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MODEL STUDIES OF A COOLING WATER DISCHARGE OUTLET MODIFICATION PRAIRIE ISLAND NUCLEAR GENERATING PLANT

by

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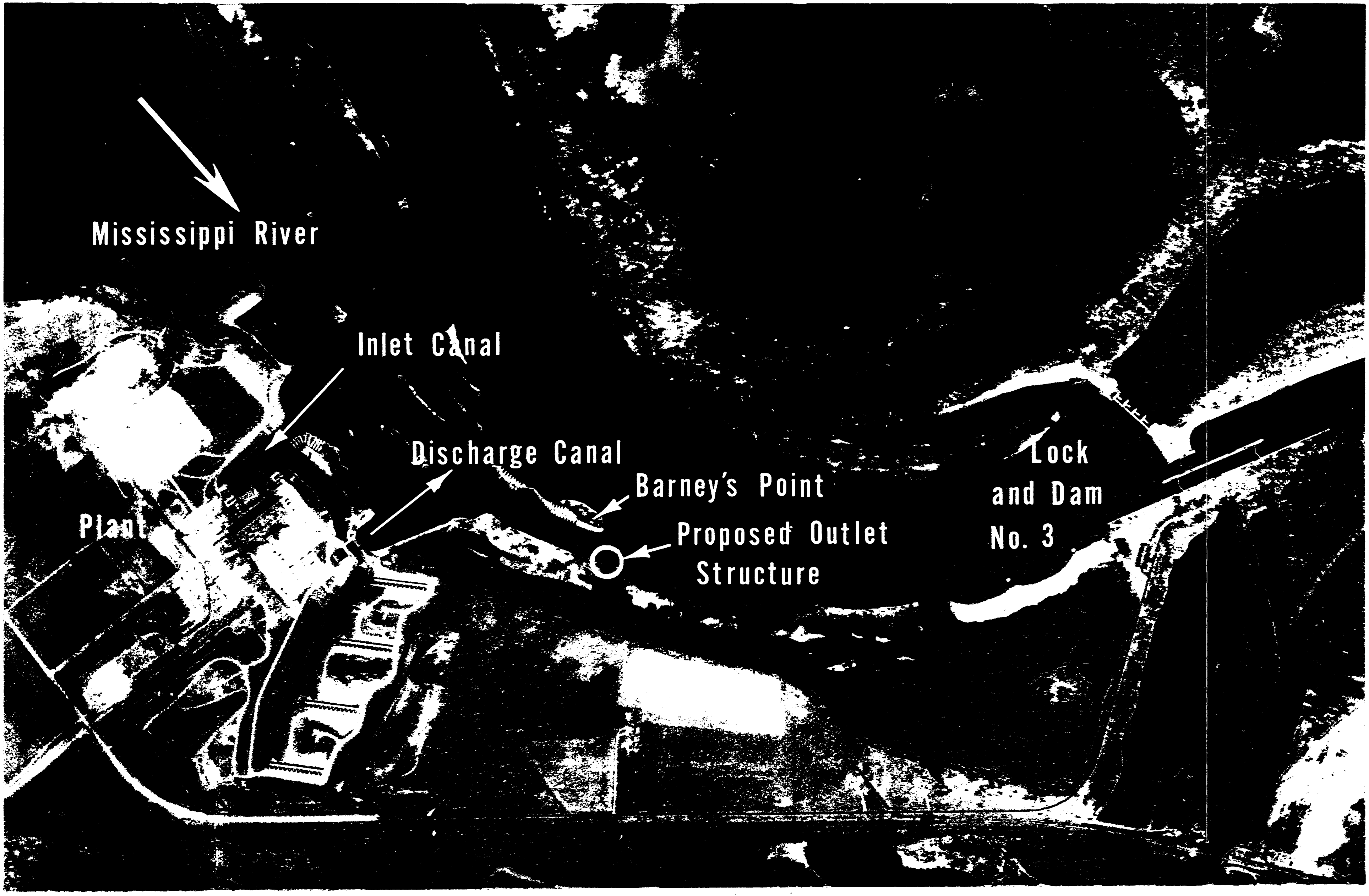
Mississippi River
Inlet Canal
Discharge Canal
Barney's Point
Proposed Outlet Structure
Lock and Dam No. 3
Plant

PREFACE

Hydraulic model studies of a modification of the cooling water discharge outlet of the Prairie Island Nuclear Generating Plant were carried out at the St. Anthony Falls Hydraulic Laboratory. The existing outlet is an open channel which discharges the warmer water into the Mississippi River. The existing outlet is in close proximity to the plant inlet resulting in some recirculation of the warmer water, and fish entering the open-channel outlet are sometimes subjected to thermal shock when the water temperature changes suddenly. To reduce these undesirable effects a discharge outlet modification was proposed which would discharge the warmer water from an impounded area through four discharge pipes into the Mississippi River. The outlet would also be moved further downstream from the plant. The purpose of the model studies was to evaluate the modification which included the determination of the local scour at the pipe outlets and the impact on navigation in the vicinity of the proposed outlet. The studies were conducted on a model constructed to an undistorted scale of 1 to 32. Ten selected flow conditions were investigated on the model. Documentation consisted of recording flow directions, measuring flow velocities, photographing the surface flow patterns, and recording the local scour.

The model studies described in this report were sponsored by Northern States Power Company. The Stone and Webster Engineering Corporation, Denver, Colorado, served as consultants on the project. Liaison between NSP and the laboratory was primarily through Mr. James Poucher and Mr. Richard McGinnis. Dr. Y. Shen and M. John R. Troka of Stone and Webster Engineering Corporation were the principal contacts of the consultant. The above persons viewed the model during construction and operation and provided continuous input during the test program and the evaluation of the test results. The model was also observed during operation by personnel from various regulatory agencies such as the Corps of Engineers, Environmental Protection Agency, Pollution Control Agency, Department of Natural Resources, and the Department of Fish and Wildlife.

The overall apsects of the model studies were under the supervision of Mr. J. M. Wetzel and Dr. S. Dhamotharan of the laboratory staff. Mr. Warren Q. Dahlin was responsible for model construction and data collection; he was assisted by Messrs. Robert Plaska and Ching Keong Teng.

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MODEL STUDIES OF A COOLING WATER DISCHARGE OUTLET MODIFICATION - PRAIRIE ISLAND NUCLEAR GENERATING PLANT

I. INTRODUCTION

The Prairie Island Nuclear Generating Plant is located on the Mississippi River near Red Wing, Minnesota. The general location is shown in Fig. 1. The plant is situated on the right bank in the bend of the river about one mile above Lock and Dam No. 3 as shown in the frontispiece. The cooling water is presently discharged through an open canal directly into the Mississippi River. The present outlet is in rather close proximity to the plant inlet resulting in some recirculation of the warmer water. Northern States Power (NSP) also has need for preventing fish from entering the outlet canal where they would be subject to cold shock mortality in case of sudden winter shutdown. Modification of the discharge outlet has therefore been proposed. The discharge outlet would be moved further downstream and the cooling water discharged into the river 500 ft downstream of Barney's Point, thus reducing recirculation. This may be seen in the frontispiece and the sketch in Fig. 2. Dikes built across a backwater area adjacent to the plant would provide an impoundment area for the plant discharge. Four pipes with diameters of 8, 7, 6, and 5 ft would convey the flow through the embankment and discharge it into the river. The velocity of the flow from the open pipes would be maintained above 8 fps. This high velocity would prevent most of the fish from swimming through the pipes and entering the impoundment pool. During operation, the pipes would be either closed or wide open, and the number of open pipes would vary from 1 to 4 depending on the plant discharge. By proper selection of the pipes to be opened, the head can be maintained at a fairly constant elevation, thus keeping the discharge velocity greater than the required 8 fps.

To provide for better mixing of the warmer water with the river water and to minimize local scour at the pipe outlets, an area would be dredged down to elevation 652 ft and the slopes adjacent to the pipe outlets would be protected with 12 in. riprap as shown in Fig. 2. The mixing of the warm water was judged not to be a problem and thus was not considered in the model studies. With jet velocities over 8 fps, local scour in the discharge area was of particular concern.

Another area of interest was the impact on navigation in the vicinity of the proposed outlet. With Lock and Dam No. 3 located at the right bank about 1 mile downstream from the plant, barges and pleasure crafts tend to hug the right bank and pass close to the outlet. To investigate the effect of the river traffic, detailed flow direction and velocity studies were conducted.

To give some insight as to the effect of the proposed outlet modification on local scour and impact on navigation, it was judged necessary to conduct hydraulic model studies. A model was constructed to a scale of 1 to 32 and tested at the laboratory for the specific purpose of evaluating the proposed design. Details of the model construction, testing program, and presentation of the experimental results are discussed in this report.

II. THE MODEL

A. Model Scale

The interaction of the flow jets emerging from the various pipes with the river flow is a three-dimensional phenomenon and is one of the important factors influencing the local scour and effects on local river traffic. To reduce scale effects and produce higher flow velocities which would give more quantitative results, it was desirable to construct a model as large as possible. On the other hand, the model should be economical, practical to operate, and fit into model areas available at the laboratory. After some deliberation, an undistorted geometric scale of 1 to 32 was selected. The undistorted scale was chosen to alleviate scaling problems associated with distorted models in regard to local scour phenomena. The model included reasonable reaches of the river, both upstream and downstream from the outlet, and most of the cross section of the river. The model was operated in accordance with the Froude law of similitude. The following expressions were used to convert dimensions and hydraulic quantities from model to prototype or vice versa. The subscripts m and p refer to model and prototype, repectively, and the subscript r denotes the ratio of model to prototype.

Quantity	Ratio	Scale Relation
Length, L	$L_r = L_m/L_p$	1:32
Velocity, V	$V_r = L_r^{1/2}$	1:5.66
Time, T	$T_r = L_r^{1/2}$	1:5.66
Discharge, Q	$Q_r = L_r^{5/2}$	1:5793

For example, if the velocity in the model is 1.0 ft/sec, the corresponding velocity in the prototype will be 5.66 ft/sec.

B. Model Layout

The generating plant is located on the right bank and outside of a bend in the Mississippi River about 1 mile upstream of Lock and Dam No. 3 as shown in the frontispiece. The thalweg, or line of greatest depth, occurs at the outside of the bend in the vicinity of the plant outlet. Several islands are scattered throughout this reach of the river with a prominent long, narrow island just streamward of the present outlet. The lower end of this island is called Barney's Point.

In designing the model layout it was first necessary to determine the river area to be included and the alignment of the river in the available model basin. Objectives considered in this selection were to:

1. Include as much of the cross-sectional area of the river as possible,

2. Include a sufficient portion of Barney's Point in order to model the flow around the island, and

3. Provide proper alignment so that approach and discharge flow angles properly simulated the prototype flow conditions.

Two orientations of the river bed with respect to the basin walls were considered: one with the basin wall approximately parallel to the river bank downstream of the discharge point, and the other with the basin wall arranged such that the river area included in the model was maximized.

The first orientation resulted in a very small section of the main river channel at Barney's Point being included in the model. It was felt the flow distribution caused by this orientation would not represent the actual case in the river, and therefore this orientation was rejected.

The second orientation was chosen for use. The arrangement of the basin with respect to the river was selected to cover the discharge from the backwater area at Barney's Point and to include the entire width of the shipping channel. It was also decided that the model should be constructed such that a constant percentage of the river flow be modeled downstream of the region of the proposed outlet. This was accomplished by installing a false wall in the basin on the side opposite the plant discharge.

To determine the area included in the model, cross sections were drawn at several range lines identified from bathometric data provided by NSP. Each cross section was subdivided,and the area for each subsection was determined by planimetry. Average velocities for each subsection were taken from the U. S. Army Corps of Engineers model studies for reference conditions with a discharge of 18,079 cfs and a tailwater elevation of 674.1 ft. Computation of flows past each section using average depths and velocities verified that the information used was acceptable, that is, flows at each section were approximately equal.

To determine the percentage of river flow to be modeled, the cross-sectional area included within the basin for the range located furthest upstream was calculated. The flow passing through the section was then determined using the sum of the average depth times the average velocity for each subsection, or portion of a subsection, included within the basin. The percentage of the total river flow was then determined and this percentage was held constant for the remaining downstream sections.

To determine the location of the wall for the downstream sections, it was first determined within which subsection the wall must be located in order to keep the modeled river flow constant. This was done by summing the average flow for each subsection until the sum exceeded the modeled flow. The location of the wall, within the subsection containing it, was determined by taking the flow required to pass the subsection (total modeled flow minus the sum of the flows for subsections fully included) and dividing it by the average depth and velocity. This provided an approximate width of the subsection to be included. Using this width, an average flow was calculated and compared to the required flow. Based on this comparison, the required width for the subsection was adjusted until the average flow passing the subsection equalled the required flow. The location of the wall from the river bank was the sum of the widths of the individual subsections needed to obtain the required flow percentages.

With this procedure, the river flow measured at the downstream end of the model was 84 per cent of the total river flow. This percentage was based on the reference flow and tailwater elevation previously stated. For flow conditions other than the reference flow, it was assumed that the percentage of the river flow would remain constant. Based on the above considerations, the model layout and alignment that evolved is presented on Fig. 3. About 1350 ft of the river length and 750 ft of the river width was modeled. The layout shows Barney's Point at the upstream end of the model, the guide wall along the left side of the model, and the location of the navigation channel through the model area.

To provide proper flow distribution around Barney's Point, two river inflow systems were installed in the model. The main river channel discharge (Q_{25}) to the left of Barney's Point was conveyed from the laboratory water supply system through a 12 in. diameter supply line to the model area. The supply line included a calibrated 4.5 in. diameter orifice meter to measure the flow rates and a control valve for flow adjustments. That portion of the river flow to the right of Barney's Point (Q_{42}) was conveyed to the model area through a 4 in. diameter supply line with a calibrated 1.625 in. diameter orifice meter and a control valve, or for lower flows, through a 2 in. diameter bypass with a calibrated 0.875 in. diameter orifice meter and control valve. For some operating conditions, it was necessary to withdraw rather than introduce flow in this area. Withdrawal was accomplished by installing a branch line downstream of the main control valve with a vertical leg extending to a lower level and terminated with a valve. By closing the main valve and opening the lower valve, the line operated as a siphon. The flow withdrawn from the model was measured with an orifice installed in the vertical leg. Both inflow systems were provided with manifolds, each with provisions to adjust the inflow for proper distribution. Wire mesh baffles were placed downstream of the manifolds to reduce turbulence and calm the water before it entered the model proper. An adjustable weir was installed at the downstream end of the model to control the tailwater elevation. To provide for the plant discharge in the model, four plastic tubes with inside diameters of 3, 2.625, 2.25, and 1.875 inches were used to represent the 8, 7, 6, and 5 ft diameter prototype pipes, respectively. The pipes were placed at the location and angle as shown in Figs. 4 and 5. The inverts of all the pipes were set to elevation 659.83 ft. Each pipe was provided with a calibrated orifice meter to measure the flow, a control valve for flow adjustments, and was connected to the laboratory water supply system.

The bed of the entire model area was erodible, using a fine sand molded to conform to topographic maps and river soundings provided by NSP. To assist in the molding procedure, sheet metal templates were positioned across the model at 5 ft intervals, and supported over the model bed. These templates were accurately cut to conform to the original river contours at their respective locations. The sand was graded to the underside of the templates and the templates were then removed. In between test runs, the templates were replaced and the model remolded so that each test started with an identical bed configuration. For the first test the model was molded to the original river contours as shown in Fig. 3. This first test was made to verify the model and to provide reference data for later comparisons.

After the initial test, the discharge outlet modification was molded into the model as shown on Figs. 4 and 5. The four pipes discharge into an area excavated to elevation 652 ft with side slopes from that elevation up to the original ground surface. The 4:1 slope at the pipe exits and a part of the basin bottom at elevation 652 ft was protected with a 24 in. thick layer of rock with a D_g of 12 in., where D_g is the median diameter of the material. The pipes discharge in a submerged condition with a minimum tailwater operating level of 673.5 ft as indicated in Fig. 5. Special templates were made to conform to the outlet area modifications and used to mold that area. The outlet area was also remolded after each test run.

C. Sediment Characteristics

It was desired to model the sediment size of the river bed as close as possible so that the local scour depth could more readily be extrapolated to full-scale values. Sediment samples were taken by the sponsor at the proposed point of discharge which is about 500 ft downstream of Barney's Point. The samples were taken at 50 ft intervals in a grid pattern consisting of six rows with six points in each row as indicated in Fig. 6. These samples were transmitted to the laboratory for analysis. A sieve analysis was made on each of the six samples in row A (5 ft from the shore) and selected locations in rows B through F for a total of 18 points. The size distributions of these samples were similar, and the results were averaged to obtain the composite size distribution curve presented in Fig. 7. The D_g is about 0.38 mm with some finer material down to about 0.04 mm (very fine sand) and some coarser material up to about 8 mm (fine gravel). Most of the prototype sediment was in the medium to coarse sand classification. With the prototype sediment this small, selecting a bed material for the model was rather difficult. The sediment size if scaled down linearly by the scale ratio would require a fine silt in the model which would not be practical to use. A search was made for fine materials that could be used in the model. The smallest material found that would be practical to use was a Badger mixing sand which has a D_g of 0.096 mm and may be classified as a very fine sand. The size distribution of the sands used in the model are presented in Fig. 8. Because of the relatively high cost of this material and the difficulty expected in molding it, the decision was made to use the Badger sand only in the area of anticipated local scour. A locally available Bay City sand with a D_g of 0.55 mm was selected for the model base (Fig. 8). For the initial verification test the entire model was molded (as shown in Fig. 3) with the Bay City sand with a D_g of 0.55 mm. For later tests including the plant discharge, the area by the pipe outlets was remolded using the Badger sand with a D_g of 0.096 mm as outlined in Fig. 4. Although this material was not as fine as desired, it was felt that the qualitative results obtainable would be a fair indication of the local scour that might occur.

The size of the riprap for protection of the area at the pipe outlets was specified by Stone and Webster to be 12 in. rock. Suitable material for the model was obtained by selective sieving to achieve a model size range from 0.36 to 0.42 inches.

D. Test Conditions and Procedures

The flow conditions used to evaluate the local scouring and impact on navigation were specified by Stone and Webster and NSP and are listed in Fig. 9. The upstream river discharge is denoted as Q_T, the discharge on the right side of Barney's Point as Q_{42}, the discharge on the left side of Barney's Point or main river channel as Q_{25}, and the plant discharge as Q_D. The plant flow may be discharged through any or all four of the pipes depending on the flow rate and the operating schedule supplied by Stone and Webster. The operating schedule is reproduced in Fig. 10 and provides the basis for determining which pipes would be open for the various plant discharges as listed in Fig. 9. To prevent fish passage through the pipes, the velocity was kept above 8 fps and was a factor in the selection of pipes to be used.

In the first trial operation of the model, it was obvious that the flow from each of the two river inflow systems was not properly distributed and the flow directions were misaligned. The two manifolds were constructed with a series of holes facing upstream from which the flow issued. Each hole was provided with a sliding plate for flow adjustment purposes. By adjusting the various sliding plates, a uniform flow distribution from each manifold was achieved. Flow straightners cut to fit around the manifold pipes, placed perpendicular to the manifolds, and extending to the wire mesh baffle successfully aligned the flow entering the model. Initial observations were made using confetti spread on the water surface to indicate flow velocities and directions. Final adjustments of each manifold were based on a series of velocity readings taken downstream of the manifold with a pygmy current meter.

The basic test procedure for operating the model was essentially the same for all flow conditions. Before each test the erodible bed was molded to the original contours using the removable, overhead templates. The model was carefully backfilled to minimize disturbance to the bed until a substantial tailwater was established. The main river flow, flow around Barney's Point, and specified plant discharge were each set to the proper values. The tailwater was then adjusted to the elevation corresponding to the total river discharge. The initial tests were made with the entire bed molded using the Bay City sand with a D_g of 0.55 mm. For the first test the bed was molded to the original river contours, and the model operated according to flow condition 1, which does not include any plant discharge. The purpose of this test was to establish a reasonable flow distribution in the model and establish a basis for comparison. For the next two tests the outlet basin geometry was molded into the model at the pipe outlets and flow conditions 2 and 10 were run on the model. These tests provided a basis for comparison with later tests with the finer sand placed in the outlet basin area. During the initial tests flow directions were determined using a fine thread attached to a thin rod, and velocity readings were made with a pygmy current meter. The model was not operated for any specified length of time.

After these initial tests, the entire model was remolded and the Badger sand with a D_g of 0.096 mm was placed in the outlet basin area as outlined in Fig. 4. Flow conditions 2 through 10 were run with this configuration, the model being remolded before each test. The model was run for a total time of 8 hours, which appeared to be adequate to achieve an equilibrium depth of scour. During the test period the flow directions were determined and velocities measured.

III. DISCUSSION OF EXPERIMENTAL RESULTS

A. Original River Bed - Flow Condition 1

The purpose of this initial test was to establish a reasonable flow distribution in the model and to provide baseline data for comparison. The model was molded to the configuration outlined in Fig. 3. Figure 11 is a plotting of the flow pattern and velocities at mid-depth for condition 1, which specifies a total river discharge (Q_T) of 12,000 cfs, zero plant flow (Q_D), and a tailwater elevation of 673.8 ft. The circles indicate points at which the mid-depth flow directions and velocity readings were observed. The velocity readings varied from less than 0.5 fps to 1.50 fps. Because of the internal friction present in the current meter, velocity values below 0.5 fps prototype scale were not reliable and therefore have been omitted as shown along the left edge of the navigation channel. It was possible to establish the flow directions at these points using the rod with the fine attached thread. Photos 1 and 2 show views of the surface flow pattern as delineated by the confetti streaks. Photo 1 is a view from a low level looking upstream at the proposed outlet area,and Photo 2 is a view from directly overhead. The overhead view was used to determine the flow pattern and velocities at the water surface presented in Fig. 12. Knowing the exact shutter speed, the surface velocities were determined by measuring the length of the confetti streaks. Experience has shown that the camera shutter speed will differ from the indicated setting. To obtain an accurate time for determining velocity values, a timer was placed on the right river bank so that it would appear in the picture. This timer may be seen in Photo 2 at the bottom of the picture. The timer had a disk which rotated one revolution per second. On the disk was a white line which swept out a white sector of a circle; the size of the section was dependent upon the camera shutter speed. The exact exposure time was then determined by measuring the sector angle and dividing by 360°.

Because of the limited ceiling height over the model, the photograph and the resulting flow pattern shown in Fig. 12 covered only the pertinent area in the region of the proposed outlet. In Fig. 12 distances along the river from about 550 to 1100 ft and across the river from about 0 to 400 ft are covered. These distances correspond to the same distances in Fig. 11 so that the flow pattern and velocities reported in Fig. 12 can be compared to those in Fig. 11. The agreement in data obtained by the two observation methods is quite good. The 1 fps velocity contour in Fig. 12 occurs about 250 to 270 ft from the right bank which generally agrees with the velocity values 250 ft from the shore as reported in Fig. 11. On both figures the velocities 300 to 400 ft from the shore are between 1 and 1.5 fps. It should be noted that the observations in Fig. 11 are at mid-depth and in Fig. 12 are on the water surface. This information correlates well with observations made on a Corps of Engineers model at the Waterways Experimental Station[1]. Their model included Lock and Dam No. 3 and about 1-3/4 miles of the river upstream of the dam. As the generating plant is about 1 mile upstream of the dam, the Corps of Engineers model included about 3/4 mile of the river above the plant. In one of their base tests the Corps observed velocities and current directions for a discharge of 15,000 cfs. The flow directions observed on the SAF model show good correlation with flow directions from the Corps' model. The flow velocities measured in the SAF model are somewhat lower than those measured in the Corps' model, as the discharge of 12,000 cfs was lower. Higher discharges could not be used in the SAF model. From the overall data correlation with the Corps' model, which included a considerable reach of the river above the plant, it was judged that this constituted a satisfactory verification of the SAF model.

B. Discharge Outlet Modification - Bed Material D_g = 0.55 mm

After the verification test, the proposed discharge outlet modification was molded in the model as outlined in Fig. 4, except that the

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[1] Department of the Army, Waterways Experiment Station, Corps of Engineers, Vicksburg, Miss., "Model Study of Lock & Dam No. 3, Mississippi River," a preliminary report, 1975.

entire model bed consisted of the Bay City sand with a D_g of 0.55 mm. Flow conditions 2 and 10 were selected for the two preliminary runs using this bed material.

1. Flow Condition 2

Flow condition 2 specifies an upstream discharge (Q_T) of 3390 cfs, a discharge on the right side of Barney's Point (Q_{42}) of -165 cfs (negative denotes upstream flow), a discharge in the main channel (Q_{25}) of 2135 cfs, a plant discharge (Q_D) of 1390 cfs, and a tailwater elevation of 674.4 ft. The plant flow is discharged through all 4 pipes, proportioned as shown in Fig. 9. This is considered a no wind condition and was selected to provide qualitative assessment of recirculation. The resulting flow pattern and velocities are presented in Fig. 13. In the vicinity of the outlet, the velocities were measured at the surface and at mid-depth. Where two values are given, the upper is the velocity near the surface and the lower is the velocity at mid-depth. If no numbers are shown, the velocity was too low to measure in the model and would be less than 0.5 fps prototype scale. If no direction arrows are shown, the flow direction was indeterminate. The centerline of the navigation channel is shown, as well as the edges of the channel at distances of 150 ft each side of the centerline. The trajectory of the jet from the outlet pipes extended across the river at about the angle of the pipes and impinged on the wall on the far side of the model. Most of the flow turned downstream with some deflecting upstream along the guide wall as shown by the flow arrows and velocity readings. As the model did not include the entire width of the river, the question arises as to how accurately this would represent the prototype phenomenon. One can speculate that in the prototype more of the jet energy would dissipate before impinging on the far river bank resulting in less upstream recirculation than indicated in the model. Some recirculation along the right bank back toward the outlet area also was observed as indicated in Fig. 13. Assuming the flow from the pipes is greater than 8 fps, the velocity readings show that the flow velocity is dissipated rather quickly near the outlet.

2. Flow Condition 10

Flow condition 10 specifies an upstream discharge (Q_T) of 12,000 cfs, a discharge on the right side of Barney's Point (Q_{42}), of 894 cfs, a discharge in the main river channel (Q_{25}) of 9686 cfs, a plant discharge of 1390 cfs, and a tailwater elevation of 673.8 ft (Fig. 9). The observed flow pattern and velocities are shown in Fig. 14. With this higher river flow, the jets from the discharge pipes did not extend very far into the river. The flow is essentially directed downstream and is similar to the flow pattern for condition 1 which has no plant discharge and was shown in Fig. 11. Higher velocities occur towards the right bank for flow condition 10 as compared to condition 1. There is also a slight recirculation near the outlet.

C. Discharge Outlet Modification - Bed Material D_g = 0.096 mm

The model was prepared for evaluation of local scour by replacing the bed material in the region of the outlet with the finer Badger sand with a D_g of 0.096 mm. This area is outlined by the dashed line in Fig. 4. The entire model and outlet area was remolded using the templates described earlier and similarly remolded before each test run. Original contours of the river bed before the test runs are shown in Fig. 4 and in Photos 3, 4, and 5. Photos 3 and 4 show views from a low level looking upstream and Photo 5 a view from directly overhead. The contour lines are delineated by nylon cords placed on the bed which were removed before the test run.

