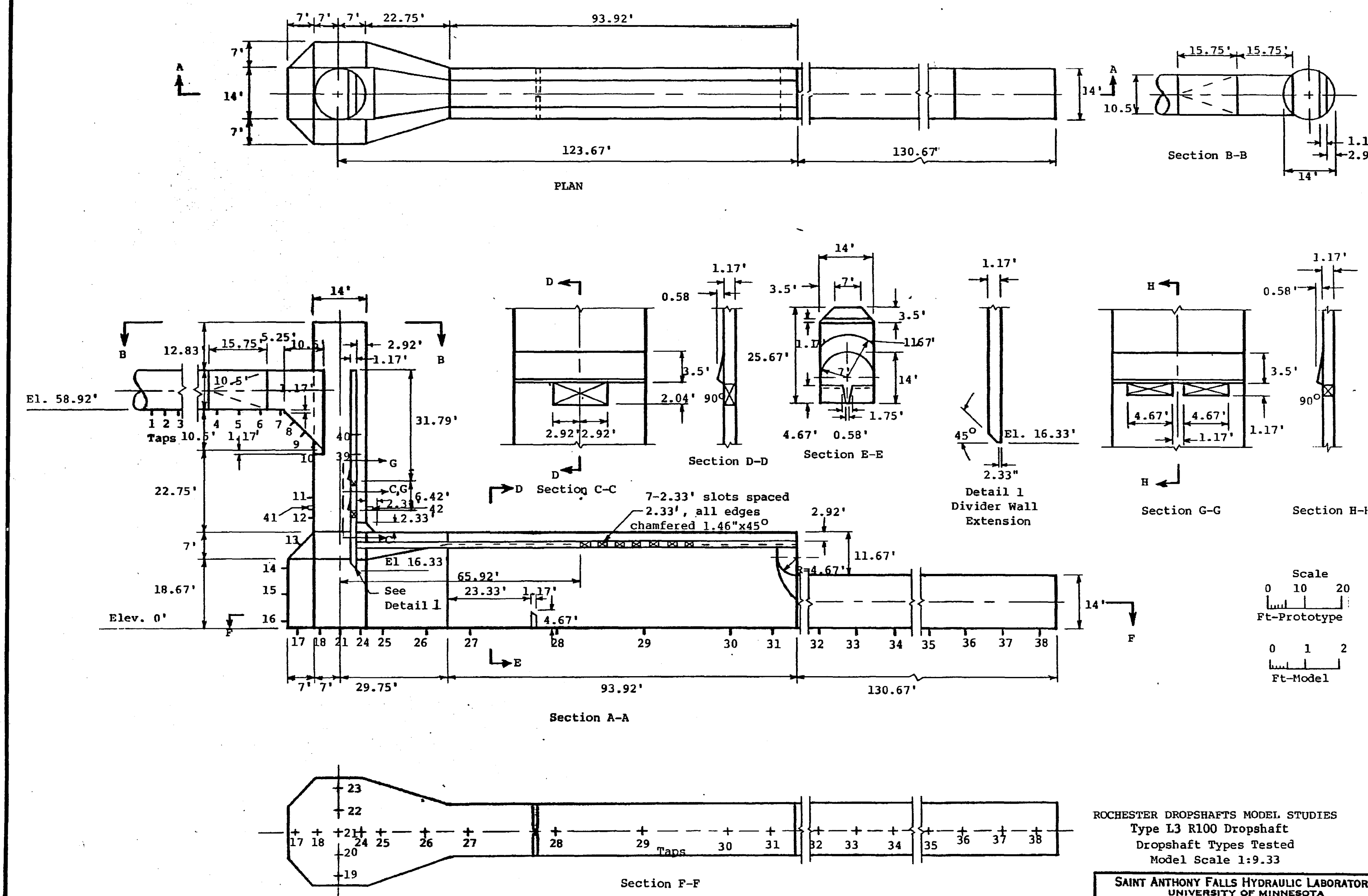
To Determine Coordinates of Any Point on the Spectrum Such as Point A:

1) Project Point to Left Side and Read Value - 0.25. Then 0.25 x 2.119 = 0.530 ft of Water Prototype (RMS)/$\sqrt{\text{Hz}}$.

2) To Determine Prototype Frequency of Point A, Project Point to Bottom Scale and Estimate Model Frequency 24 Hz. Then fp = fm/2.828 = 24/2.828 = 8.49 Hz.

ROCHESTER DROPSHAFTS MODEL STUDIES
Determining Spectrum Values
Spectrum at tap 39, elevation = 40.5 ft
Q = 600 cfs, T.W. Elev. = 6.9 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN B.B.	CHECKED [illegible]	APPROVED
SCALE	DATE 10/21/81	NO. 302A234-239



ROCHESTER DROPSHAFTS MODEL STUDIES
Type L3 R100 Dropshaft
Dropshaft Types Tested
Model Scale 1:9.33

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN B.B.	CHECKED	APPROVED
SCALE	DATE 11/1/82	NO. 302B511-12

CHART 173