For evaluation of local scour, test runs were made for each of the flow conditions from 2 through 10. The model was run for 8 hours, which appeared to be adequate to reach an equilibrium depth of scour. The flow direction was established using the thread indicator,velocity measurements were made with the pygmy current meter, and photographs were taken.

1. Flow Condition 2

Flow condition 2 has a low river discharge of 3390 cfs and a maximum plant discharge of 1390 cfs. This is a condition with a zero wind velocity. Photos 6, 7, and 8 show the flow pattern in the outlet area. Confetti streaks delineate the jet trajectory quite clearly, particularly in the close up views in Photos 7 and 8. The camera shutter speed was selected to give optimum streak lengths. The flow pattern and measured velocities are presented in Fig. 15. The flow pattern shown in Fig. 15 appears quite similar to the pattern in Fig. 13. Both are for flow condition 2 with different size bed material. The velocity values reported in the figures show some variation between the two tests. In repeating the tests on the model it was noticed that the flow velocities would fluctuate considerably at times, and the flow pattern would change especially for conditions with the lower river flows. This created difficulty in making observations for low flows in the model and resulted in discrepancies in the data collected. The flow pattern and velocities at the water surface shown in Fig. 16 were determined from Photo 8 and compare reasonably well with the information in Fig. 15.

It is evident from the photos and the information presented in the figures, that for flow condition 2, some upstream recirculation occurs along the far or left side and also along the right bank near the outlet.

After an 8 hour run, the flows were stopped and the model drained. Photos 9 and 10 show the resulting scour pattern. The scour was evident only near the toe of the riprap apron as indicated by the small area of light-colored sand ripples. The maximum depth of erosion was down to elevation 650 ft for a depth of scour of about 2 ft. As the scour was confined to the region near the toe of the rock apron, the river bed contours surrounding the excavated outlet basin have not changed and therefore are not shown in the photos. The lighter regions outside the immediate vicinity of the outlet are not scour patterns and should be disregarded. The point of maximum scour is also shown in Fig. 15.

2. Flow Condition 3

Flow condition 3 is similar to flow condition 2 in that the upstream discharge, plant discharge, and the tailwater elevation are the same. Flow condition 3 includes a 10 mph south wind which causes an increase in recirculation on the right side of Barney's Point. The flow on the right side of Barney's Point (Q_{42}) achieved by siphoning is -540 cfs and the main channel flow (Q_{25}) is 2510 cfs (Fig. 9). Photos 11 and 12 show the surface flow pattern for flow condition 3 as delineated by the confetti streaks and may be compared to Photos 7 and 8 which show the pattern for flow condition 2. It is interesting to note that the jet trajectory appears similar in Photos 12 and 8 which are from overhead; however, when comparing Photo 11 with Photo 7 which are from low level looking upstream, the jet trajectory in Photo 11 has a noticeable deflection towards the right bank (left side of the picture). This is not evident in Photo 12. As mentioned earlier, the flow pattern did shift occasionally for the lower river flows which is indicated here.

Figure 17 shows the observed flow pattern and velocities, and Fig. 18 shows the flow pattern and velocities at the water surface developed from Photo 12. The velocities on the two figures compare favorably, but the jet trajectory indicated in Fig. 17 has a slight deflection toward the right bank. When comparing the flow pattern and velocities for condition 3 (Fig. 17) and condition 2 (Fig. 15) some variations are noted. Most noticeable is the reduced upstream recirculation along the right bank and the slight deflection of the jet trajectory toward the right bank for condition 3. After 8 hours of flow, the local scour at the toe of the rock apron had reached an elevation of 651.6 ft as shown in Photos 13 and 14 and Fig. 17. This is a rather insignificant scour depth of only 0.4 ft.

3. Flow Condition 4

Flow condition 4 specifies an upstream river flow of 3700 cfs, a low plant discharge of 150 cfs through the 5 ft diameter pipe, and a tailwater elevation of 674.4 ft (Fig. 9). This is the lowest plant discharge used in the model. The flow pattern for condition 4 is shown in Photos 15 and 16, and the pattern and velocities are plotted in Figs. 19 and 20. The flow pattern and velocities at the water surface presented in Fig. 20 were derived from Photo 16. The flow pattern is generally downstream and the velocities low, for the most part less than 0.5 fps. No measurable scour could be detected as indicated in Photo 17 and Fig. 19.

4. Flow Condition 5

Flow condition 5 has the same upstream river discharge of 3700 cfs and tailwater elevation of 674.4 ft. The plant flow has been increased to 350 cfs and was discharged through the 7 ft diameter pipe.

Photos 18 and 19 show the flow pattern in the outlet area and Figs. 21 and 22 present the flow pattern and velocities. Figure 22 was based on Photo 19. With the increase plant discharge, the velocities along the right bank also increased as indicated in a comparison of Figs. 21 and 22 (flow condition 5) with Figs. 19 and 20 (flow condition 4). The flow directions as well as velocities were indeterminate along the left side of the model as indicated by the absence of data on Fig. 21. By adjusting the shutter speed on the camera to obtain the most distinguishable confetti traces as shown in Photo 19, the flow pattern and velocities at the water surface were determined and presented in Fig. 22. The flow pattern is essentially downstream and the jet trajectory deflected to the right and parallel to the bank.

After 8 hours of flow, the local scour reached an elevation of 651.7 ft as shown in Photo 20 and Fig. 21 for a minimal scour of only 0.3 ft.

5. Flow Condition 6

Flow condition 6 has the same upstream river discharge of 3700 cfs and tailwater elevation of 674.4 ft. The plant discharge has been increased to 700 cfs and was discharged through the 8 ft and 5 ft diameter pipes (Fig. 9).

Photos 21 and 22 show the flow pattern on the water surface using confetti. Figure 23 shows the flow pattern and velocities determined with the measuring equipment, and Fig. 24 the flow pattern and velocities at the water surface derived from Photo 22.

The flow jets emerging from the two open pipes are deflected to the right in a short distance and the higher velocity flow is parallel to the right bank. The effect on the navigation channel is minimal. A slow upstream recirculation is noted along the far left bank starting at a distance of 1300 ft but only extends upstream to a distance of 850 ft as indicated in Fig. 23. In comparing Fig. 24 with Fig. 23, some variations in the flow pattern are noticeable at distances 200 to 400 ft across the river. Again, this is probably due to a shift in the flow pattern, and also the very low flow velocities made it difficult to accurately determine the directions. The local scour is slight with only 0.1 ft detected at the toe of the rock apron at the location shown in Fig. 23 and Photo 23.

6. Flow Condition 7

Flow condition 7 specifies an upstream river discharge of 5000 cfs and the maximum plant discharge of 1390 cfs which is discharged through all four pipes (Fig. 9). The flow pattern for condition 7 shown in Photos 24 and 25, and Figs. 25 and 26, is similar to the pattern for condition 6. The jet trajectory is deflected to the right and the high velocity flow parallels the right bank. The upstream recirculation along the far left bank also occurs. In both of these areas the velocities are somewhat higher for condition 7 as compared to condition 6 as would be expected with higher discharges in both the river and from the plant. Local scour reached a depth of 0.5 ft at the location shown in Fig. 25 and Photo 26.

7. Flow Condition 8

Flow condition 8 has an upstream river flow of 6400 cfs and a plant discharge of 800 cfs through the 8 ft and 7 ft diameter pipes (Fig. 9). With this higher river flow and lower plant flow the overall flow pattern is in a downstream direction as indicated in Photos 27 and 28, and in Figs. 27 and 28. A slight reversal of flow occurs from a river distance of 900 ft back toward the outlet to distance 700 ft as indicated in Fig. 28. The main river channel remains essentially unaffected by this plant flow. Local scour of 0.6 ft was measured at the location shown in Fig. 27 and Photo 29.

8. Flow Condition 9

Flow condition 9 specifies an increased upstream river flow of 7500 cfs and the maximum plant discharge of 1390 cfs (Fig. 9). Pictures of the flow pattern with confetti streaks delineating the pattern are shown in Photos 30 and 31. The flow directions determined with the thread indicator and measured velocities are presented in Fig. 29. An area along the left side of the model has little motion and the flow directions could not be determined. Figure 30 shows the flow pattern and velocities at the water surface that were derived from Photo 31. Figure 30 compares quite well with Fig. 29. The flow pattern is characterized by the higher velocities along the right bank and lower unmeasurable velocities along the left bank. Local scour increased to a depth of 1.4 ft as indicated in Fig. 29 and Photo 32.

9. Flow Condition 10

Flow condition 10 specifies an upstream river discharge of 12,000 cfs, the maximum tested in the model, and the maximum plant discharge of 1390 cfs (Fig. 9).

Photos 33, 34, and 35 show the flow pattern delineated by confetti streaks. The pattern determined using the thread indicator and velocities measured with the pygmy current meter are presented in Fig. 31. The pattern and velocities determined from Photo 35 are shown in Fig. 32 and agree quite well with those in Fig. 31. As is evident in examining the figures, the flow velocities are higher along the right side of the river. A slight recirculation occurs along the right bank just downstream of the outlet. Figure 31 may also be compared with Fig. 11, which shows the flow pattern and velocities at mid-depth with original river contours and for flow condition 1. The comparison shows the velocities have increased along the right side of the river when the plant is discharging the maximum flow of 1390 cfs as in flow condition 10. The local scour reached an elevation of 651.1 ft at the toe of rock apron at the location indicated in Fig. 31 and Photos 36, 37, and 38. This is a depth of scour of 0.9 ft. In these photos the contours outside of the outlet basin have been included and are the same as the original contours shown in Photos 3, 4, and 5. No erosion has taken place except the minimum local scour that occurred at the toe of the rock apron in the outlet basin.

IV. CONCLUSIONS

1. Good correlation of flow patterns and velocities observed on the laboratory model with the Corps of Engineers model provided a positive verification of the laboratory model.

2. For the lowest river flow of 3390 cfs and the maximum plant discharge of 1390 cfs (flow conditions 2 and 3), the jet trajectory from the discharge pipes extended across the model impinging on the far side. Most of the flow was turned downstream with some recirculated upstream. A recirculation along the right bank, back toward the outlet was also observed and was stronger for flow condition 2, which was a condition of zero wind velocity.

   For a river discharge of 3700 cfs and the lower plant discharged of 150 cfs and 350 cfs, which are flow conditions 4 and 5, respectively, the flow pattern is essentially downstream with some higher velocities along the right bank. For flow condition 6 which specifies an upstream river discharge of 3700 cfs and a plant discharge of 700 cfs, the jet was deflected and paralled the right bank. Also a slight recirculation occurred along the left side.

   For flow condition 7 which specifies an upstream river discharge of 5000 cfs and a plant discharge of 1390 cfs the jet trajectory also parallels the right bank. The velocities along the right bank and the recirculating velocities on the left side are higher for condition 7 as compared to condition 6.

   With higher upstream river discharges of 6400, 7500, and 12,000 cfs as specified in flow conditions 8, 9, and 10, respectively, the river flow appears dominant and the flow pattern is essentially downstream. The velocities are higher along the right bank.

3. The only erosion that occurred was confined to local scour at the toe of the rock apron in the outlet basin. The scour depths varied from

no measurable amount to 2.0 ft. For flow condition 2, the scour depth was the maximum of 2.0 ft and for condition 9 was 1.4 ft; for all other conditions the scour depth was less than 1.0 ft. The outlet basin with the protection riprap was quite effective in keeping scour to a minimum.

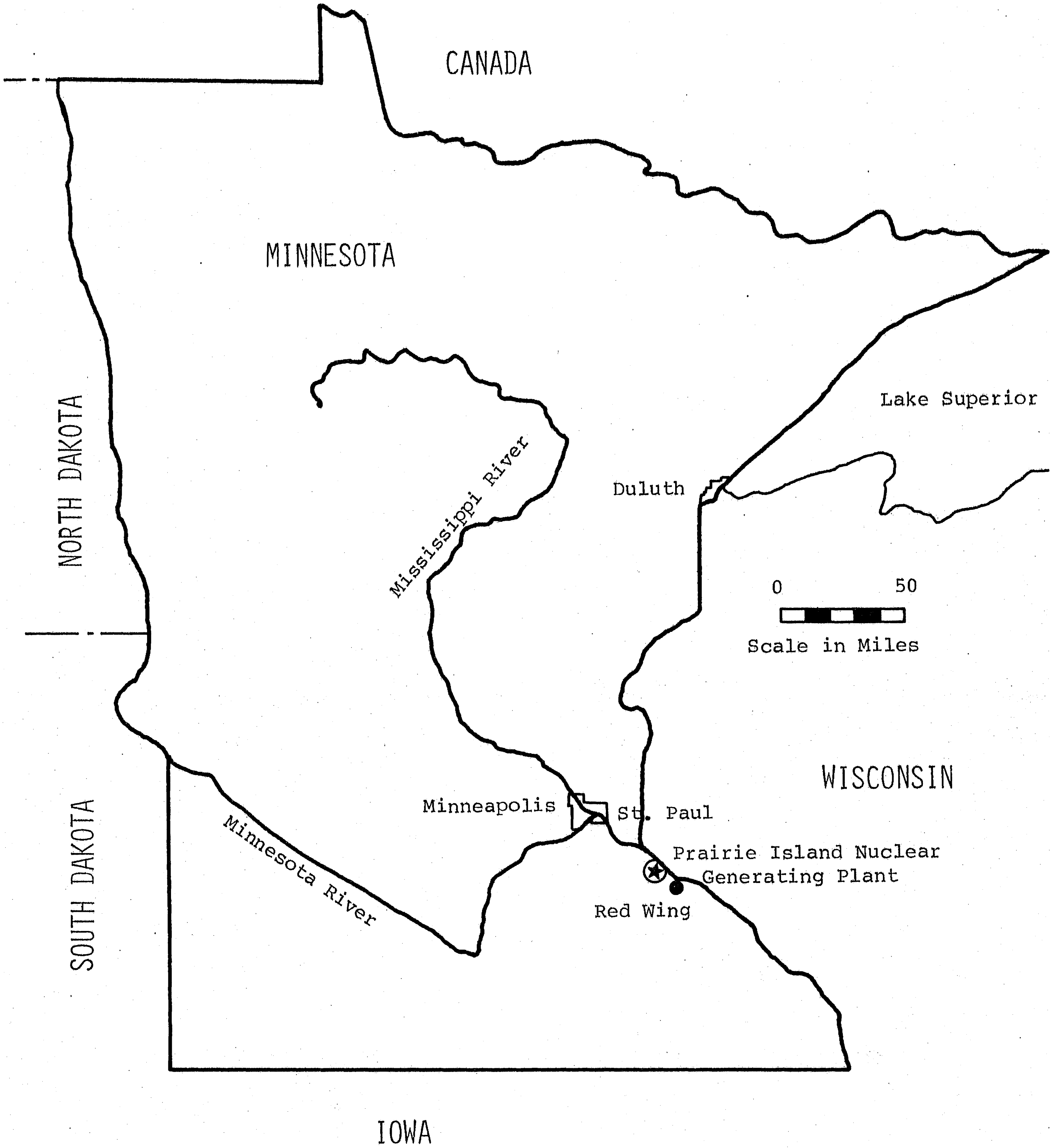
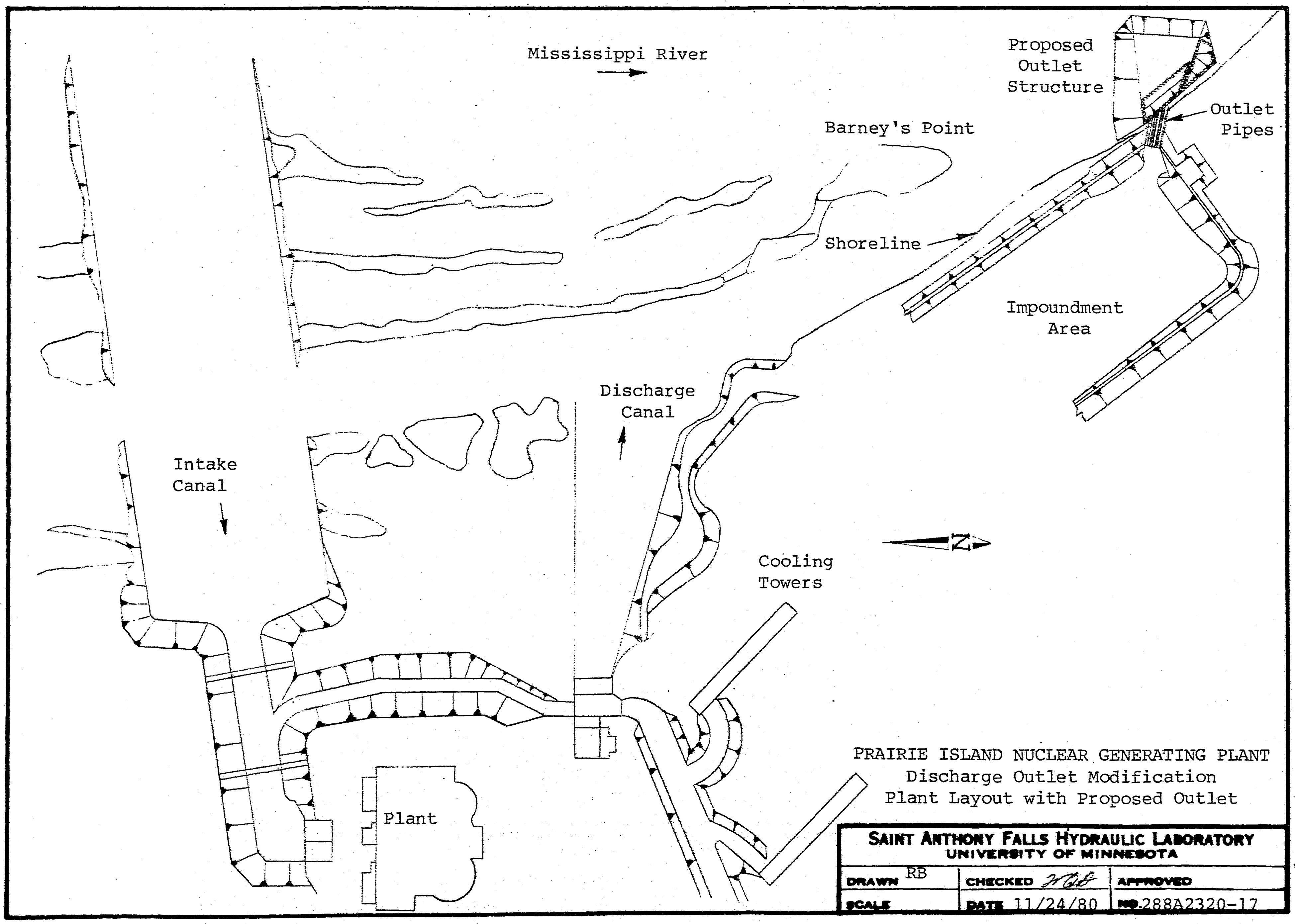


Fig. 1. Location of Prairie Island Nuclear Generating Plant.


Mississippi River
Proposed
Outlet
Structure
Outlet
Pipes
Barney's Point
Shoreline
Impoundment
Area
Discharge
Canal
Intake
Canal
Cooling
Towers
N
Plant
PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Plant Layout with Proposed Outlet
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
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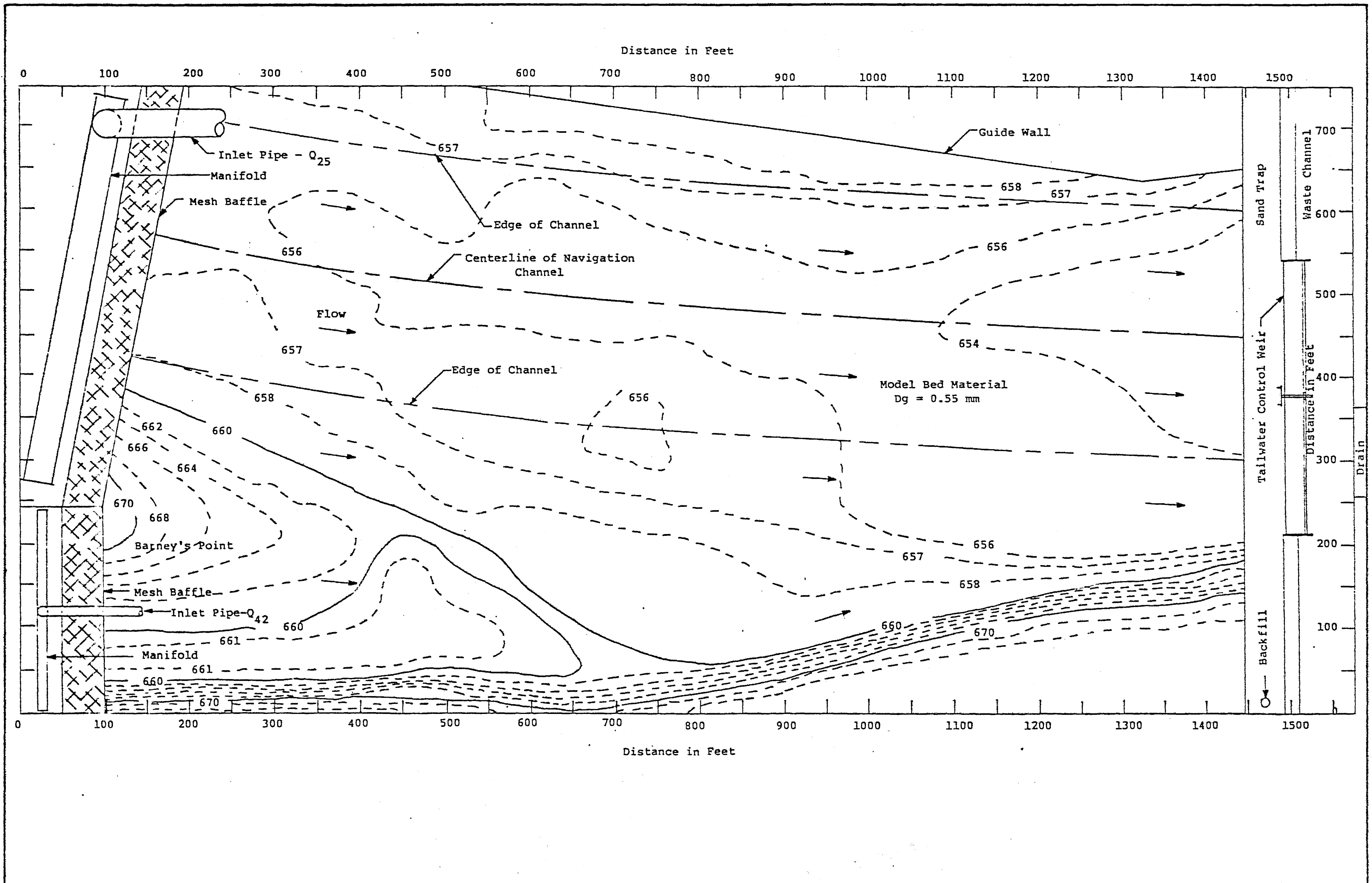
CHECKED
APPROVED
SCALE
DATE 11/24/80
NO. 288A2320-17

Fig. 2



PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Model Layout With Original River Contours
Model Scale 1:32
Contour Elevations are in Feet

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
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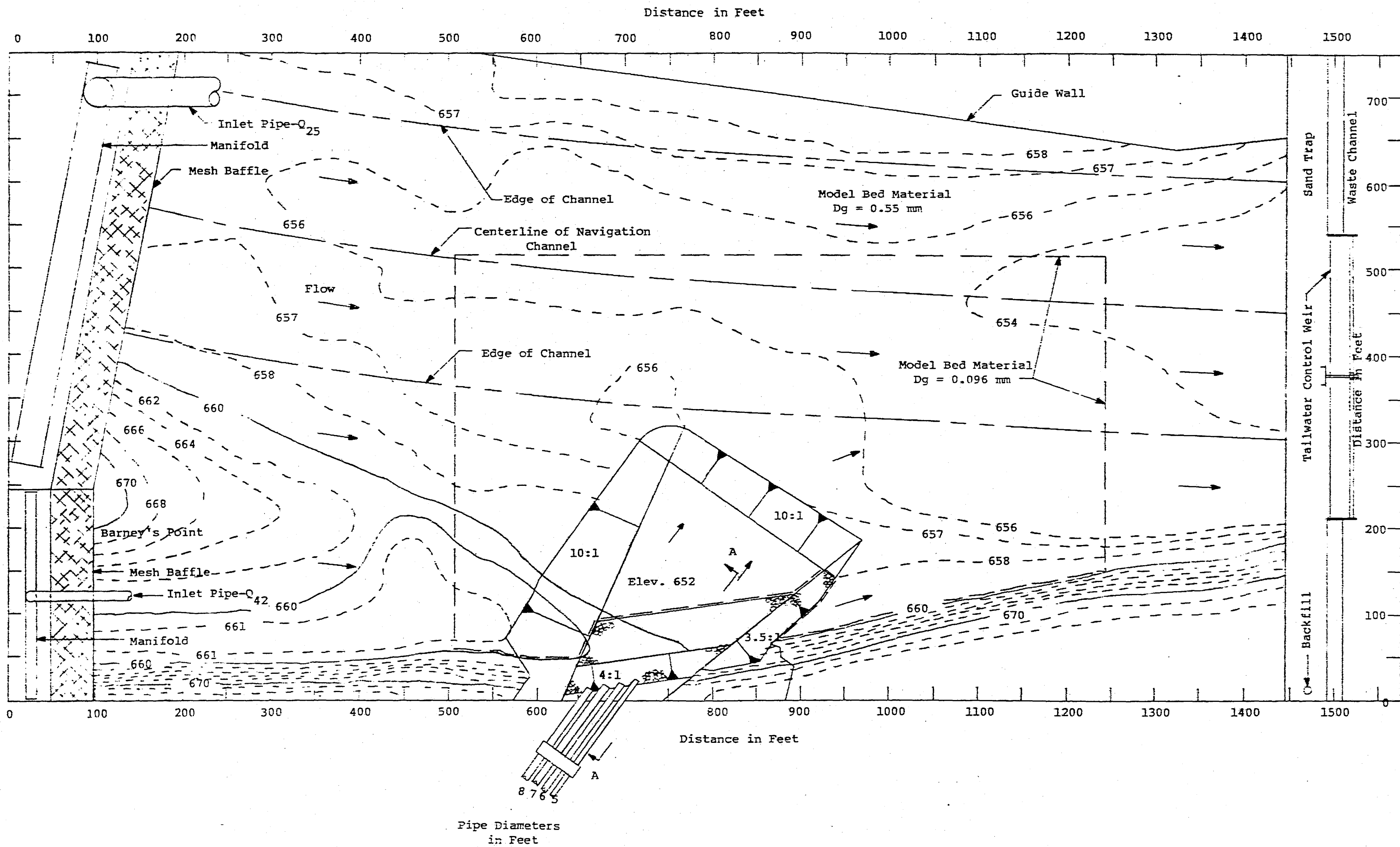
SCALE	DATE 5/8/80	NO. 288B510-1

Fig. 3



PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Model Layout With Discharge Structure
Model Scale 1:32
Contour Elevations are in Feet

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
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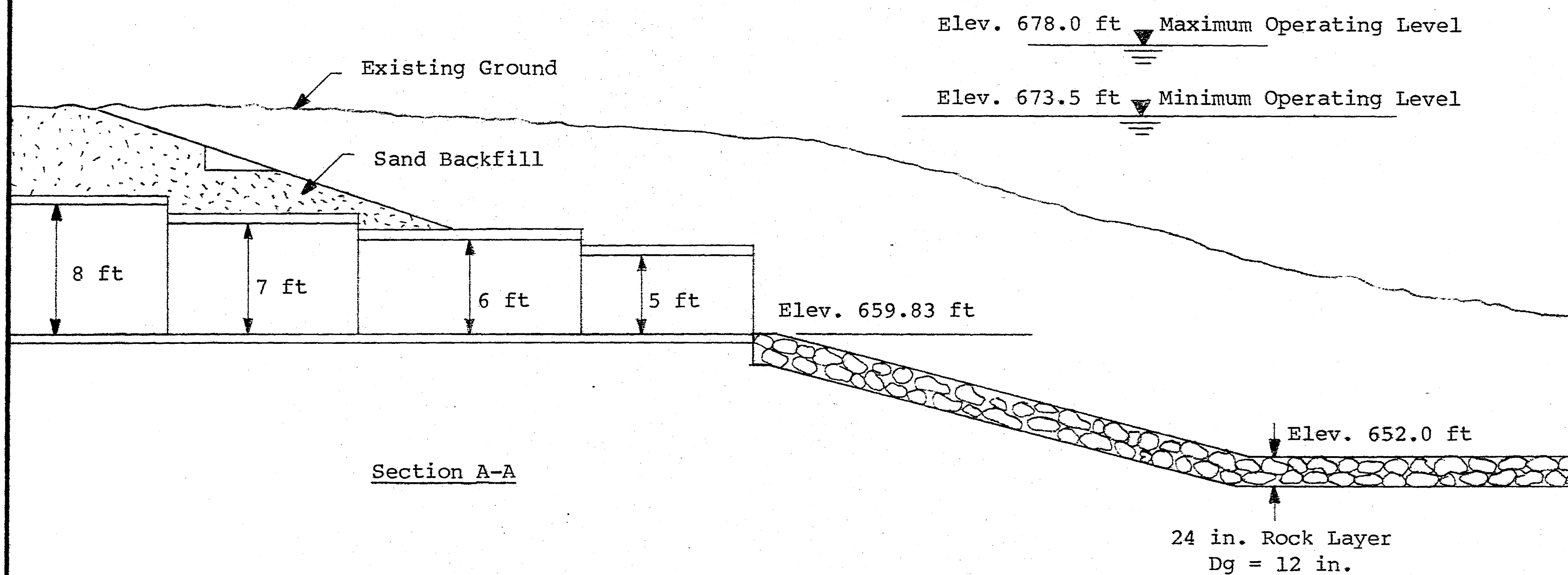
Fig. 4



PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Model Layout With Discharge Structure
Model Scale 1:32

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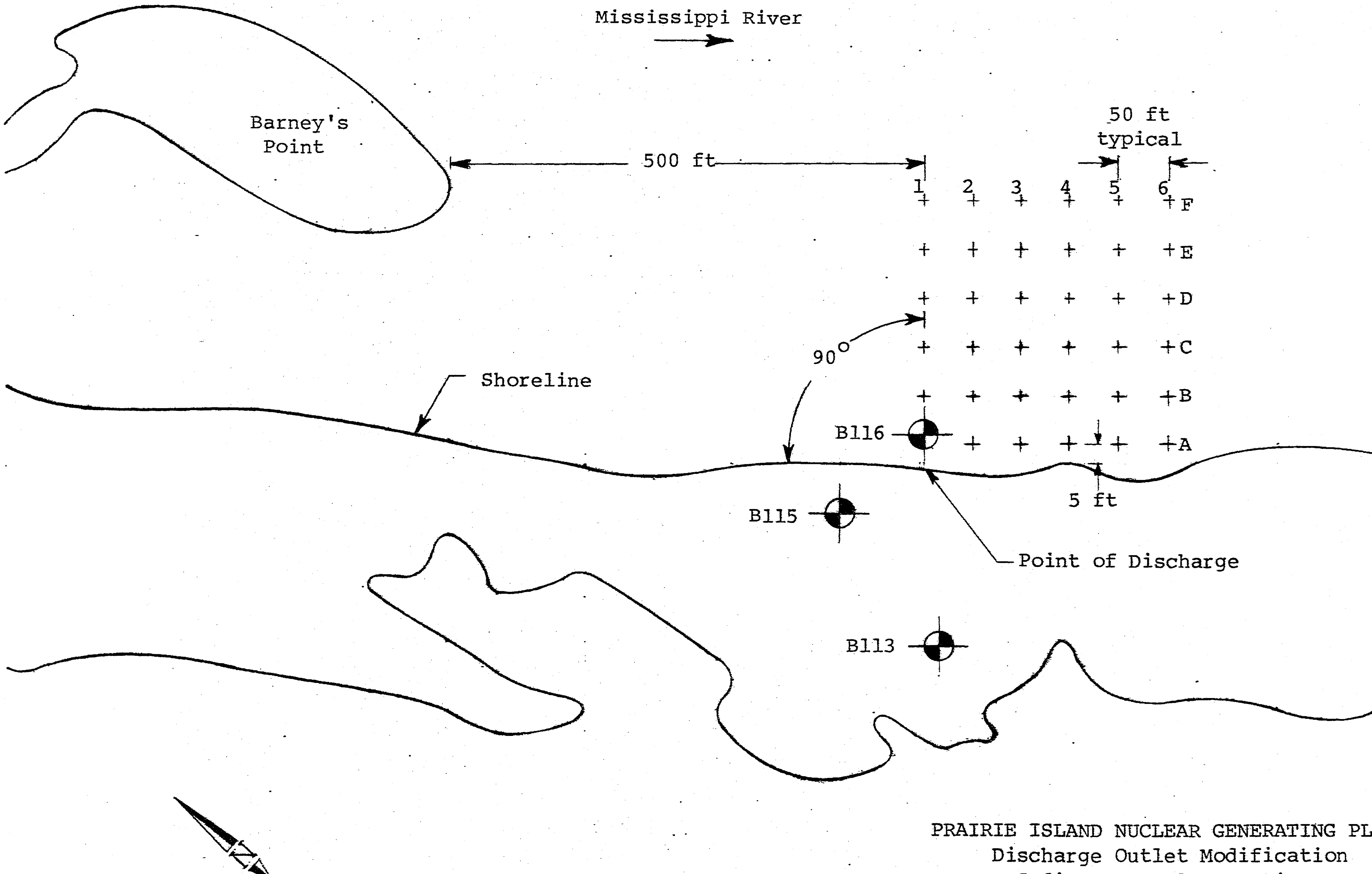
SCALE	DATE 6/13/80	NO. 288A2320-1

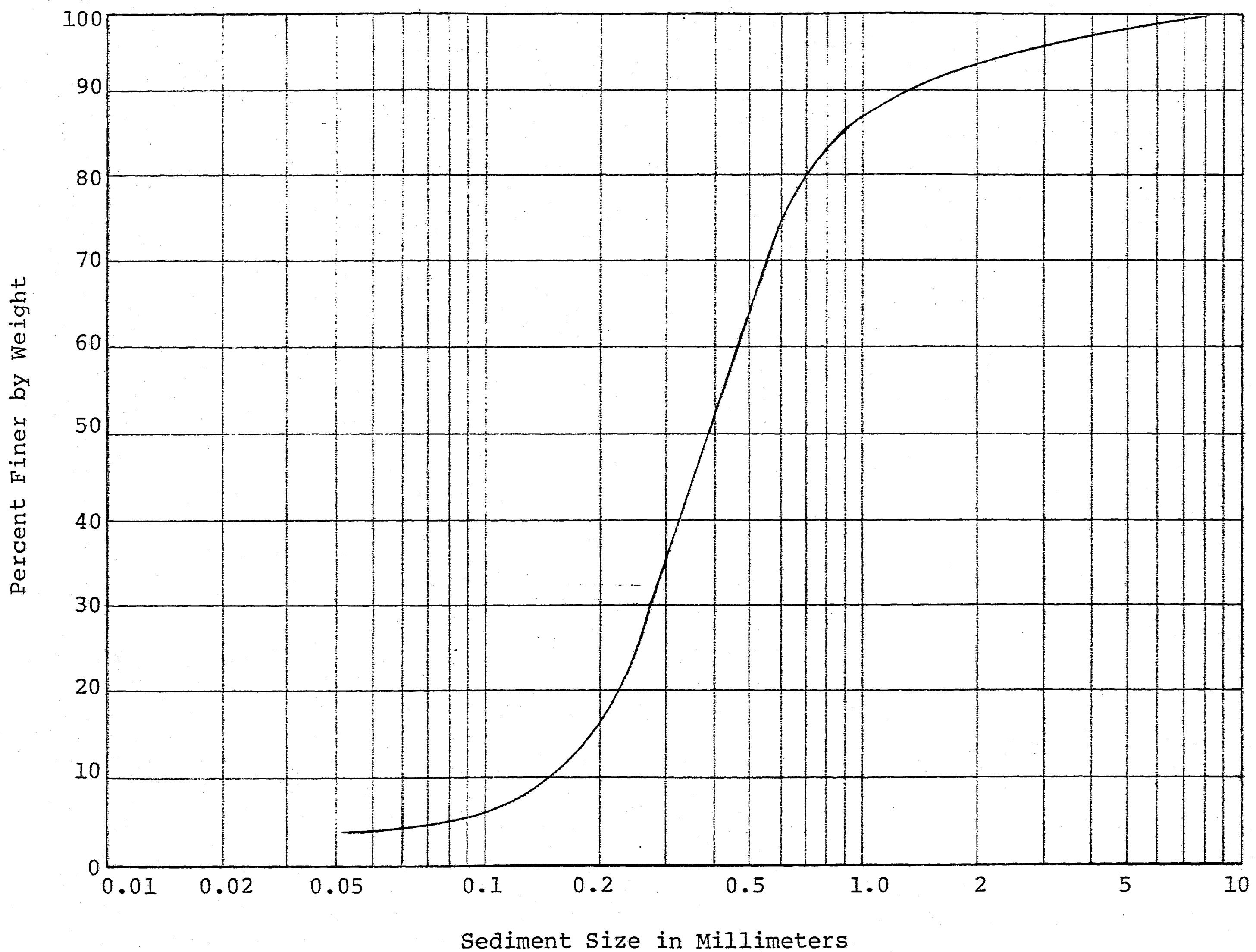
Fig. 5



PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Sediment Sample Locations

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN RB	CHECKED [illegible]	APPROVED
SCALE	DATE 11/24/80	NO. 288A2320-16

Fig. 6



PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Composite Size Distribution of Prototype Samples

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
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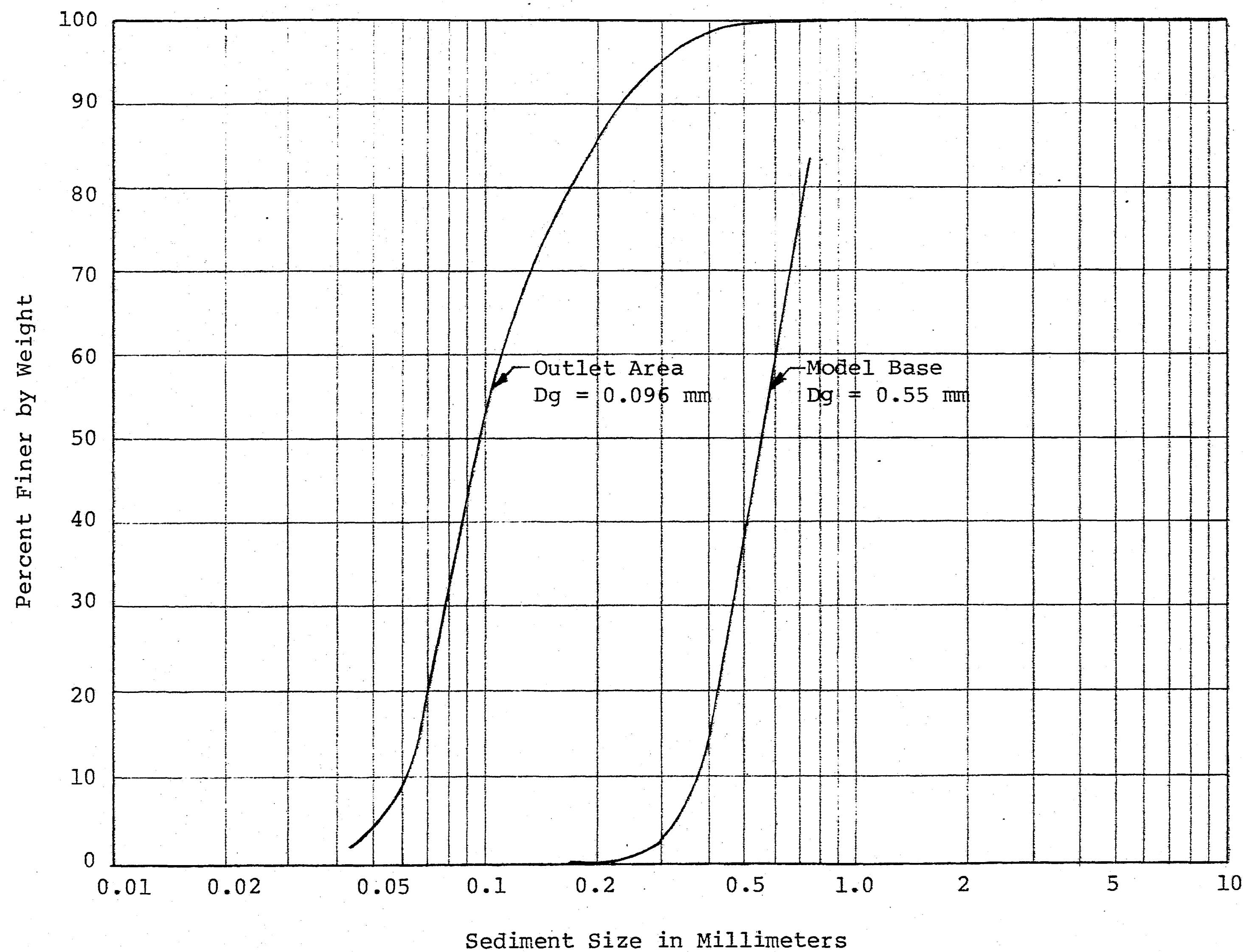
Fig. 7



PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Size Distribution of Sands Used in the Model
Model Scale 1:32

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Fig. 8

FLOW CONDITIONS INVESTIGATED

Flow Condition No.	Upstream Discharge Q_T - cfs	Q_{42}^{*} cfs	Q_{25}^{**} cfs	Plant Discharge Q_D - cfs	Pipe Discharges - cfs 8 ft dia.	7 ft dia.	6 ft dia.	5 ft dia.	T.W. Elev. ft	Comments
1	12,000	1314	10,656	0					673.8	Existing Discharge
2	3,390	-165	2,135	1,390	521	394	284	197	674.4	No Wind
3	3,390	-540	2,510	1,390	521	394	284	197	674.4	10 mph south wind
4	3,700	329	3,191	150				150	674.4	
5	3,700	291	3,029	350		350			674.4	
6	3,700	193	2,777	700	521			197	674.4	
7	5,000	106	3,474	1,390	521	394	284	197	674.4	
8	6,400	457	5,113	800	455	345			674.3	
9	7,500	409	5,671	1,390	521	394	284	197	674.2	
10	12,000	894	9,686	1,390	521	394	284	197	673.8	

*Discharge on right side of Barney's Point

**Discharge in main river channel (left side of Barney's Point)

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Conditions Investigated
Model Scale 1:32

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

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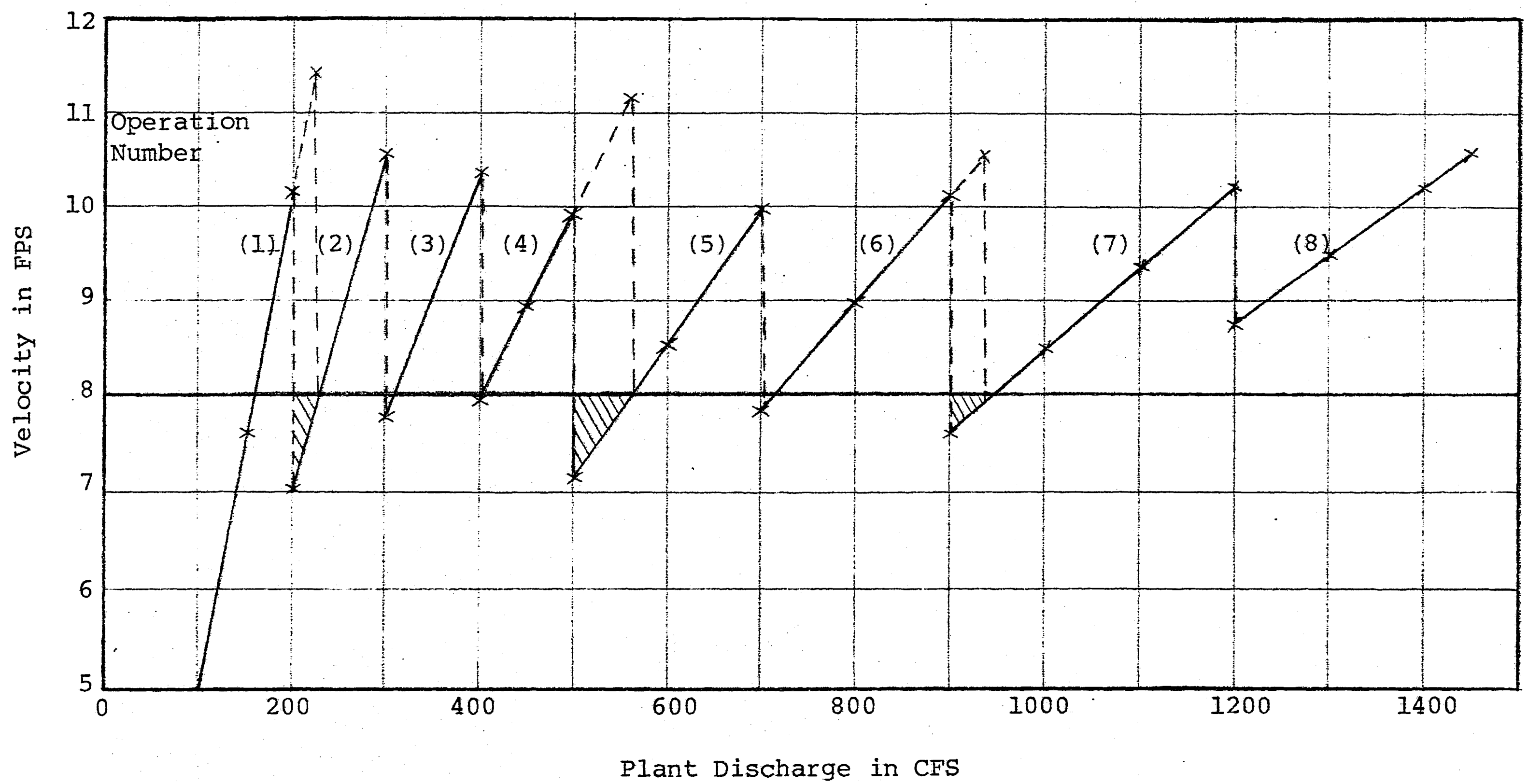
SCALE	DATE 11/24/80	NO. 288A2320-15

Fig. 9



Plant Discharges Tested-cfs	Operation Number	Pipes Open Diameter in ft
150	1	5
-	2	6
350	3	7
-	4	8
700	5	8 and 5
800	6	8 and 7
-	7	8, 7 and 6
1390	8	8, 7, 6 and 5

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Operating Schedule for Plant Discharges
Model Scale 1:32

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UNIVERSITY OF MINNESOTA

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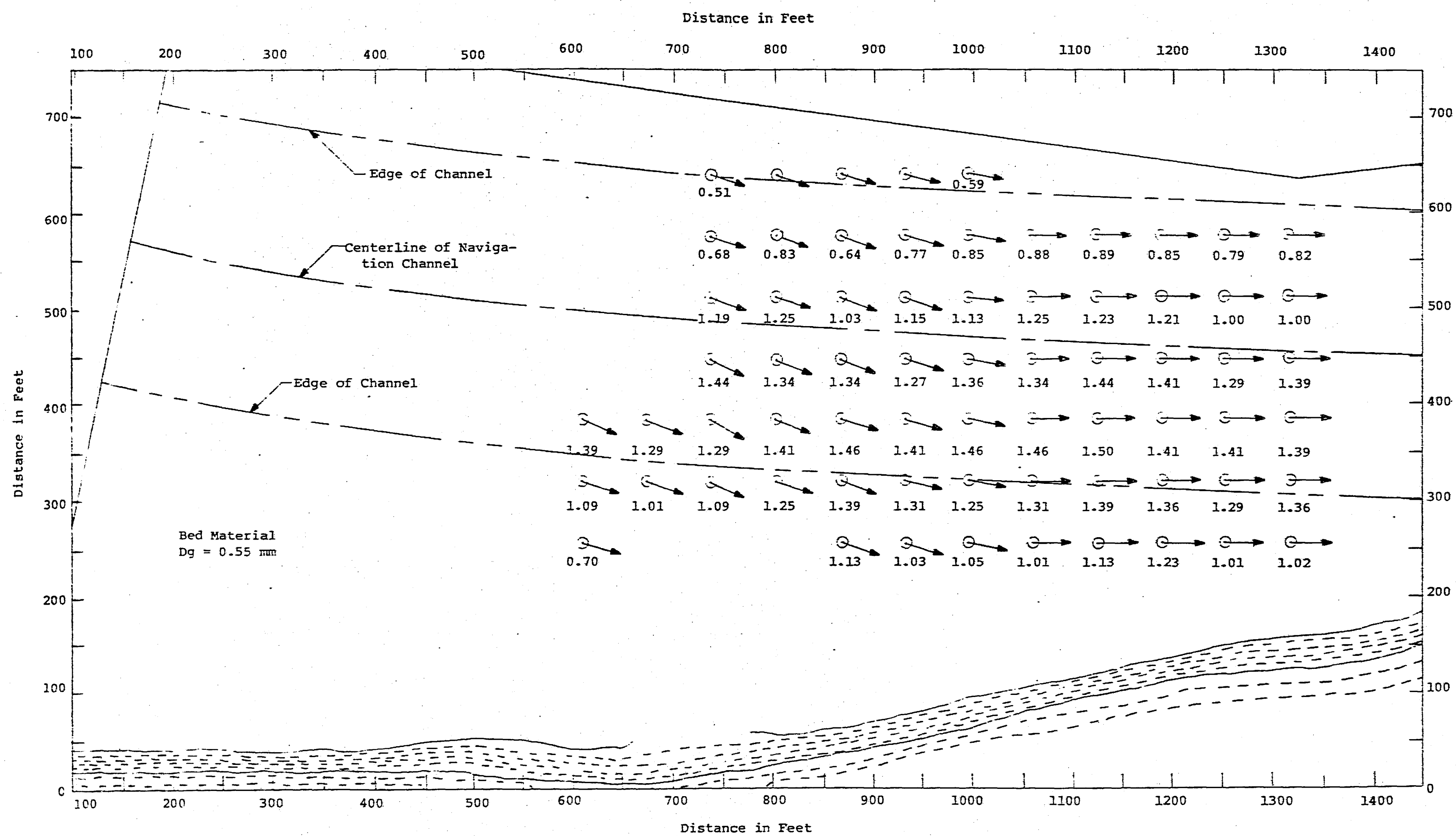
Fig. 10



Velocity less than 0.5 fps, direction indeterminate

Velocity less than 0.5 fps, direction as indicated

Velocity in fps, direction as indicated
1.39

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Velocity Pattern With Original River Contours
Flow Pattern and Velocities at Mid-Depth
Flow Condition 1, Model Scale 1:32
Q_T=12,000 cfs, Q_D=0 cfs, T.W.=673.8 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
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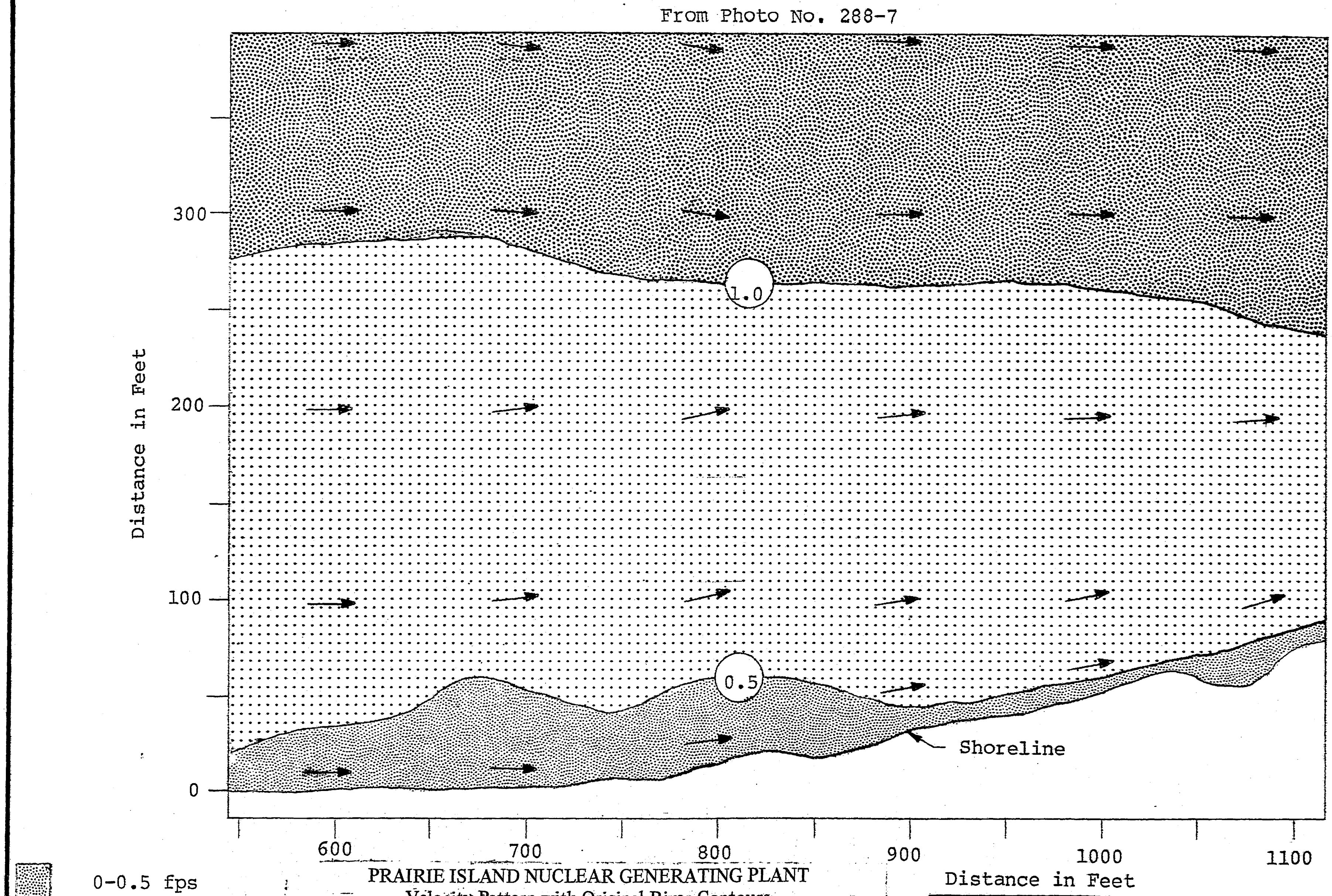
SCALE	DATE 5/12/80	NO. 288B510-3

Fig. 11



PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Velocity Pattern with Original River Contours
Flow Pattern and Velocities at the Water Surface
Flow Condition 1, Model Scale 1:32
Q_T = 12,000 cfs, Q_D = 0 cfs, T.W. = 673.8 ft

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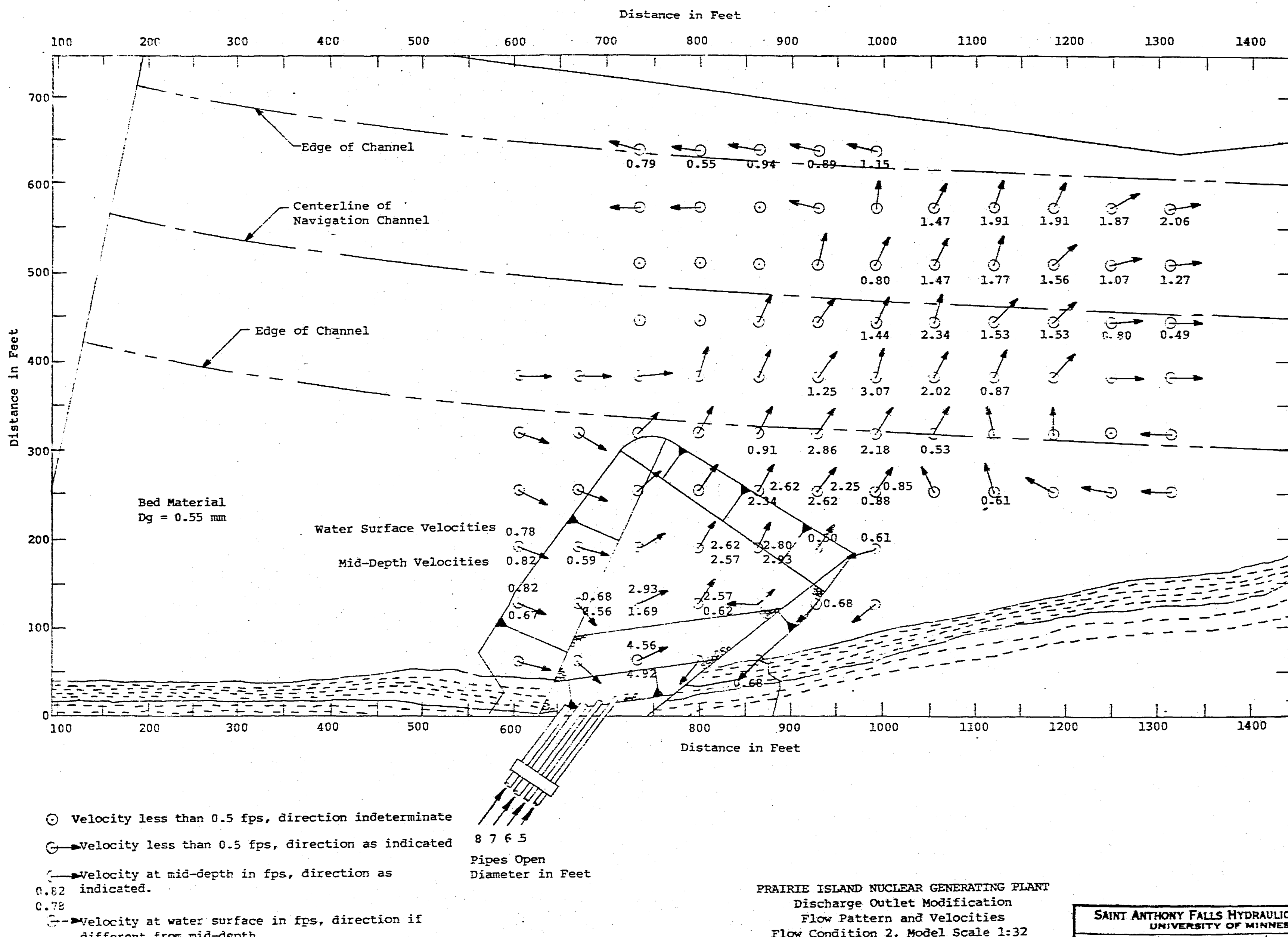
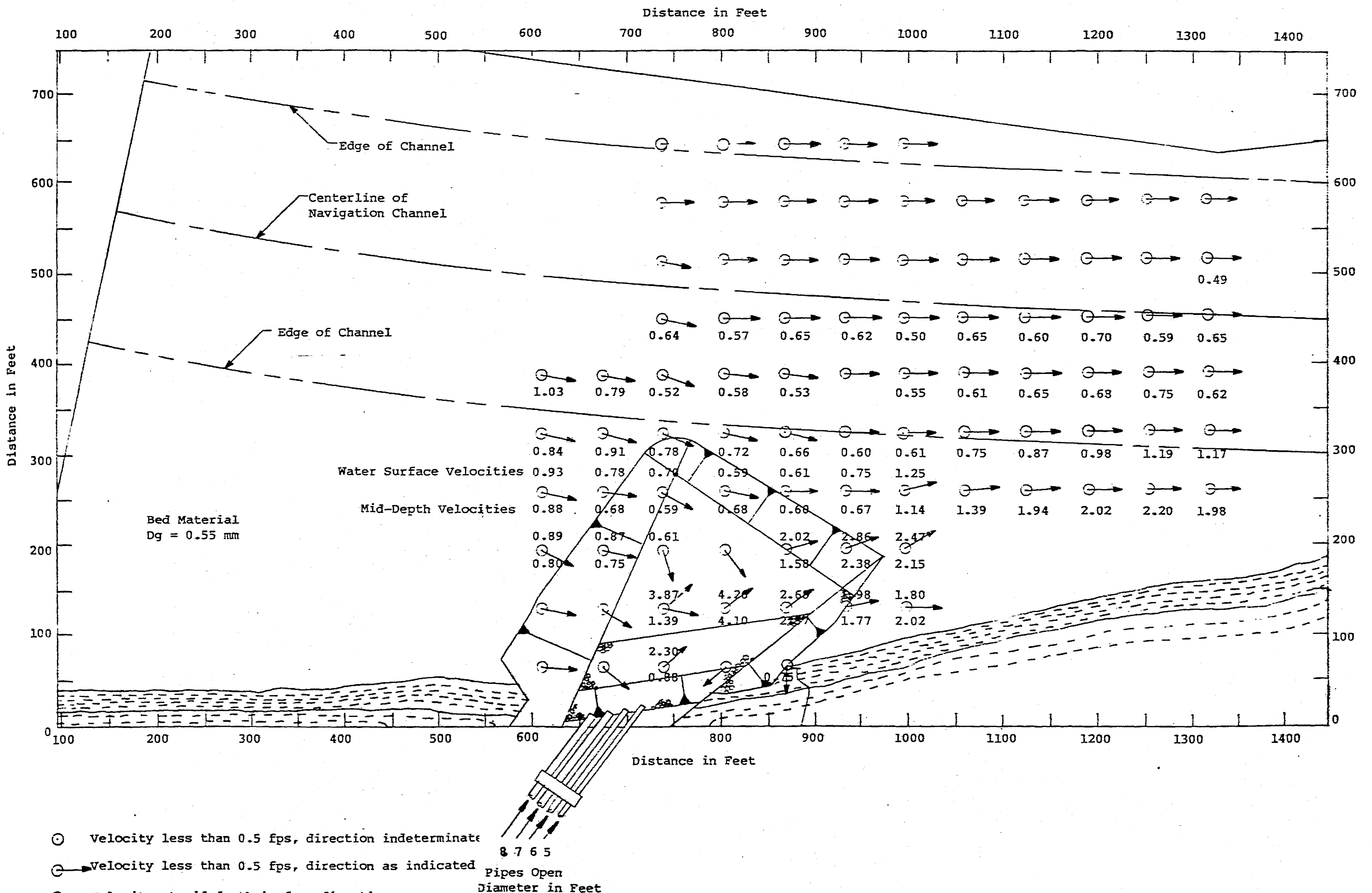
Fig. 12



PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities
Flow Condition 2, Model Scale 1:32
Q_T=3390 cfs, Q_D=1390 cfs, T.W.=674.4 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY, UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 5/14/80	NO. 288B510-4

Fig. 13



⊙ Velocity less than 0.5 fps, direction indeterminate

⊖→ Velocity less than 0.5 fps, direction as indicated

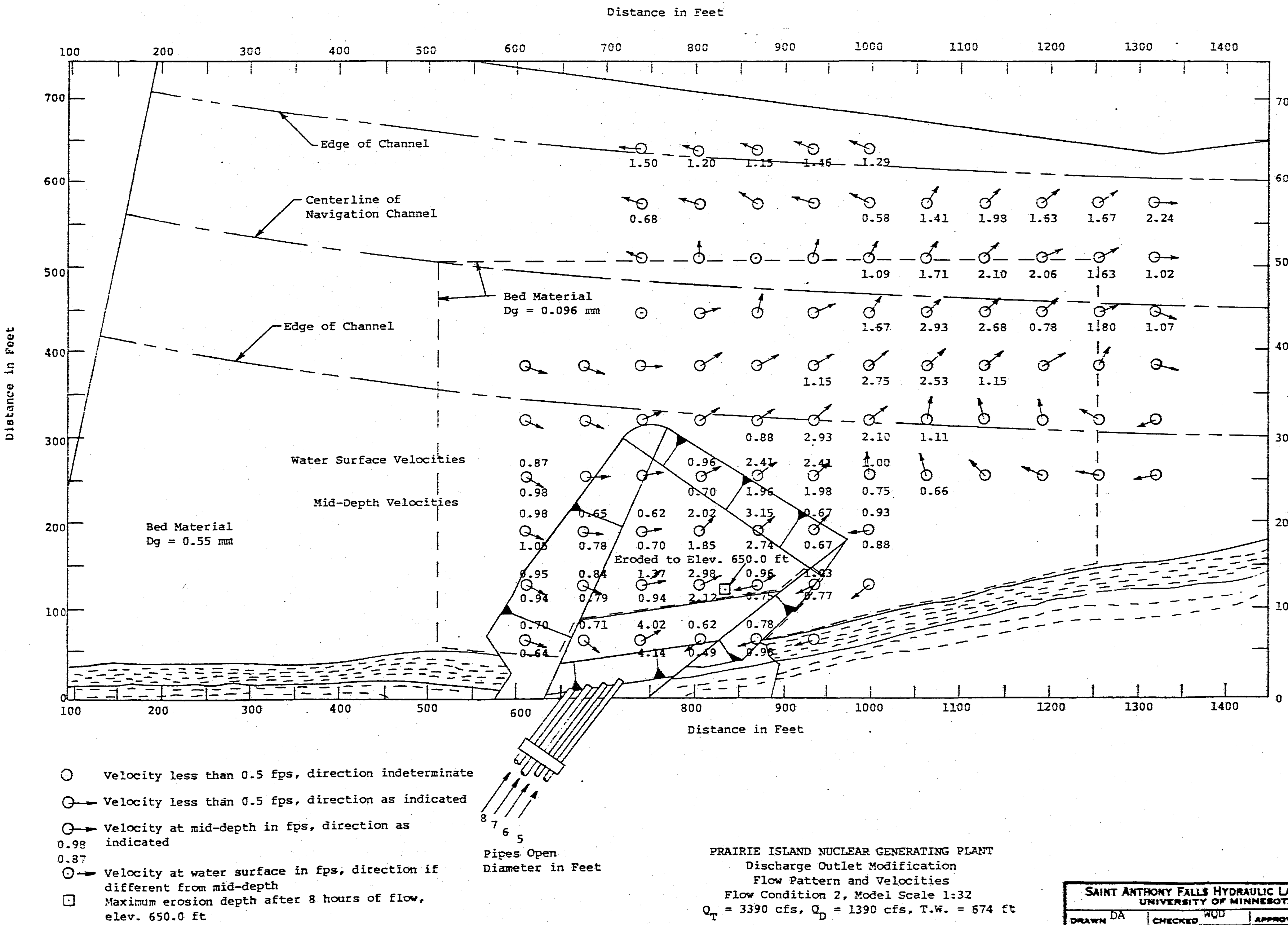
⊖→ Velocity at mid-depth in fps, direction as indicated
0.88
0.93

⊖→ Velocity at water surface in fps, direction if different from mid-depth

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities
Flow Condition 10, Model Scale 1:32
Q_T=12000 cfs, Q_D=1390 cfs, T.W.=673.8 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 5/14/80	NO. 288B510-5

Fig. 14



PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities
Flow Condition 2, Model Scale 1:32
Q_T = 3390 cfs, Q_D = 1390 cfs, T.W. = 674 ft

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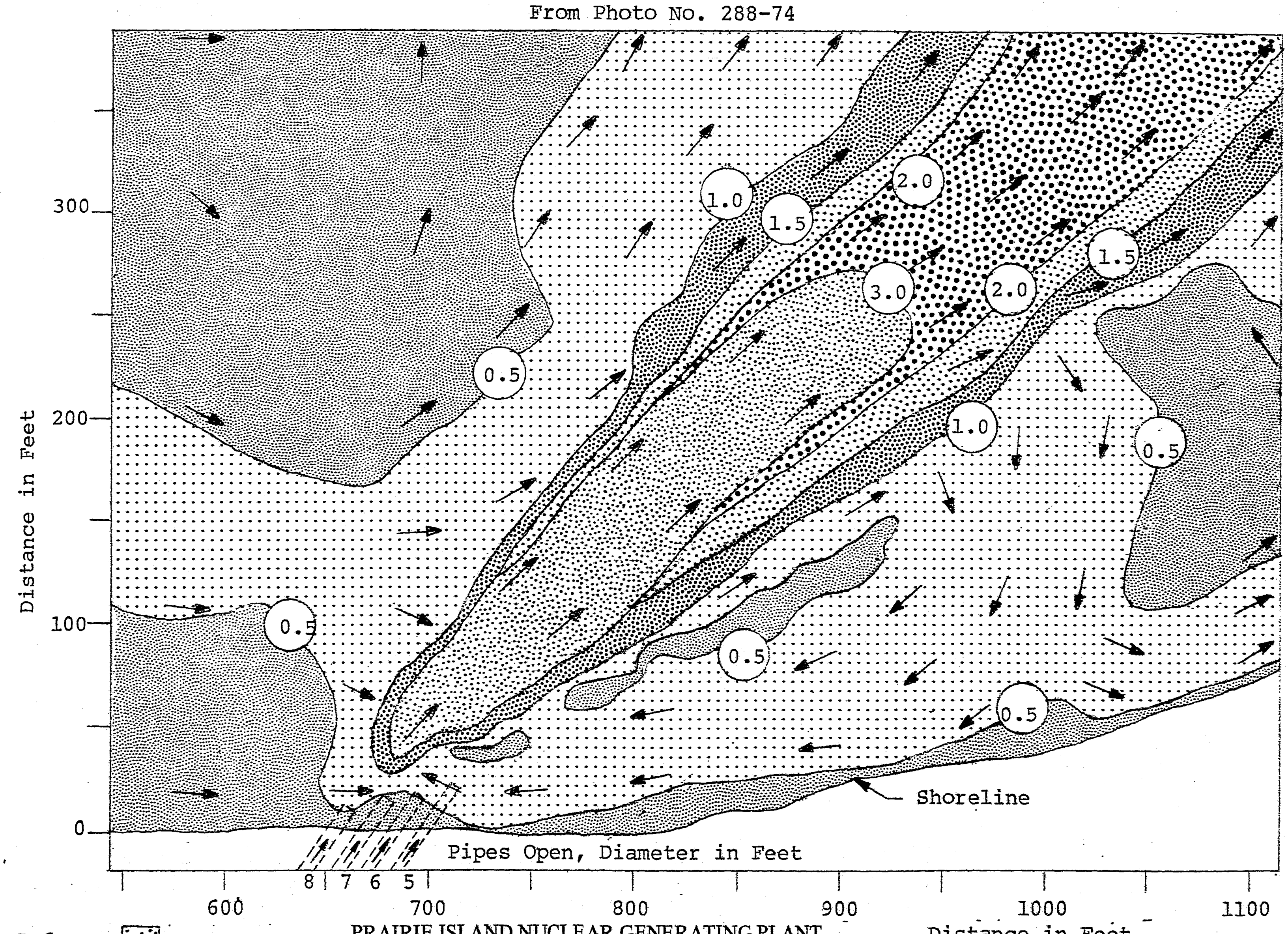
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED WQD	APPROVED
SCALE	DATE 5/14/80	NO. 288B510-6

Fig. 15



- 0-0.5 fps
- 0.5-1.0 fps
- 1.0-1.5 fps
- 1.5-2.0 fps
- 2.0-3.0 fps
- > 3.0 fps

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities at the Water Surface
Flow Condition 2, Model Scale 1:32
Q_T = 3390 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 7/1/80	NO. 288A2320-5

Fig. 16

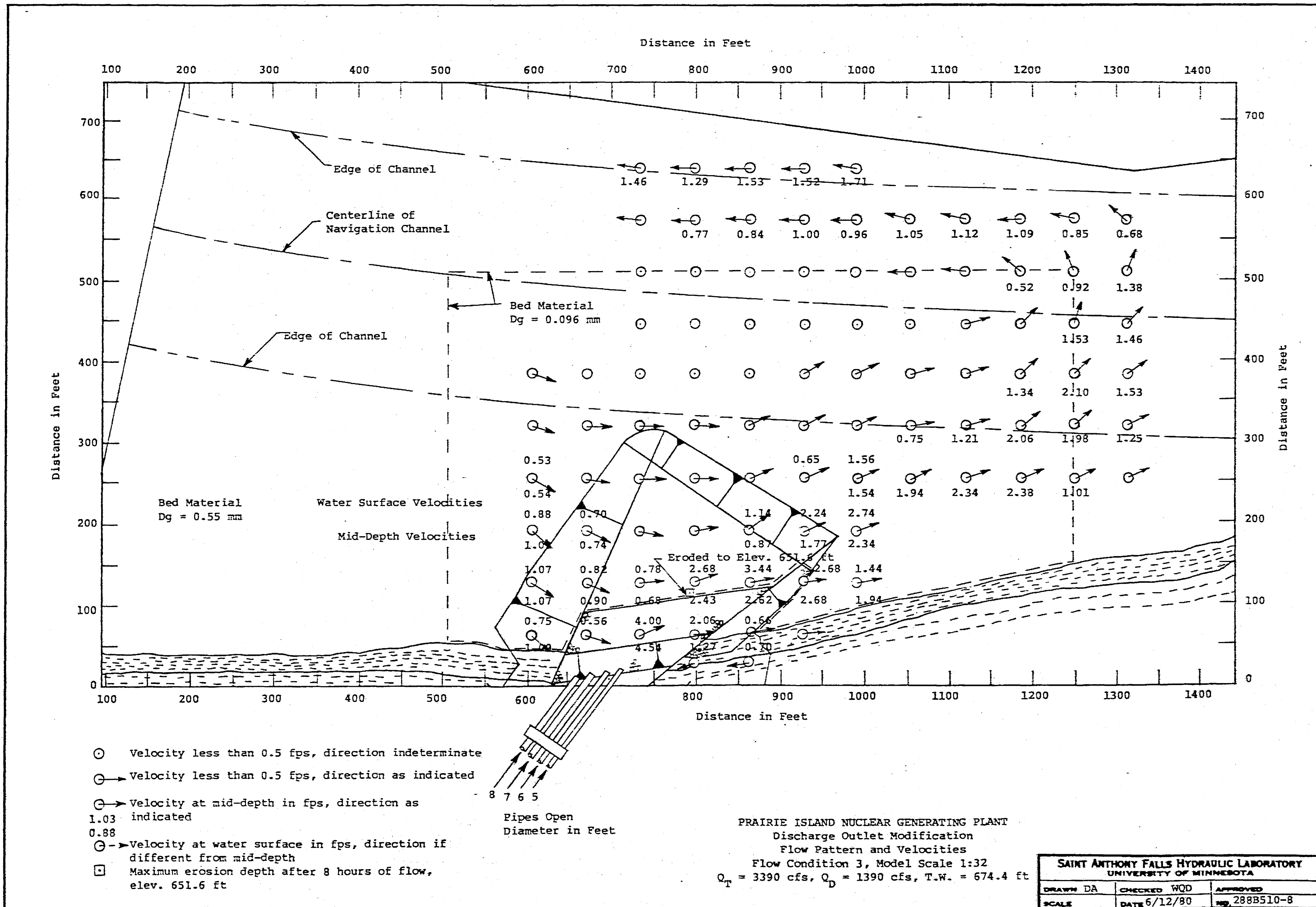
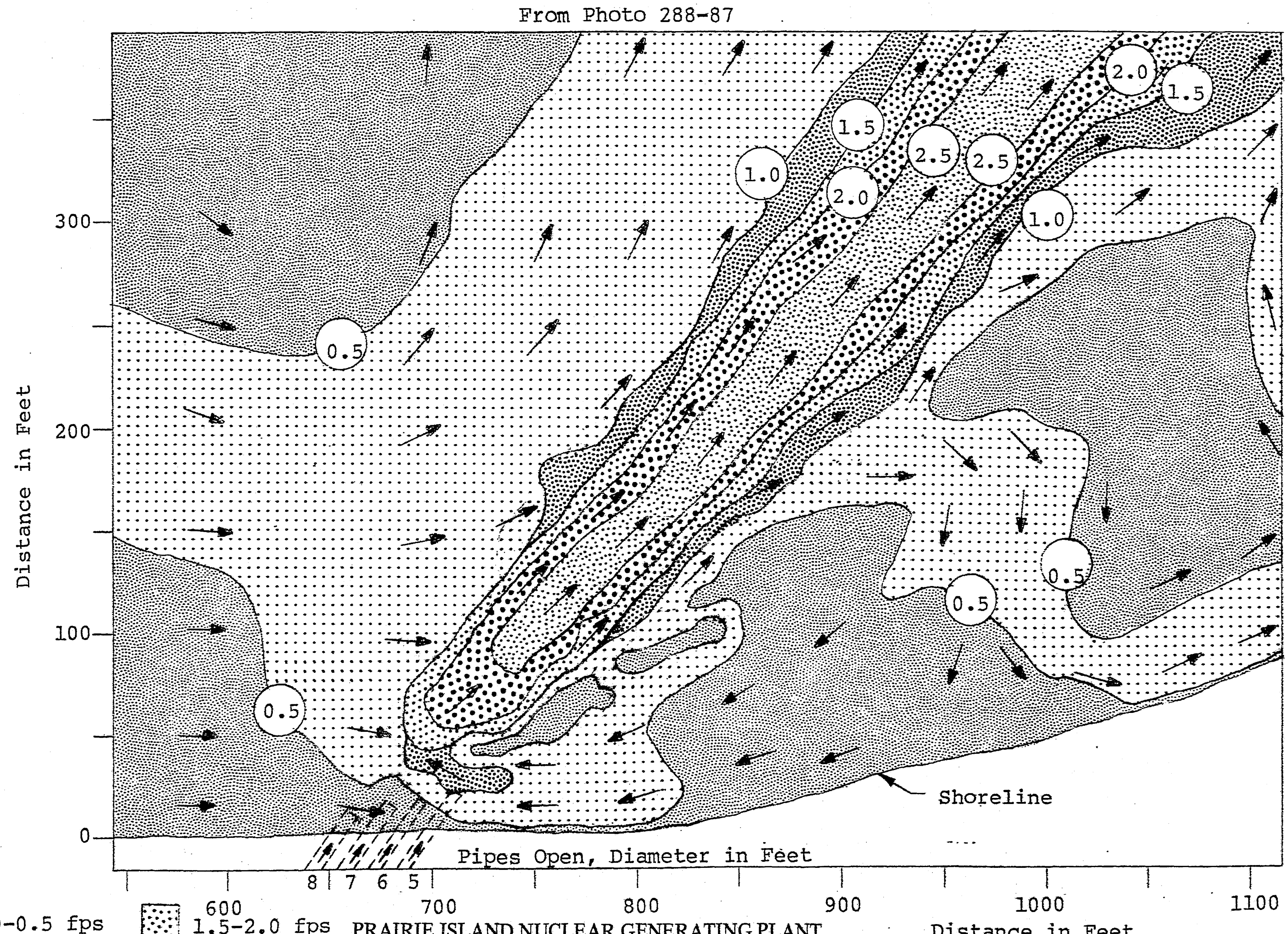

Distance in Feet
Distance in Feet
Distance in Feet
Distance in Feet
Edge of Channel
Centerline of Navigation Channel
Edge of Channel
Bed Material Dg = 0.096 mm
Bed Material Dg = 0.55 mm
Water Surface Velocities
Mid-Depth Velocities
Eroded to Elev. 651.6 ft
8 7 6 5
Pipes Open
Diameter in Feet
Velocity less than 0.5 fps, direction indeterminate
Velocity less than 0.5 fps, direction as indicated
Velocity at mid-depth in fps, direction as indicated
1.03
0.88
Velocity at water surface in fps, direction if different from mid-depth
Maximum erosion depth after 8 hours of flow, elev. 651.6 ft
PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities
Flow Condition 3, Model Scale 1:32
Q_T = 3390 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN DA
CHECKED WQD
APPROVED
SCALE
DATE 6/12/80
NO. 288B510-8

Fig. 17

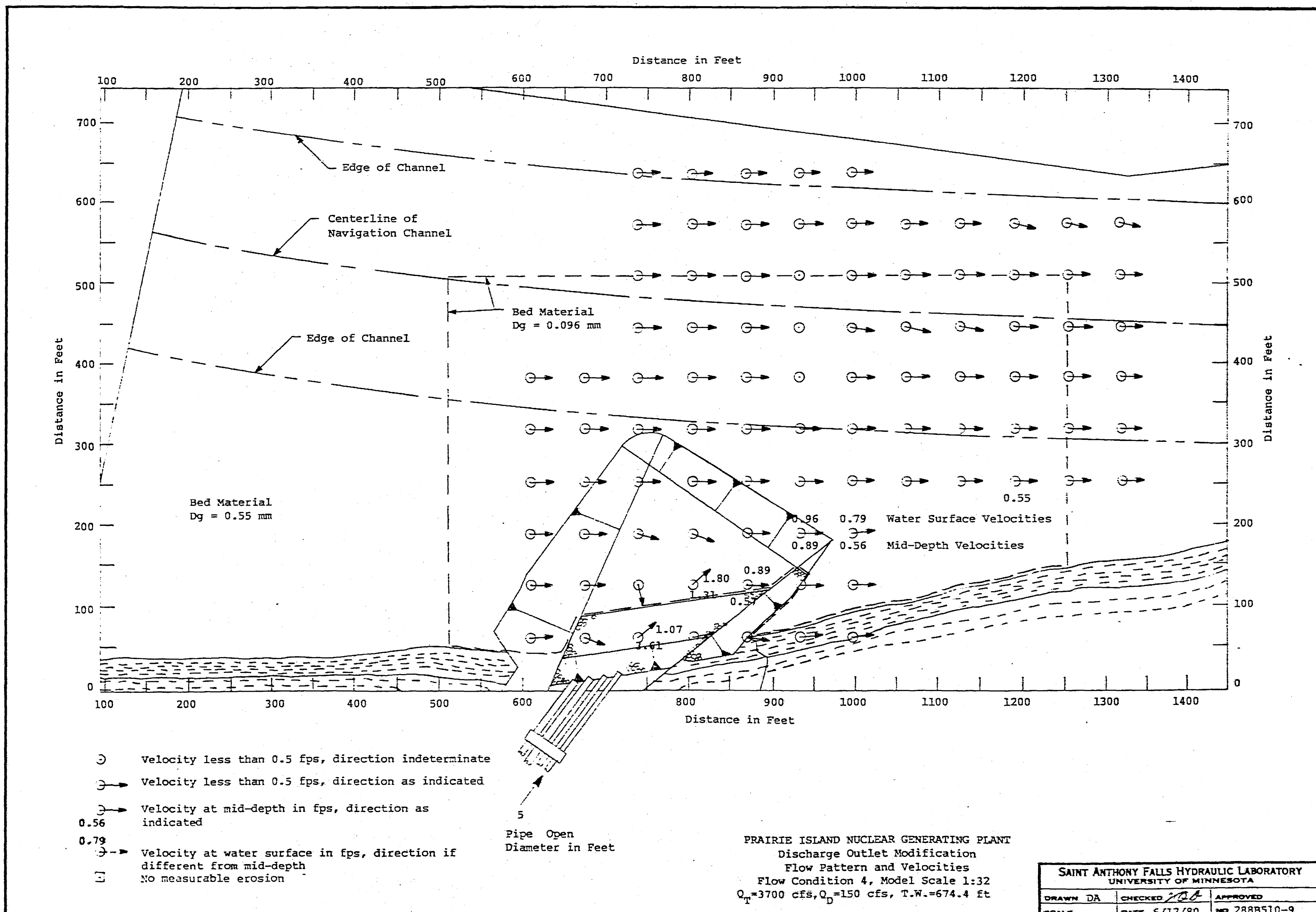


0-0.5 fps
0.5-1.0 fps
1.0-1.5 fps
1.5-2.0 fps
2.0-2.5 fps
> 2.5 fps

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities at the Water Surface
Flow Condition 3, Model Scale 1:32
Q_T = 3390 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED [illegible]	APPROVED
SCALE	DATE 7/1/80	NO. 288A2320-6

Fig. 18



Distance in Feet
Distance in Feet
Distance in Feet
Distance in Feet
Edge of Channel
Centerline of Navigation Channel
Edge of Channel
Bed Material Dg = 0.096 mm
Bed Material Dg = 0.55 mm
0.96 0.79 Water Surface Velocities
0.89 0.56 Mid-Depth Velocities
0.55
1.80
0.89
1.31
0.57
1.07
1.61
5
Pipe Open Diameter in Feet
Velocity less than 0.5 fps, direction indeterminate
Velocity less than 0.5 fps, direction as indicated
Velocity at mid-depth in fps, direction as indicated
0.56
0.79
Velocity at water surface in fps, direction if different from mid-depth
No measurable erosion
PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities
Flow Condition 4, Model Scale 1:32
Q_T=3700 cfs, Q_D=150 cfs, T.W.=674.4 ft
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
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APPROVED
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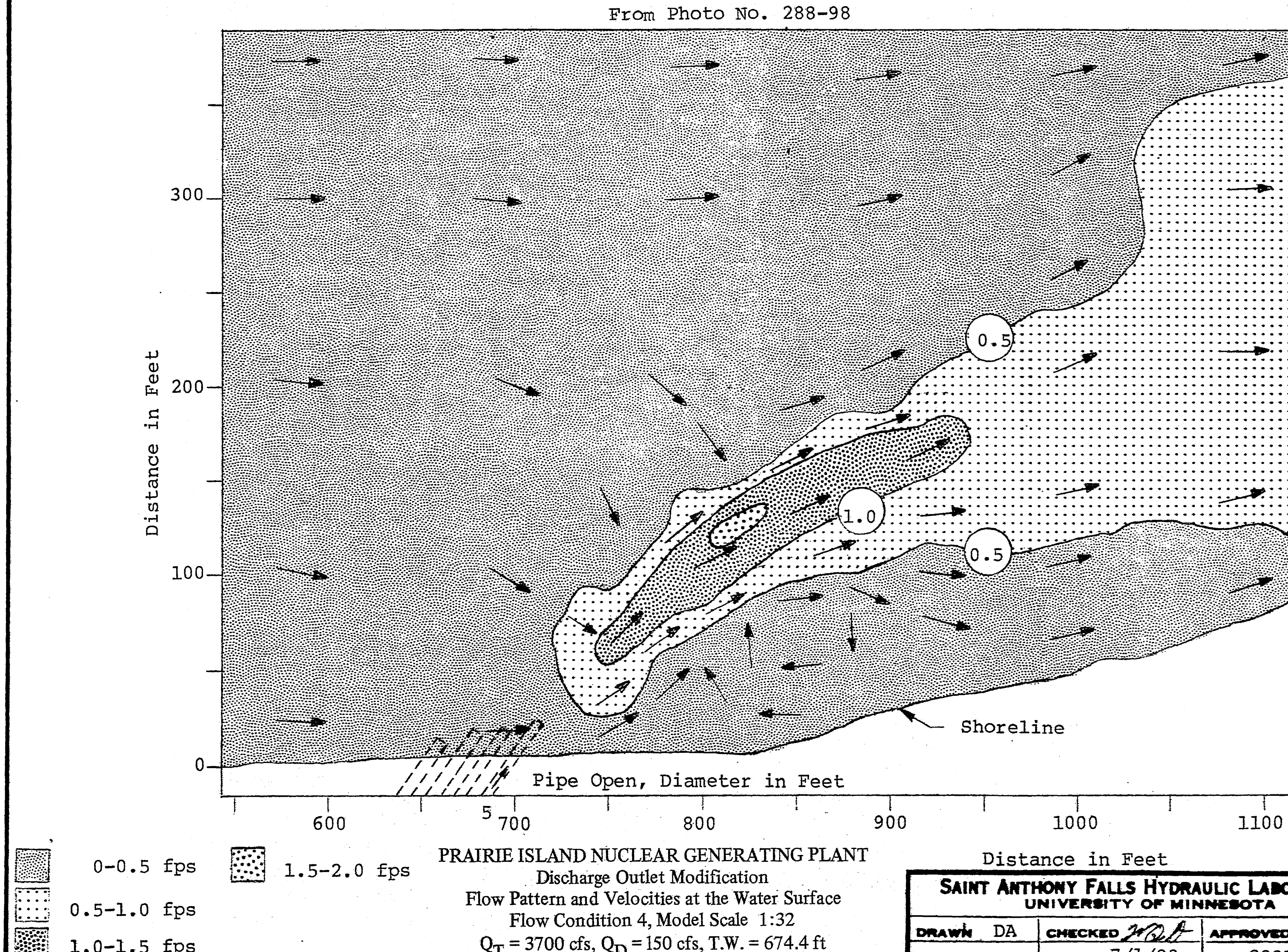
DATE 5/12/80
NO. 288B510-9

Fig. 19



PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities at the Water Surface
Flow Condition 4, Model Scale 1:32
Q_T = 3700 cfs, Q_D = 150 cfs, T.W. = 674.4 ft

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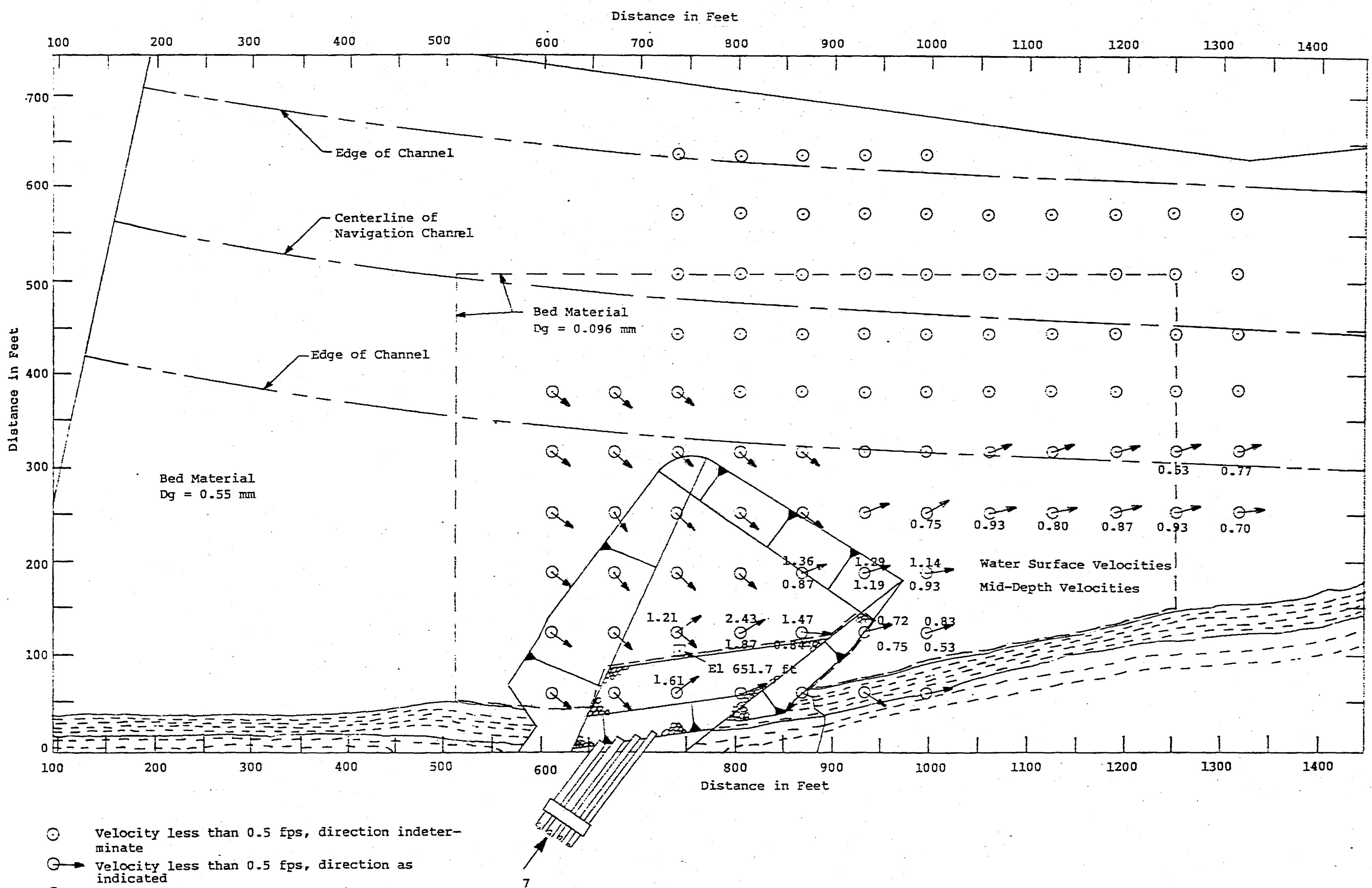
DRAWN DA	CHECKED [illegible]	APPROVED
SCALE	DATE 7/1/80	NO. 288A2320-7

Fig. 20



Velocity less than 0.5 fps, direction indeterminate

Velocity less than 0.5 fps, direction as indicated

0.93 Velocity at mid-depth in fps, direction as indicated

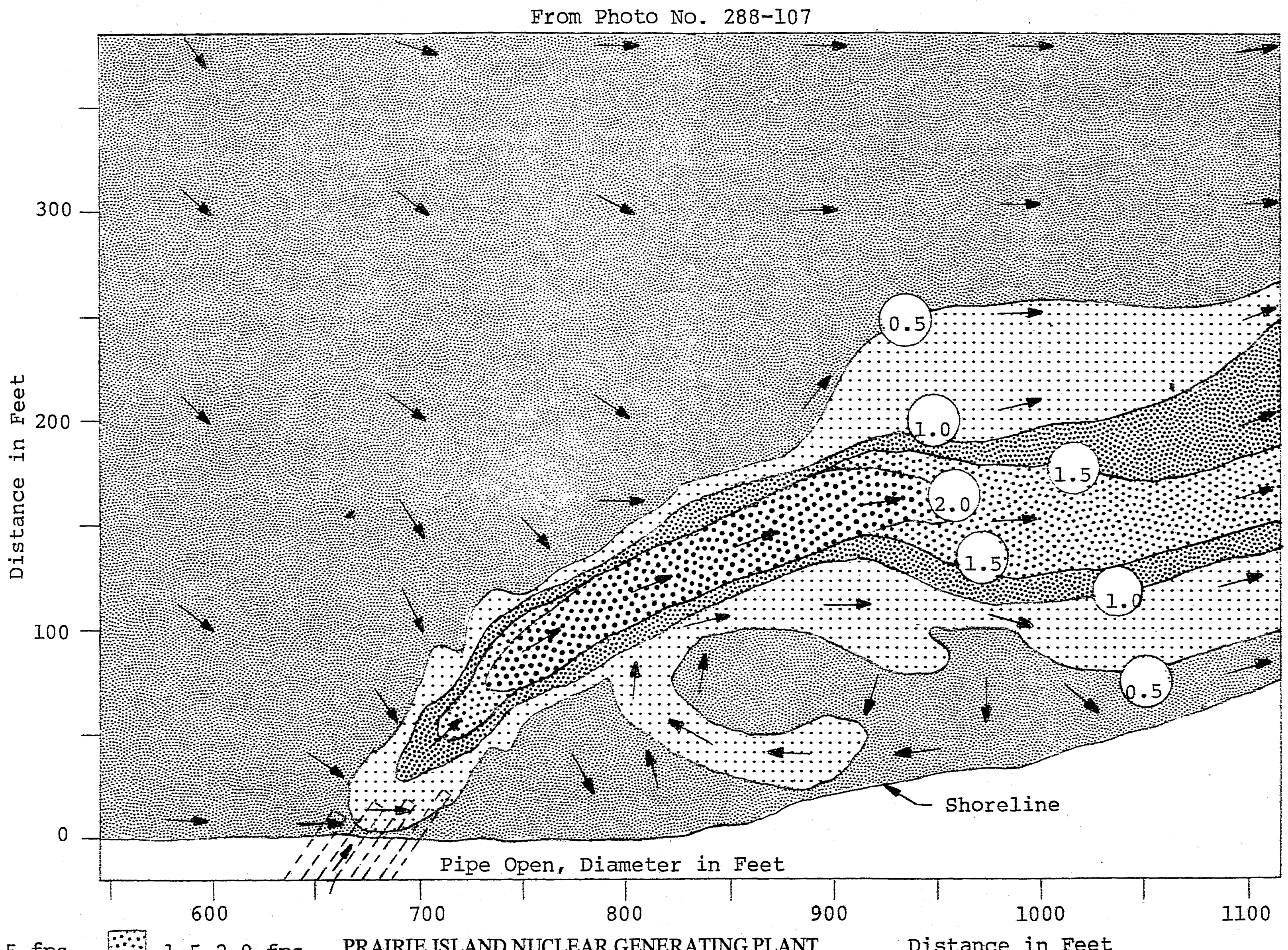
1.14 Velocity at water surface in fps, direction if different from mid-depth

Maximum erosion depth after 8 hours of flow, elev. 651.7 ft

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities
Flow Condition 5, Model Scale 1:32
Q_T=3700 cfs, Q_D=350 cfs, T.W.=674.4 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 6/12/80	NO. 288B510-10

Fig. 21



- 0-0.5 fps
- 0.5-1.0 fps
- 1.0-1.5 fps
- 1.5-2.0 fps
- > 2.0 fps

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities at the Water Surface
Flow Condition 5, Model Scale 1:32
Q_T = 3700 cfs, Q_D = 350 cfs, T.W. = 674.4 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED WQH	APPROVED
SCALE	DATE 7/1/80	NO. 288A2320-8

Fig. 22

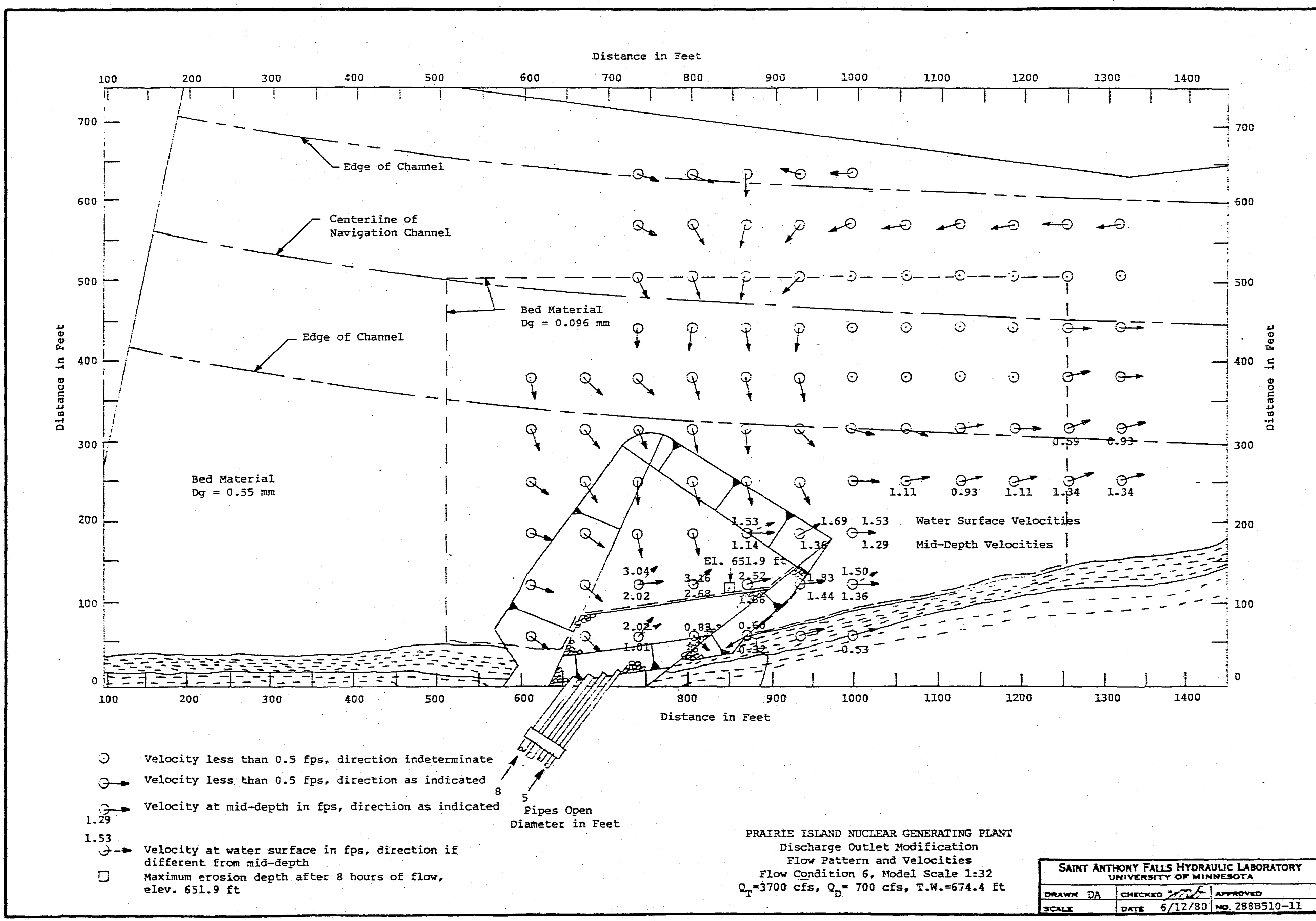
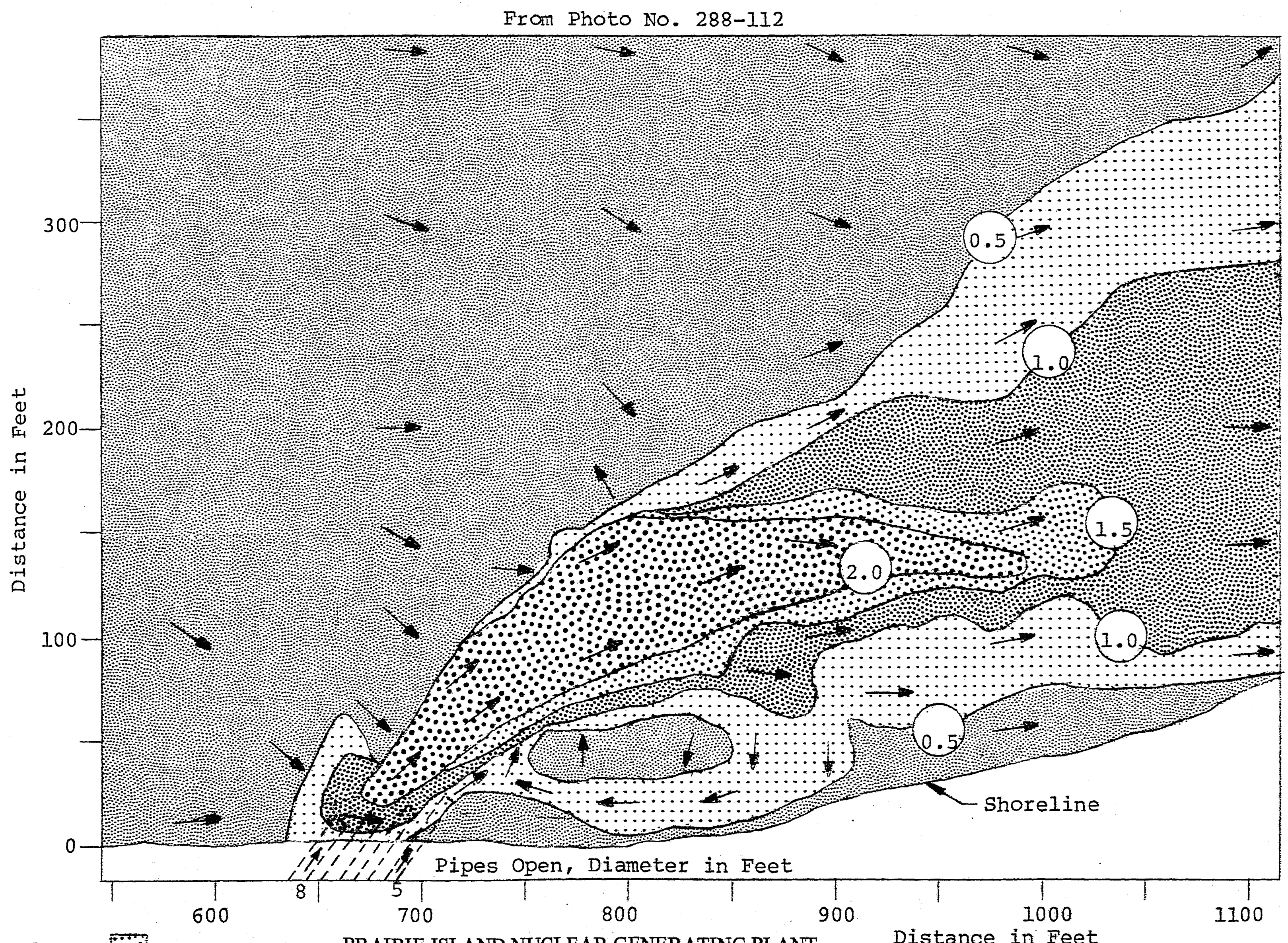

Distance in Feet
Edge of Channel
Centerline of Navigation Channel
Bed Material Dg = 0.096 mm
Edge of Channel
Bed Material Dg = 0.55 mm
Water Surface Velocities
Mid-Depth Velocities
El. 651.9 ft
Distance in Feet
Distance in Feet
8
5
Pipes Open
Diameter in Feet
Velocity less than 0.5 fps, direction indeterminate
Velocity less than 0.5 fps, direction as indicated
Velocity at mid-depth in fps, direction as indicated
Velocity at water surface in fps, direction if different from mid-depth
Maximum erosion depth after 8 hours of flow, elev. 651.9 ft
PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities
Flow Condition 6, Model Scale 1:32
QT=3700 cfs, QD= 700 cfs, T.W.=674.4 ft
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN DA
CHECKED
APPROVED
SCALE
DATE 6/12/80
NO. 288B510-11

Fig. 23

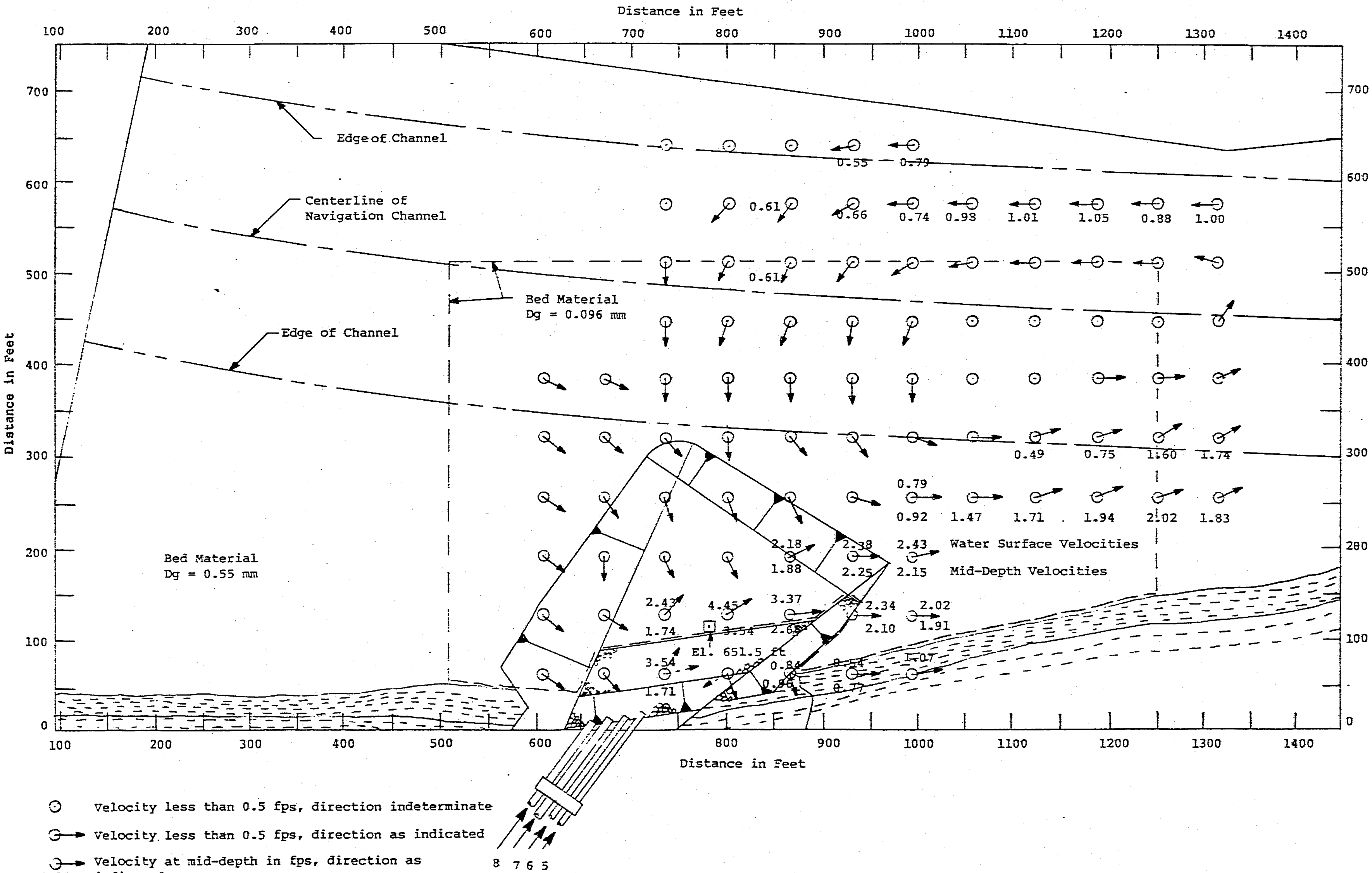


0-0.5 fps
0.5-1.0 fps
1.0-1.5 fps
1.5-2.0 fps
2.0-3.0 fps

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities at the Water Surface
Flow Condition 6, Model Scale 1:32
Q_T = 3700 cfs, Q_D = 700 cfs, T.W. = 674.4 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 7/1/80	NO. 288A2320-9

Fig. 24



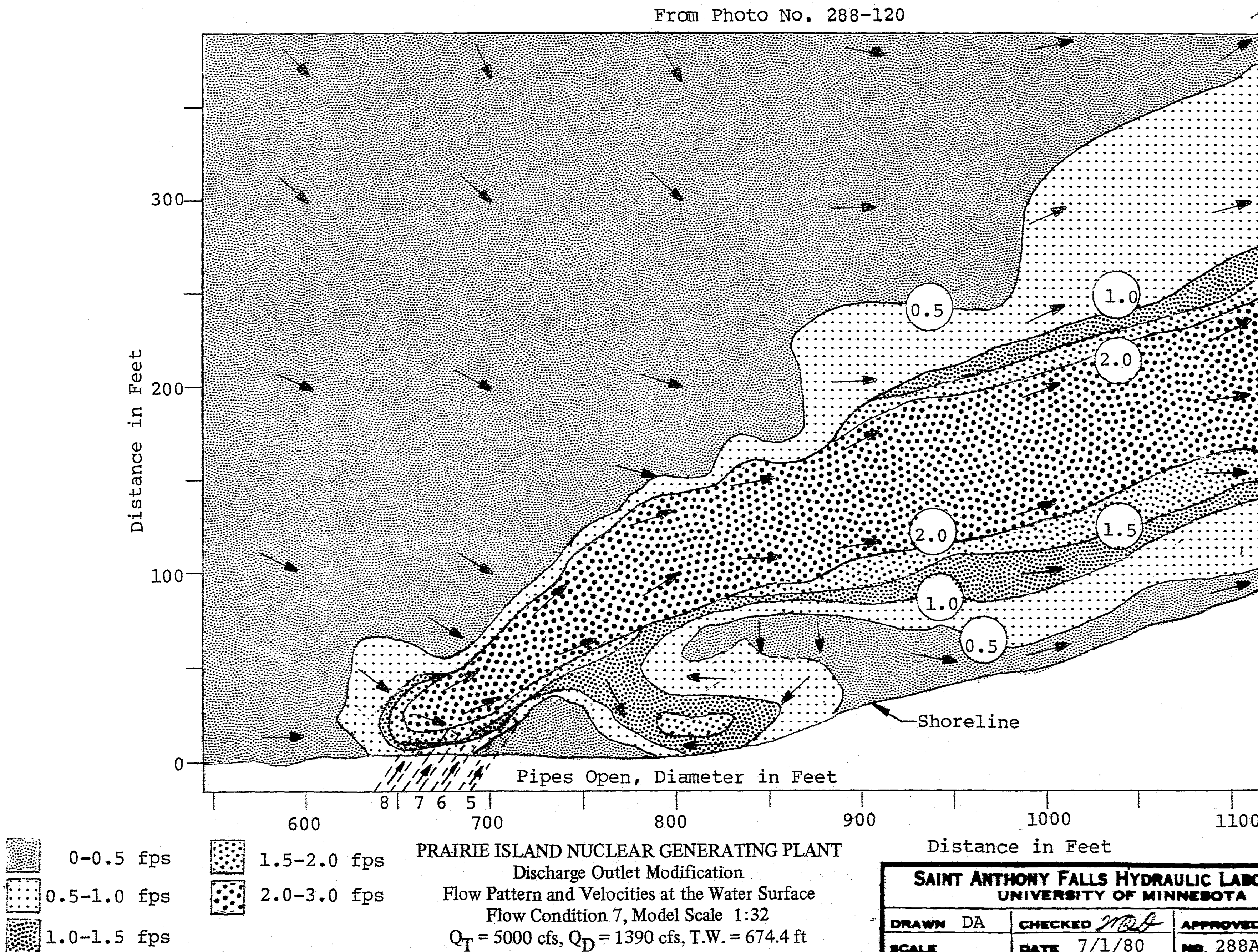
- ⊙ Velocity less than 0.5 fps, direction indeterminate
- ⊙→ Velocity less than 0.5 fps, direction as indicated
- 2.15 Velocity at mid-depth in fps, direction as indicated
- 2.43 Velocity at water surface in fps, direction if different from mid-depth
- ☐ Maximum erosion depth after 8 hours of flow, elev. 651.5 ft

Pipes Open
Diameter in Feet

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities
Flow Condition 7, Model Scale 1:32
Q_T=5000 cfs, Q_D=1390 cfs, T.W.=674.4 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 6/12/80	NO. 288B510-12

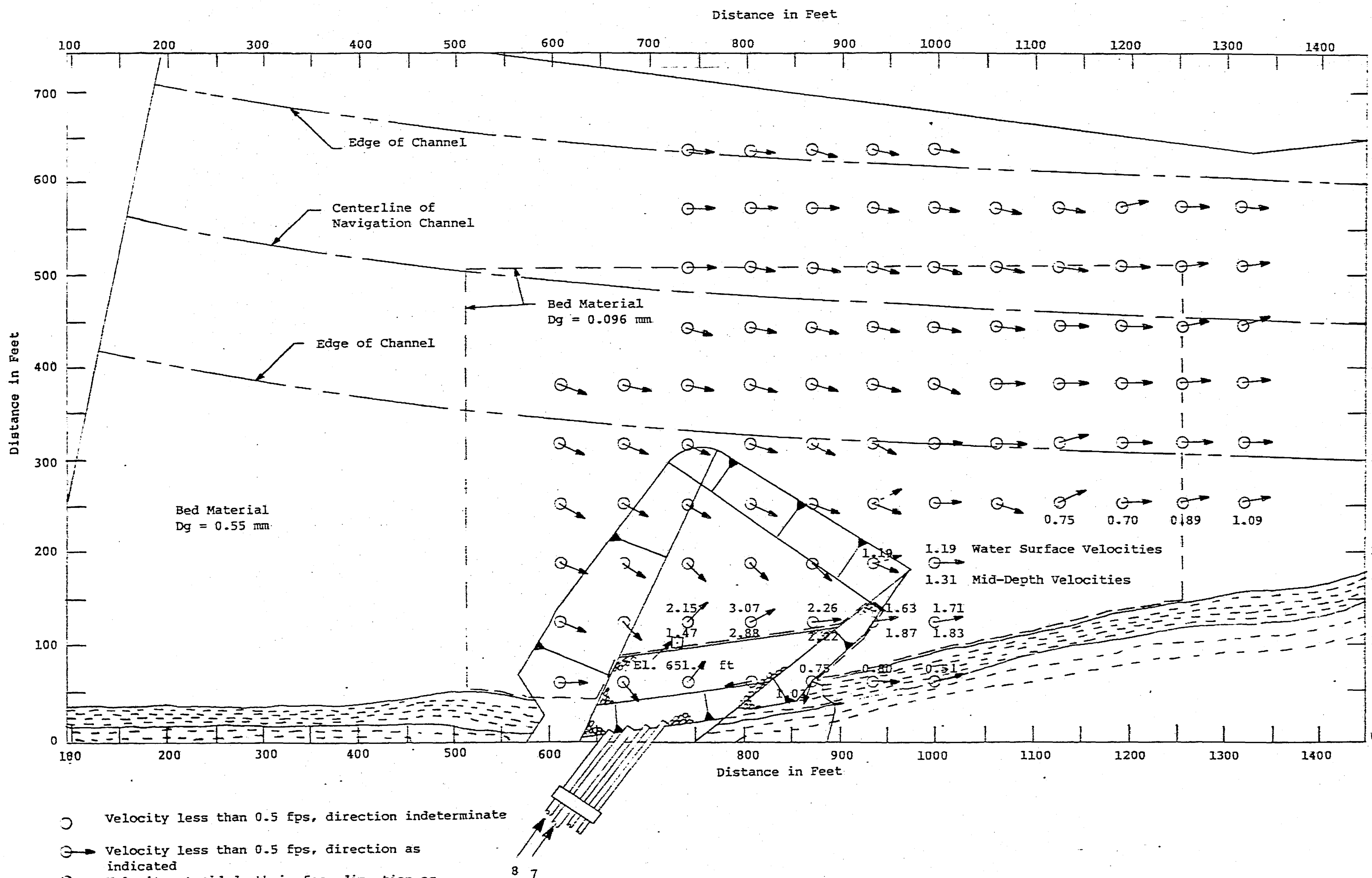
Fig. 25



PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities at the Water Surface
Flow Condition 7, Model Scale 1:32
Q_T = 5000 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED MRA	APPROVED
SCALE	DATE 7/1/80	NO. 288A2320-10

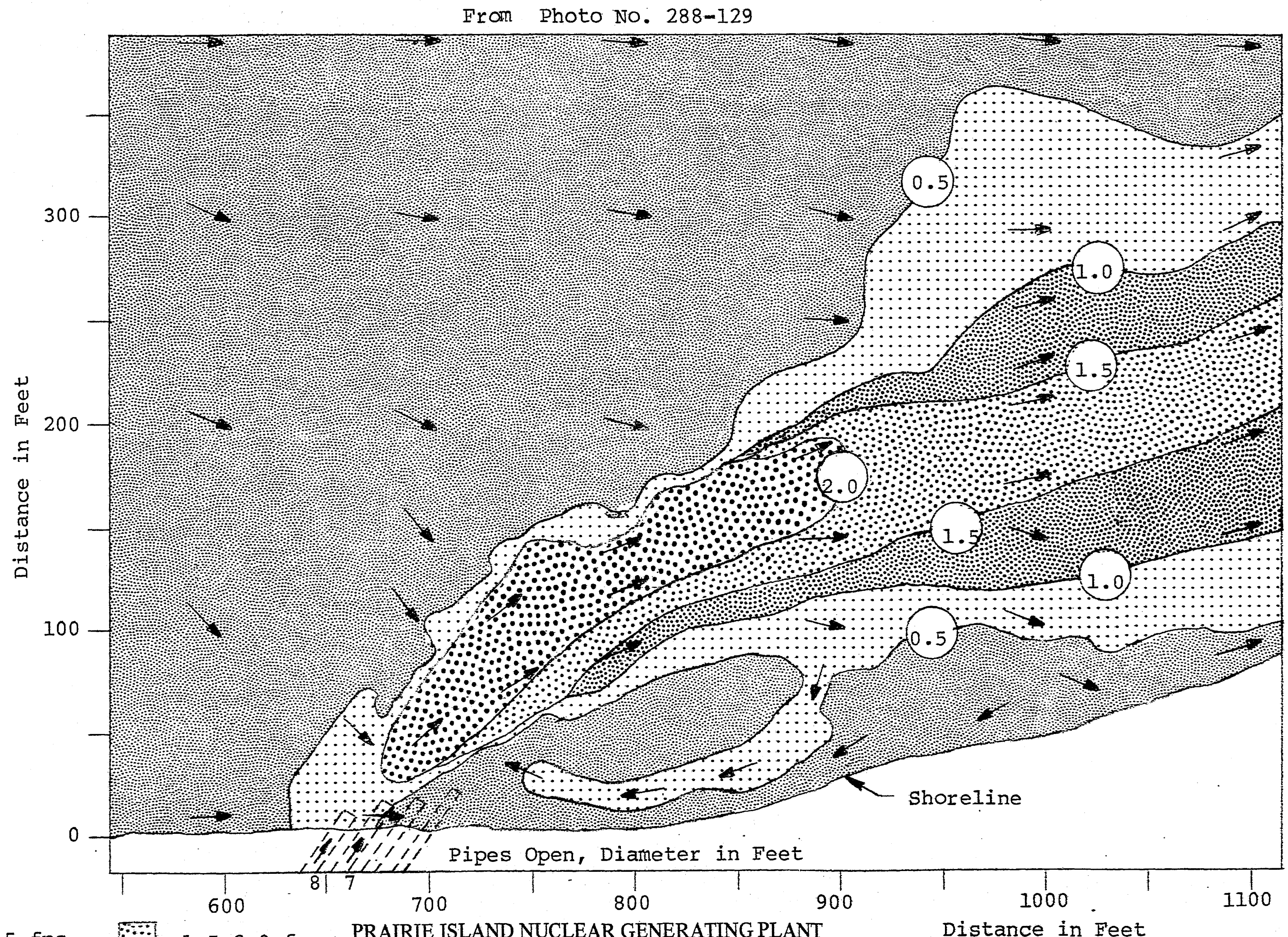
Fig. 26



PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities
Flow Condition 8, Model Scale 1:32
Q_T=6400 cfs, Q_D=800 cfs, T.W.=674.3 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 6/12/80	NO. 288B510-13

Fig. 27

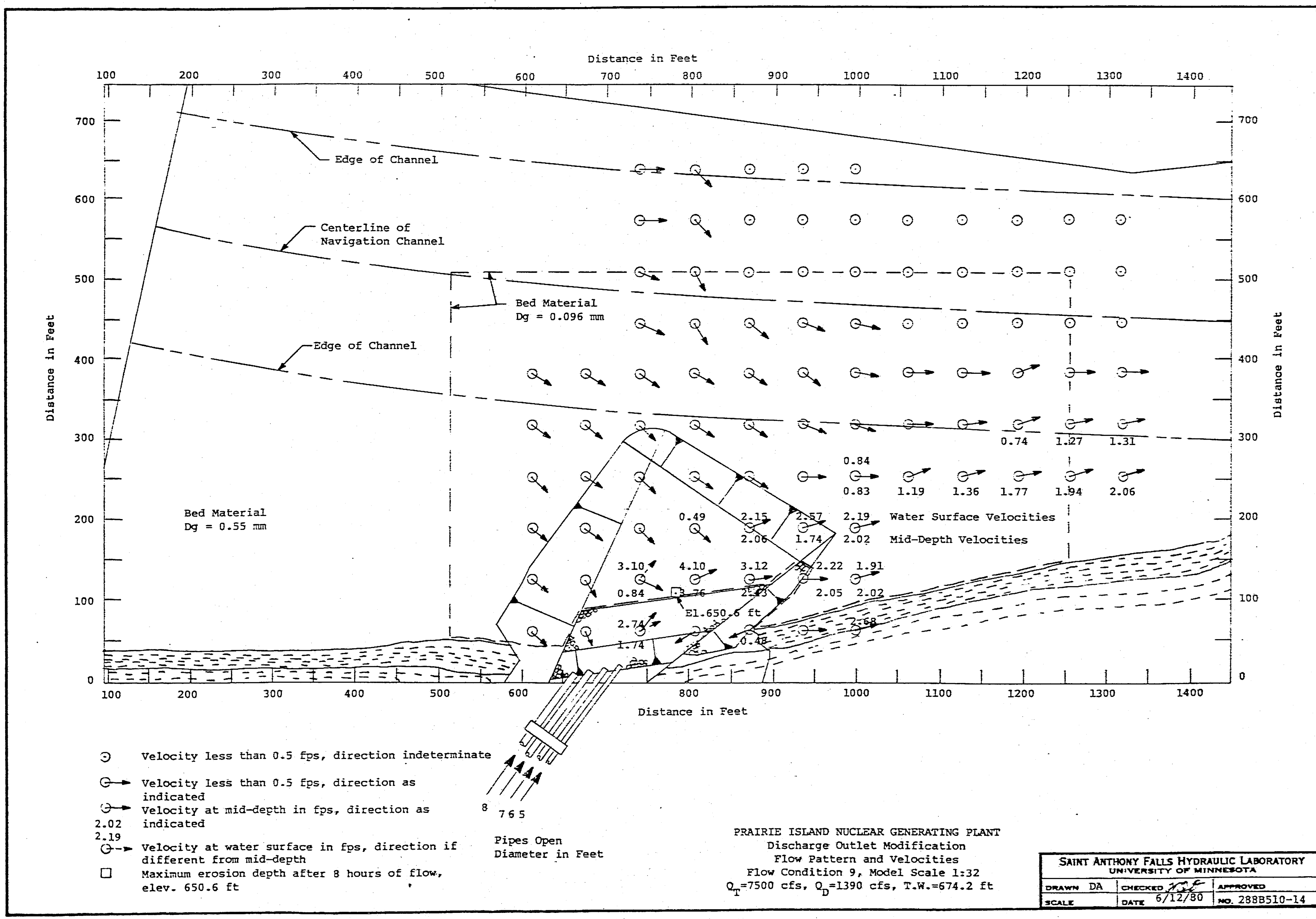


0-0.5 fps
0.5-1.0 fps
1.0-1.5 fps
1.5-2.0 fps
2.0-3.0 fps

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities at the Water Surface
Flow Condition 8, Model Scale 1:32
Q_T = 6400 cfs, Q_D = 800 cfs, T.W. 674.3 ft

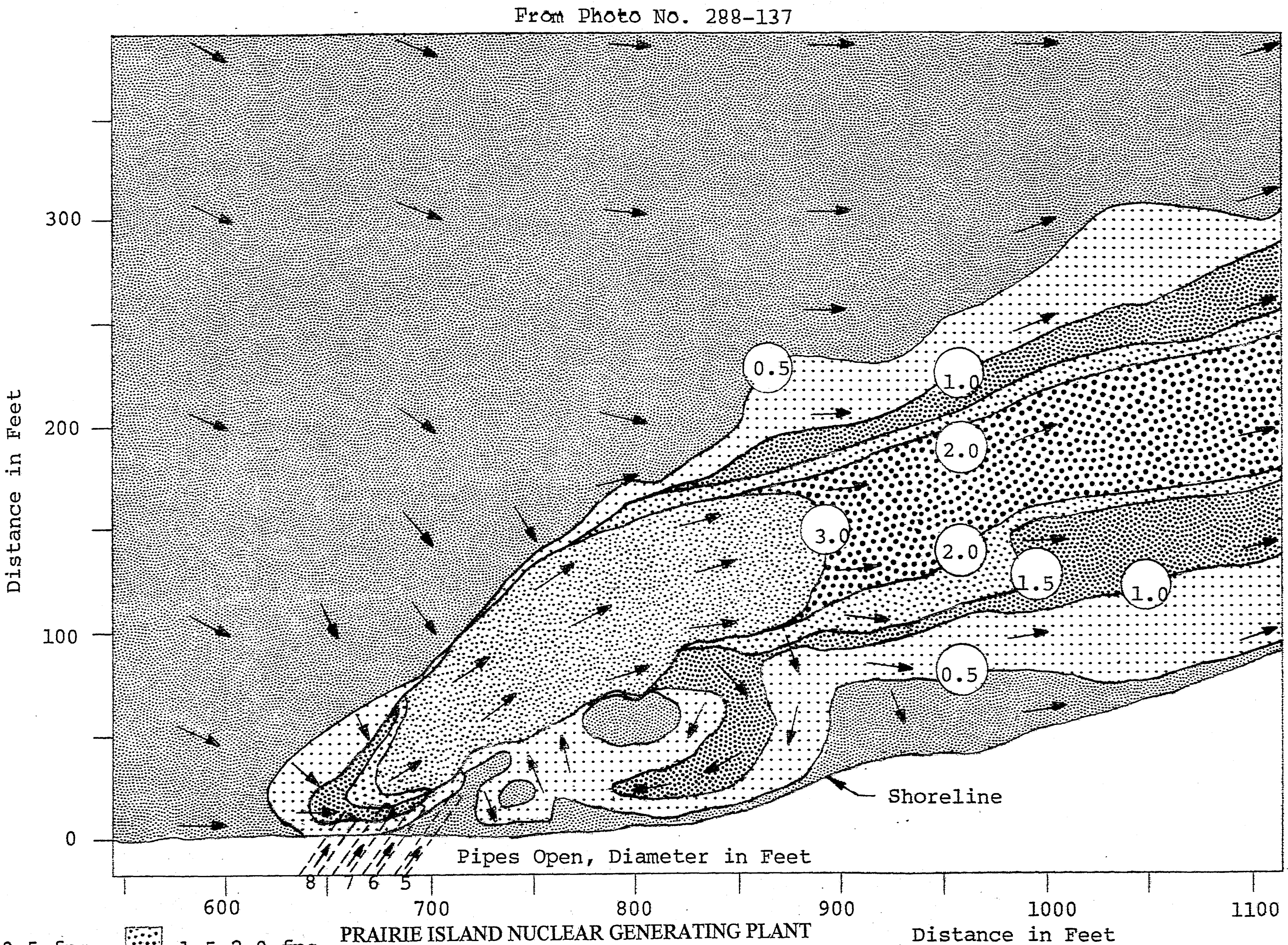
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN - DA	CHECKED [signature]	APPROVED
SCALE	DATE 7/1/80	NO. 288A2320-11

Fig. 28



Distance in Feet
Distance in Feet
Distance in Feet
Distance in Feet
Edge of Channel
Centerline of Navigation Channel
Edge of Channel
Bed Material Dg = 0.096 mm
Bed Material Dg = 0.55 mm
Water Surface Velocities
Mid-Depth Velocities
El.650.6 ft
Velocity less than 0.5 fps, direction indeterminate
Velocity less than 0.5 fps, direction as indicated
Velocity at mid-depth in fps, direction as indicated
2.02
2.19
Velocity at water surface in fps, direction if different from mid-depth
Maximum erosion depth after 8 hours of flow, elev. 650.6 ft
8
7 6 5
Pipes Open
Diameter in Feet
PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities
Flow Condition 9, Model Scale 1:32
Q_T=7500 cfs, Q_D=1390 cfs, T.W.=674.2 ft
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN DA
CHECKED
APPROVED
SCALE
DATE 6/12/80
NO. 288B510-14

Fig. 29



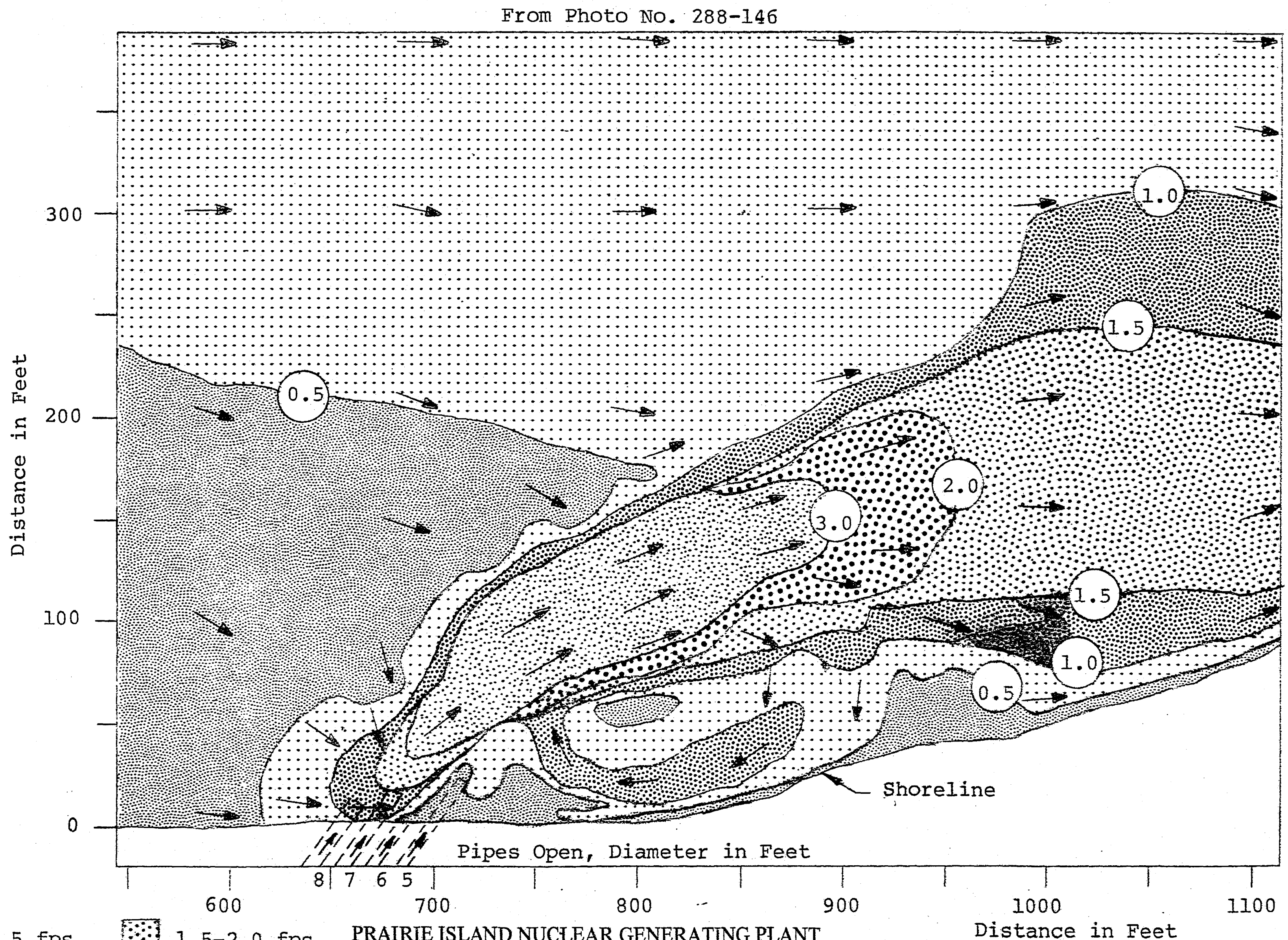
0-0.5 fps	1.5-2.0 fps
0.5-1.0 fps	2.0-3.0 fps
1.0-1.5 fps	> 3.0 fps

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities at the Water Surface
Flow Condition 9, Model Scale 1:32
Q_T = 7500 cfs, Q_D = 1390 cfs, T.W. = 674.2 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 7/1/80	NO. 288A2320-12

Fig. 30



0-0.5 fps
0.5-1.0 fps
1.0-1.5 fps
1.5-2.0 fps
2.0-3.0 fps
> 3.0 fps

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Discharge Outlet Modification
Flow Pattern and Velocities at the Water Surface
Flow Condition 10, Model Scale 1:32
Q_T = 12,000 cfs, Q_D = 1390 cfs, T.W. = 673.8 ft

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED [illegible]	APPROVED
SCALE	DATE 7/1/80	NO. 288A2320-13

Fig. 32

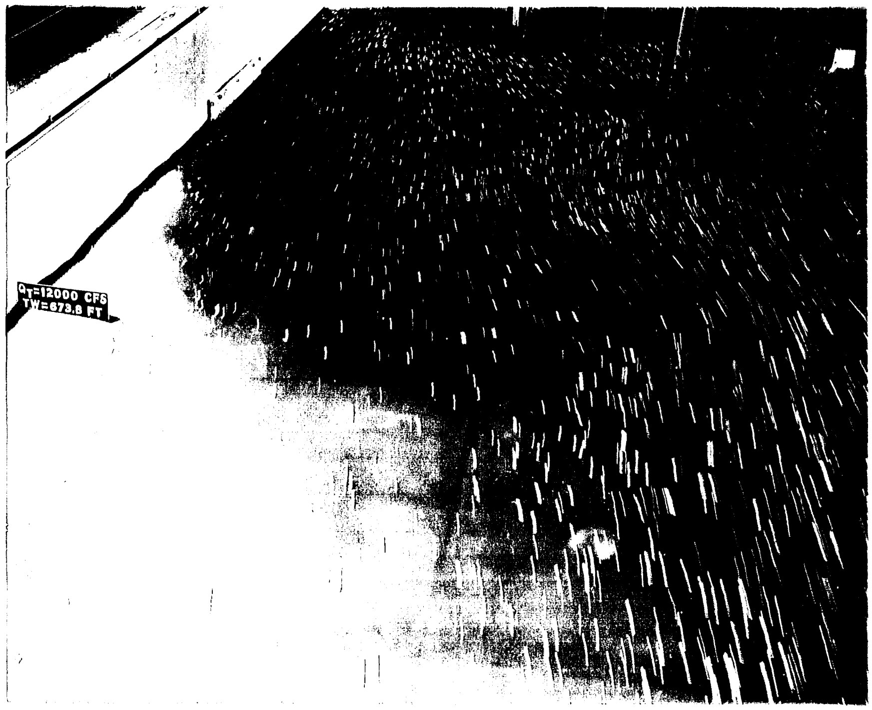


Photo 1 - Original River Bed. Flow Condition 1, Q_T = 12,000 cfs, Q_D = 0 cfs, T.W. = 673.8 ft; flow pattern.

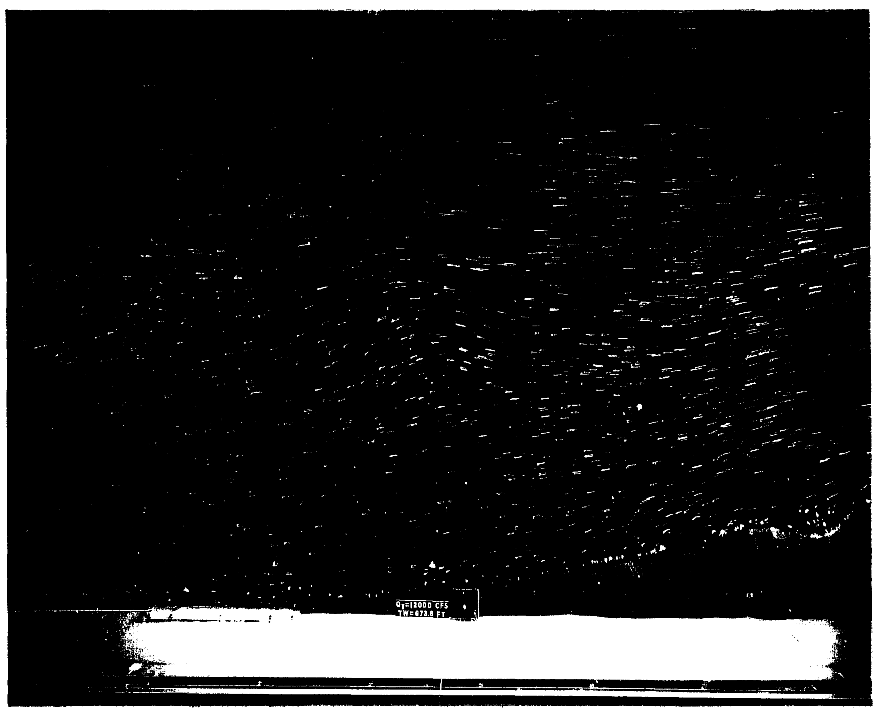


Photo 2 - Original River Bed. Flow Condition 1, Q_T = 12,000 cfs, Q_D = 0 cfs, T.W. = 673.8 ft; flow pattern.

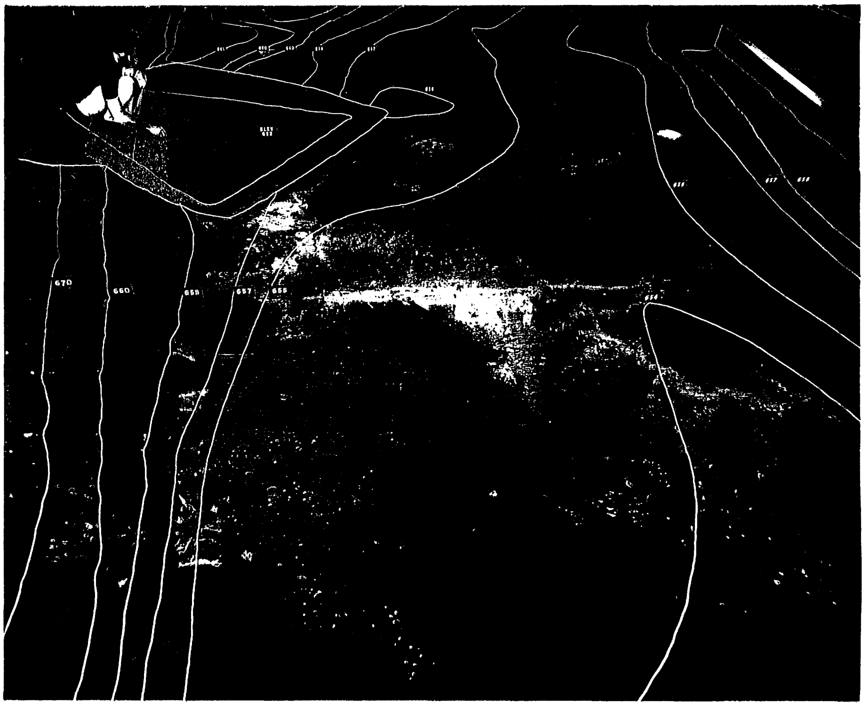


Photo 3 - Discharge Outlet Modification.
Model layout with original contours.

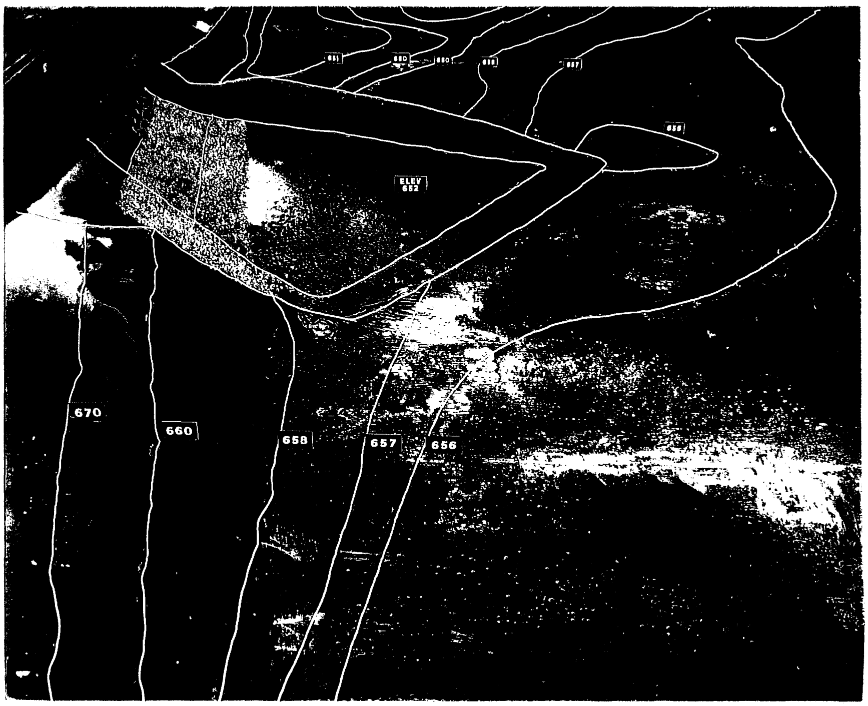


Photo 4 - Discharge Outlet Modification.
Model layout with original contours.

Photo 5 - Discharge Outlet Modification.
Model layout with original contours.

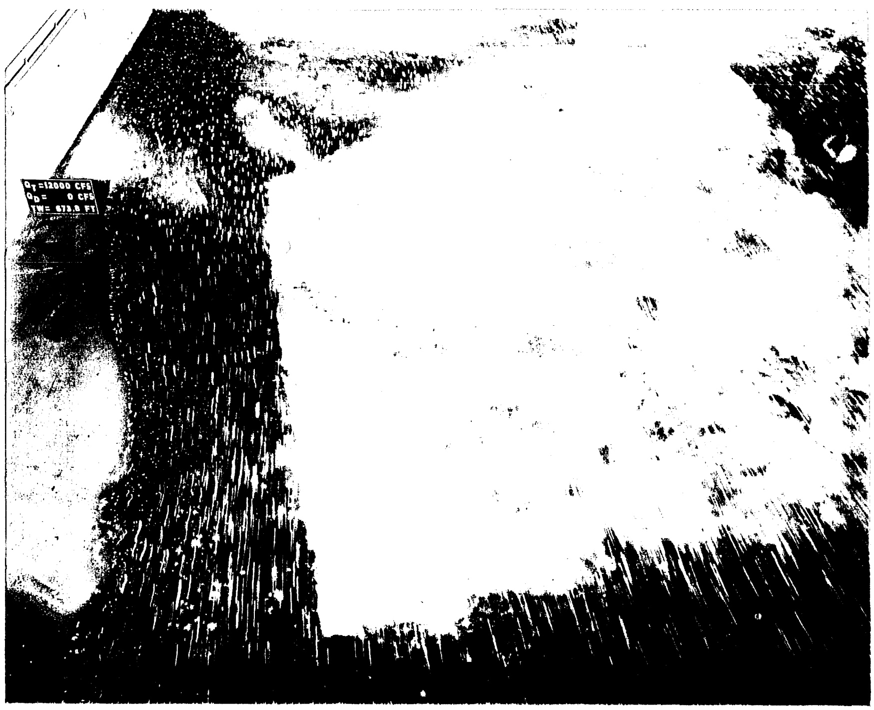


Photo 6 - Discharge Outlet Modification. Flow Condition 1, Q_T = 12,000 cfs, Q_D = 0 cfs, T.W. = 673.8 ft; flow pattern.

Photo 7 - Discharge Outlet Modification. Flow Condition 2, Q_T = 3390 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft, Pipes Open = 8, 7, 6 & 5; flow pattern.

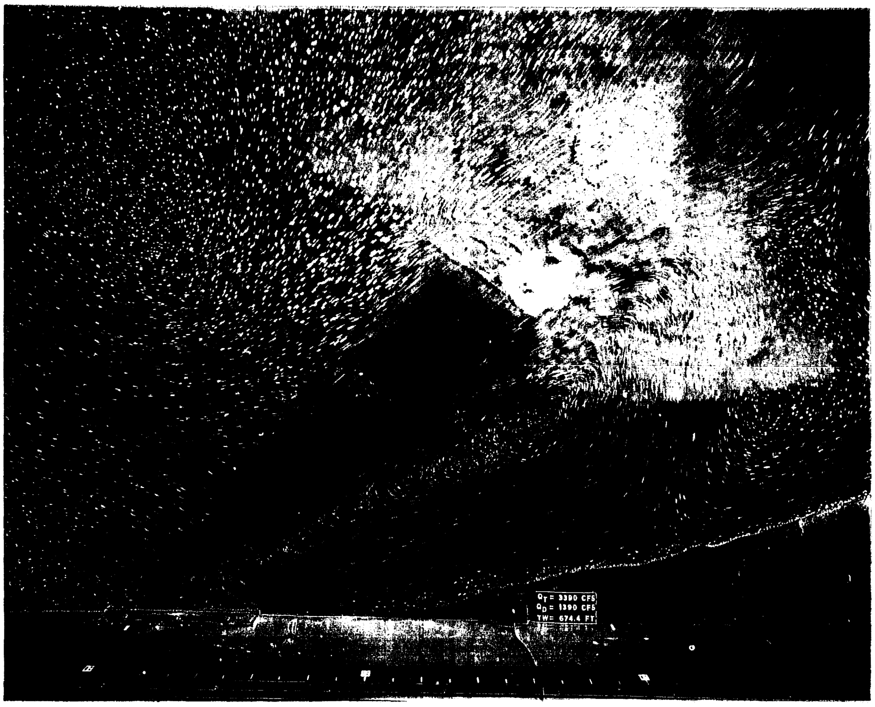


Photo 8 - Discharge Outlet Modification. Flow Condition 2, Q_T = 3390 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft, Pipes Open = 8, 7, 6 & 5; flow pattern.

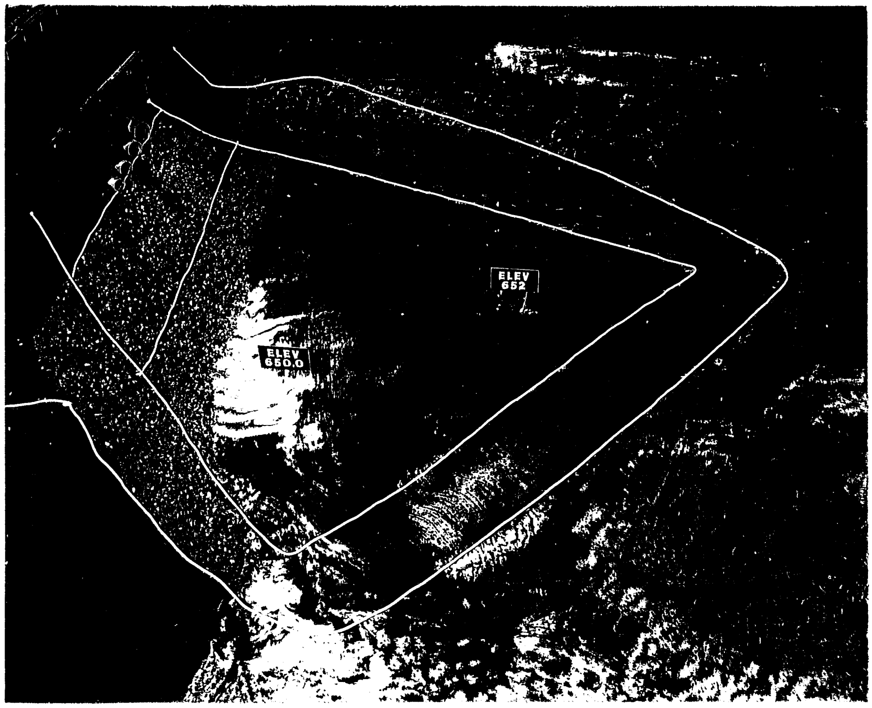


Photo 9 - Discharge Outlet Modification. Flow Condition 2, Q_T = 3390 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft, Pipes Open = 8, 7, 6 & 5; Local scour after 8 hours of flow.

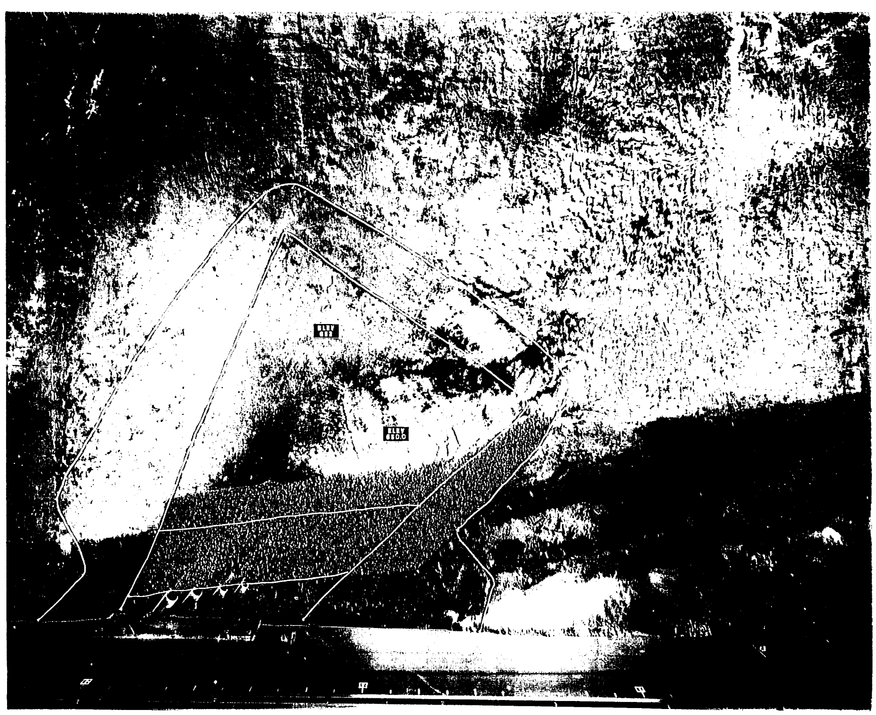


Photo 10 - Discharge Outlet Modification. Flow Condition 2, Q_T = 3390 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft, Pipes Open = 8, 7, 6 & 5; local scour after 8 hours of flow.

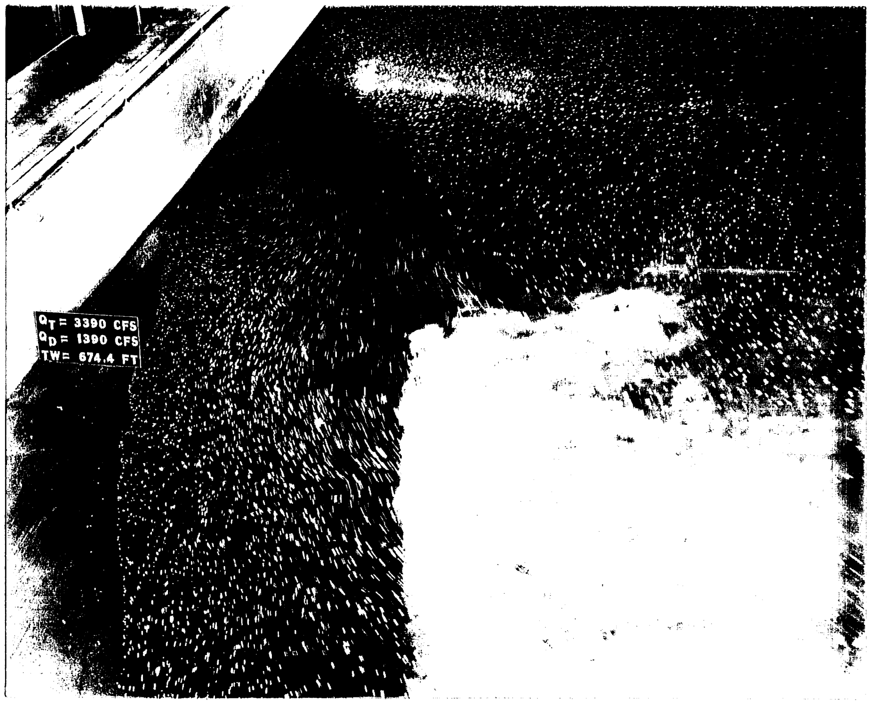


Photo 11 - Discharge Outlet Modification. Flow Condition 3, Q_T = 3390 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft, Pipes Open = 8, 7, 6 & 5; flow pattern.

Photo 12 - Discharge Outlet Modification. Flow Condition 3, Q_T = 3390 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft, Pipes Open = 8, 7, 6 & 5; flow pattern.

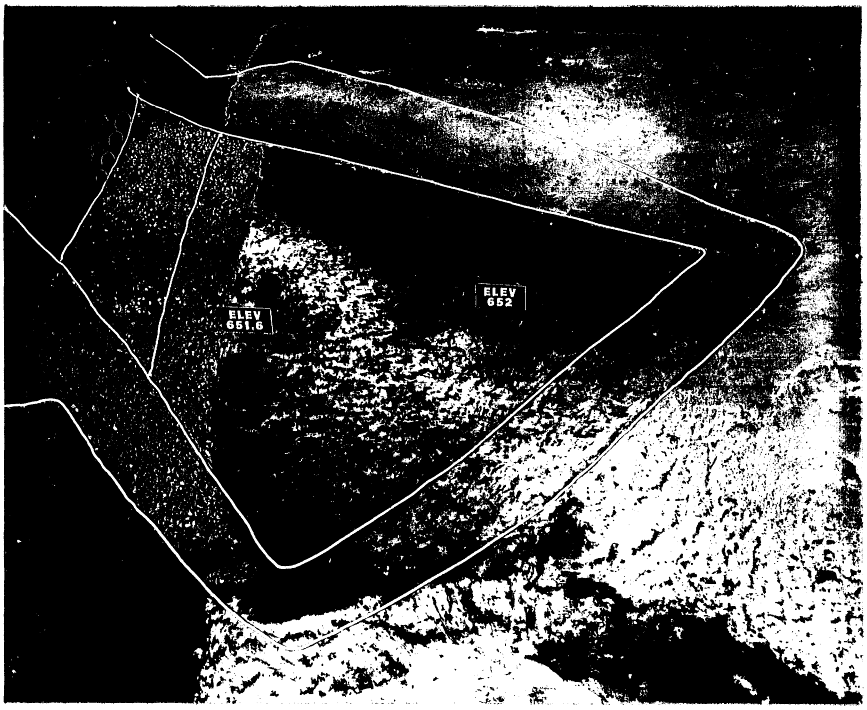


Photo 13 - Discharge Outlet Modification. Flow Condition 3, Q_T = 3390 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft, Pipes Open = 8, 7, 6 & 5; local scour after 8 hours of flow.

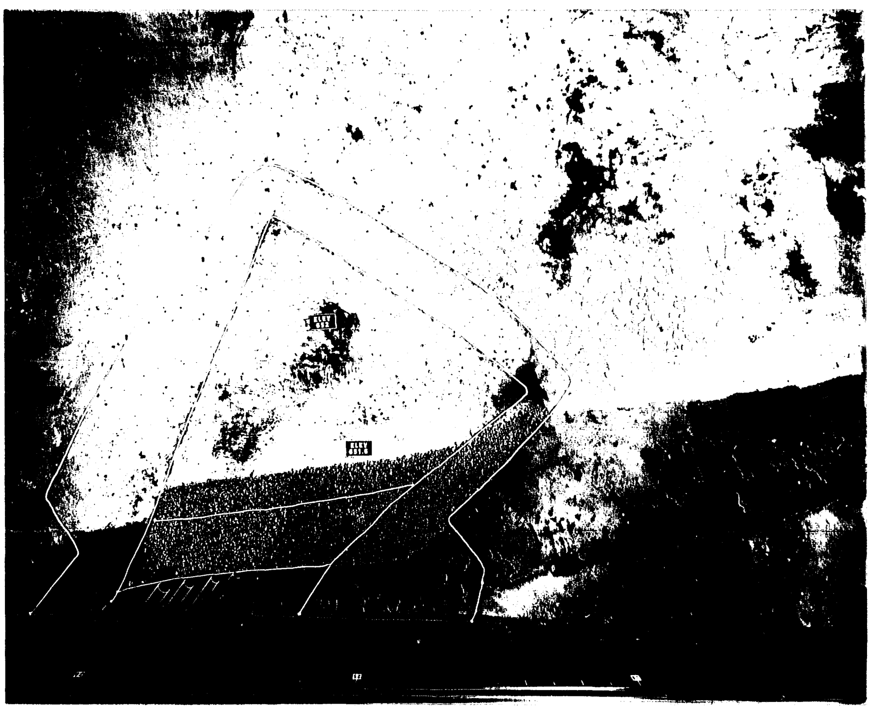


Photo 14 - Discharge Outlet Modification. Flow Condition 3, Q_T = 3390 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft, Pipes Open = 8, 7, 6 & 5; local scour after 8 hours of flow.

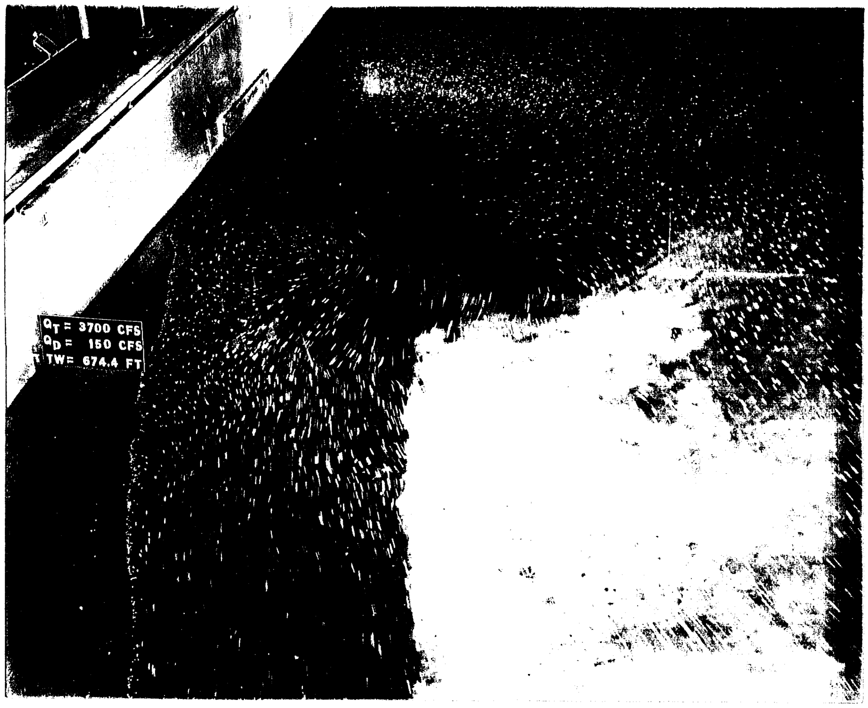


Photo 15 - Discharge Outlet Modification. Flow Condition 4, Q_T = 3700 cfs, Q_D = 150 cfs, T.W. = 674.4 ft, Pipe Open = 5; flow pattern.

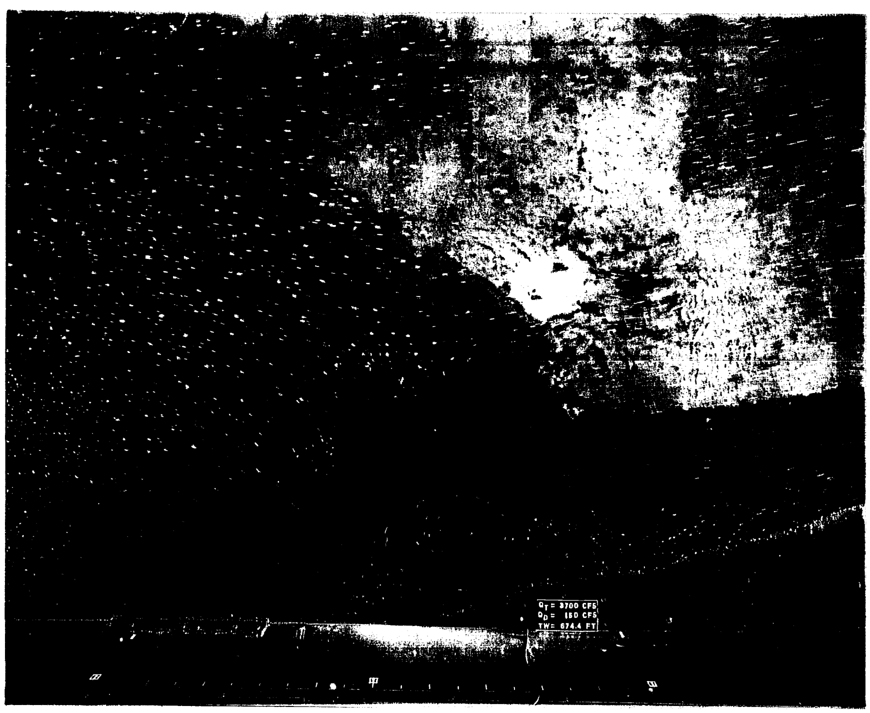


Photo 16 - Discharge Outlet Modification. Flow Condition 4, Q_T = 3700 cfs, Q_D = 150 cfs, T.W. = 674.4 ft, Pipe Open = 5; flow pattern.

Photo 17 - Discharge Outlet Modification. Flow Condition 4, Q_T = 3700 cfs, Q_D = 150 cfs, T.W. = 674.4 ft, Pipe Open = 5; local scour after 8 hours of flow.

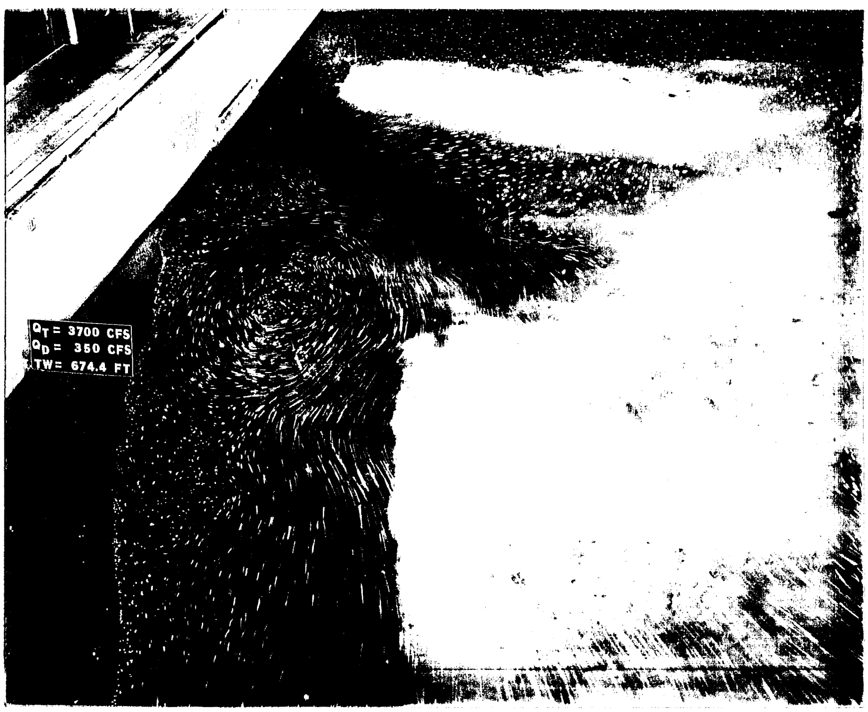


Photo 18 - Discharge Outlet Modification. Flow Condition 5, Q_T = 3700 cfs, Q_D = 350 cfs, T.W. = 674.4 ft, Pipe Open = 7; flow pattern.

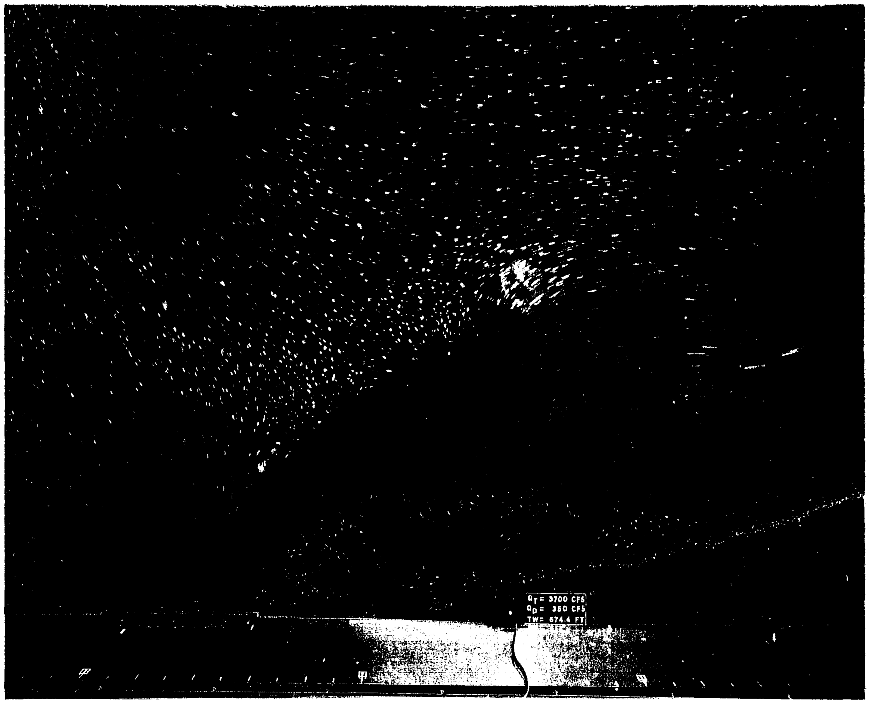


Photo 19 - Discharge Outlet Modification. Flow Condition 5, Q_T = 3700 cfs, Q_D = 350 cfs, T.W. = 674.4 ft, Pipe Open = 7; flow pattern.

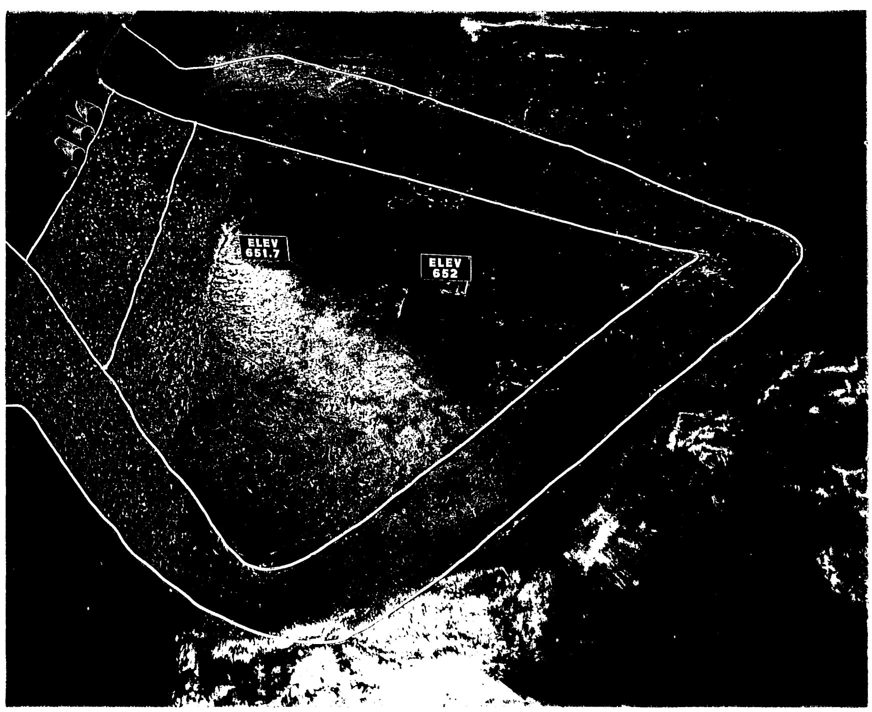


Photo 20 - Discharge Outlet Modification. Flow Condition 5, Q_T = 3700 cfs, Q_D = 350 cfs, T.W. = 674.4 ft, Pipe Open = 7; local scour after 8 hours of flow.

Photo 21 - Discharge Outlet Modification. Flow Condition 6, Q_T = 3700 cfs, Q_D = 700 cfs, T.W. = 674.4 ft, Pipes Open = 8 & 5; flow pattern.

Photo 22 - Discharge Outlet Modification. Flow Condition 6, Q_T = 3700 cfs, Q_D = 700 cfs, T.W. = 674.4 ft, Pipes Open = 8 & 5; flow pattern.

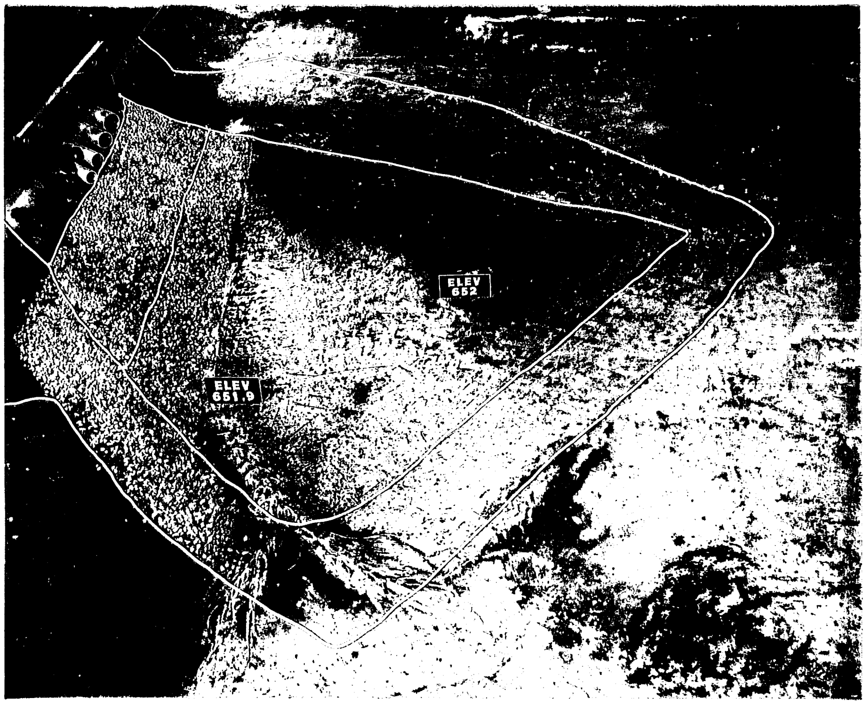


Photo 23 - Discharge Outlet Modification. Flow Condition 6, Q_T = 3700 cfs, Q_D = 700 cfs, T.W. = 674.4 ft, Pipes Open = 8 & 5; local scour after 8 hours of flow.

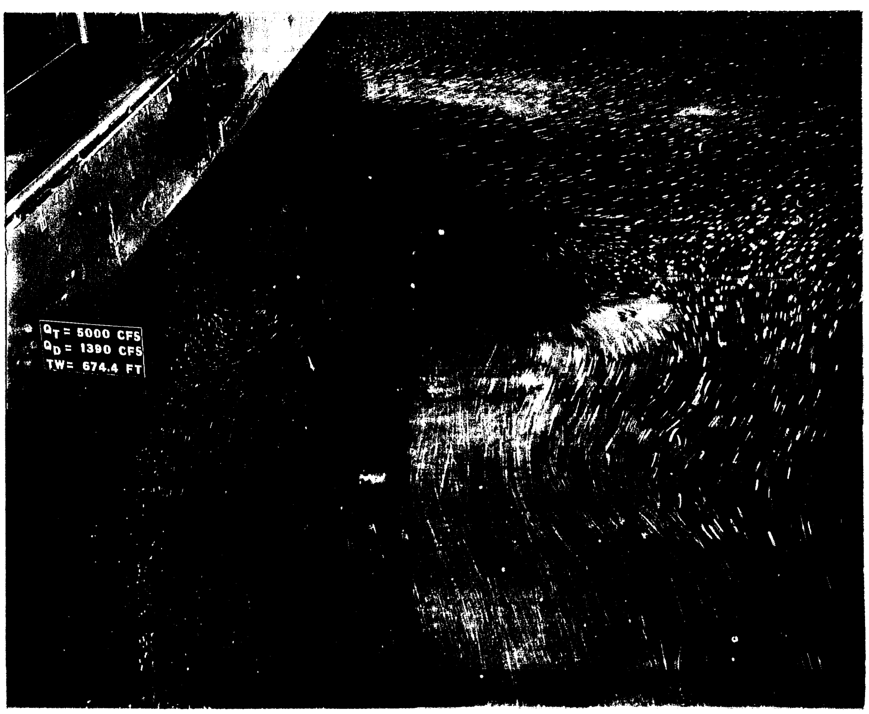


Photo 24 - Discharge Outlet Modification. Flow Condition 7, Q_T = 5000 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft, Pipes Open = 8, 7, 6 & 5; flow pattern.

Photo 25 - Discharge Outlet Modification. Flow Condition 7, Q_T = 5000 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft, Pipes Open = 8, 7, 6 & 5; flow pattern.

Photo 26 - Discharge Outlet Modification. Flow Condition 7, Q_T = 5000 cfs, Q_D = 1390 cfs, T.W. = 674.4 ft, Pipes Open = 8, 7, 6 & 5; local scour after 8 hours of flow.

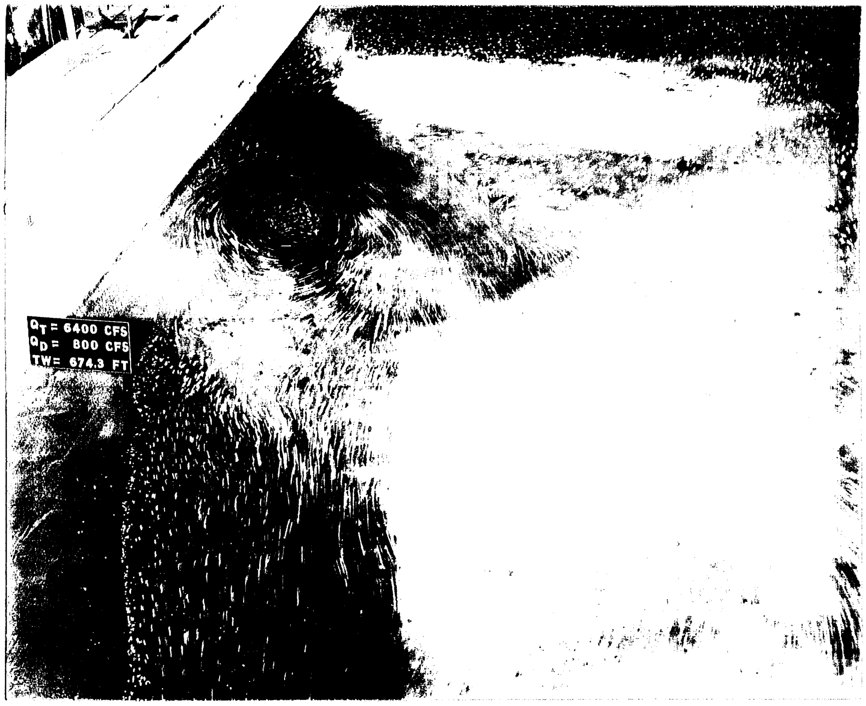


Photo 27 - Discharge Outlet Modification. Flow Condition 8, Q_T = 6400 cfs, Q_D = 800 cfs, T.W. = 674.3 ft, Pipes Open = 8 & 7; flow pattern.

Photo 28 - Discharge Outlet Modification. Flow Condition 8, Q_T = 6400 cfs, Q_D = 800 cfs, T.W. = 674.3 ft, Pipes Open = 8 & 7; flow pattern.

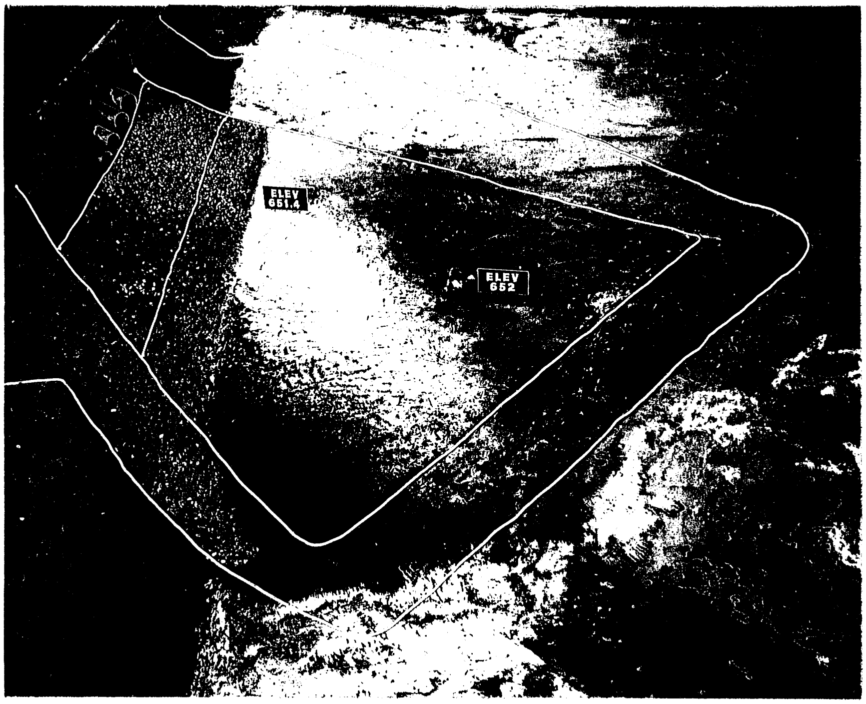


Photo 29 - Discharge Outlet Modification. Flow Condition 8, Q_T = 6400 cfs, Q_D = 800 cfs, T.W. = 674.3 ft, Pipes Open = 8 & 7; local scour after 8 hours of flow.

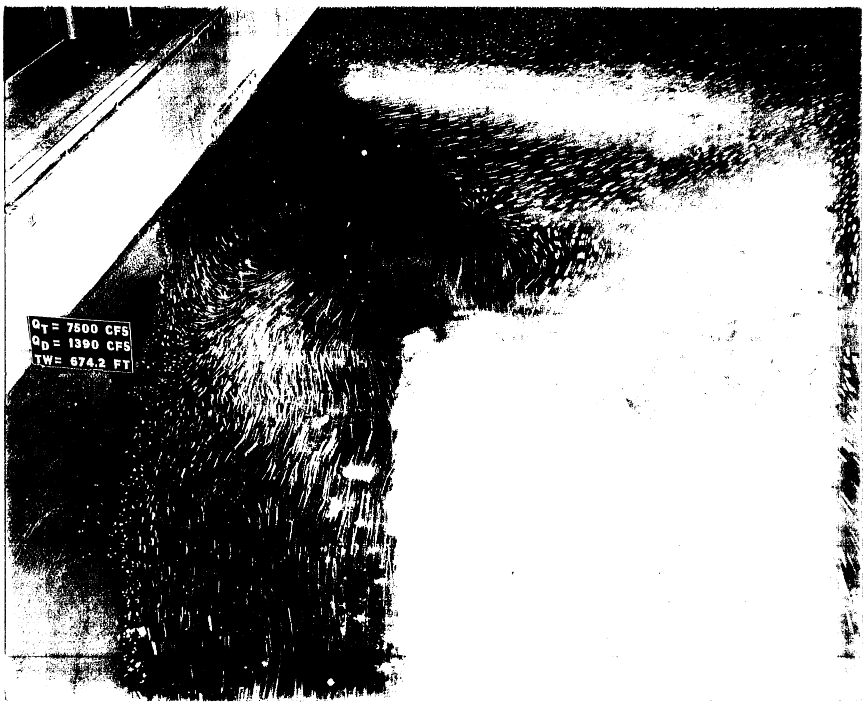


Photo 30 - Discharge Outlet Modification. Flow Condition 9, Q_T = 7500 cfs, Q_D = 1390 cfs, T.W. = 674.2 ft, Pipes Open = 8, 7, 6 & 5; flow pattern.

Photo 31 - Discharge Outlet Modification. Flow Condition 9, Q_T = 7500 cfs, Q_D = 1390 cfs, T.W. = 674.2 ft, Pipes Open = 8, 7, 6 & 5; flow pattern.

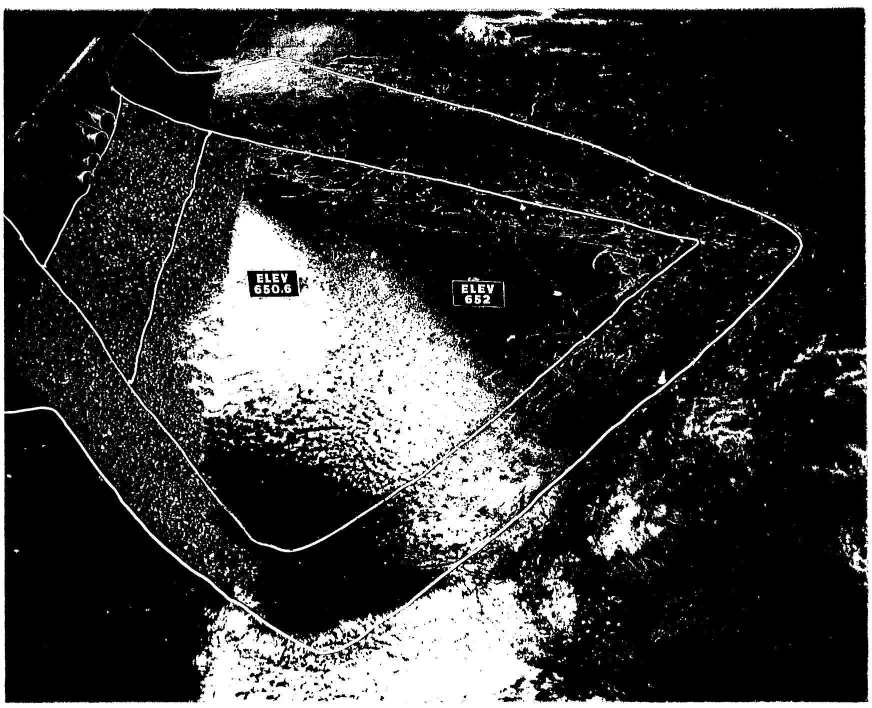


Photo 32 - Discharge Outlet Modification. Flow Condition 9, Q_T = 7500 cfs, Q_D = 1390 cfs, T.W. = 674.2 ft, Pipes Open = 8, 7, 6 & 5; local scour after 8 hours of flow.

Photo 33 - Discharge Outlet Modification. Flow Condition 10, Q_T = 12,000 cfs, Q_D = 1390 cfs, T.W. = 673.8 ft, Pipes Open = 8, 7, 6 & 5; flow pattern.

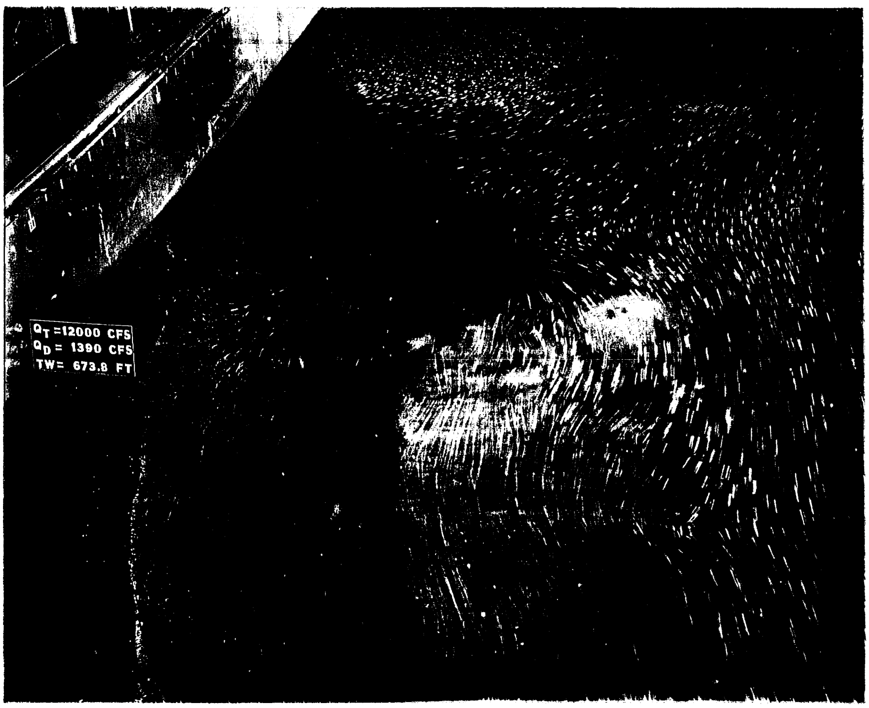


Photo 34 - Discharge Outlet Modification. Flow Condition 10, Q_T = 12,000 cfs, Q_D = 1390 cfs, T.W. = 673.8 ft, Pipes Open = 8, 7, 6 & 5; flow pattern.

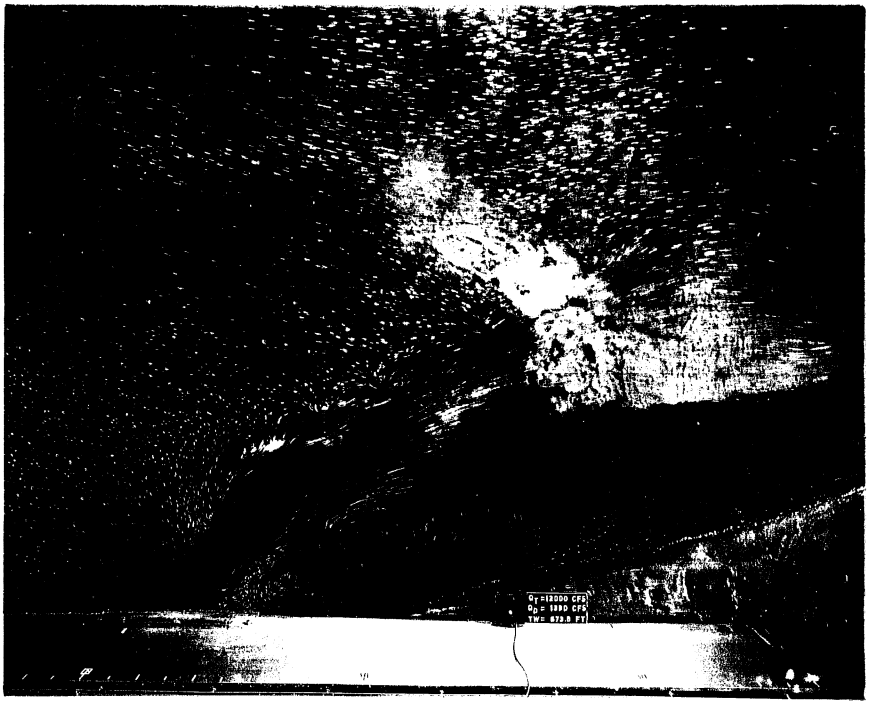


Photo 35 - Discharge Outlet Modification. Flow Condition 10, Q_T = 12,000 cfs, Q_D = 1390 cfs, T.W. = 673.8 ft, Pipes Open = 8, 7, 6 & 5; flow pattern.

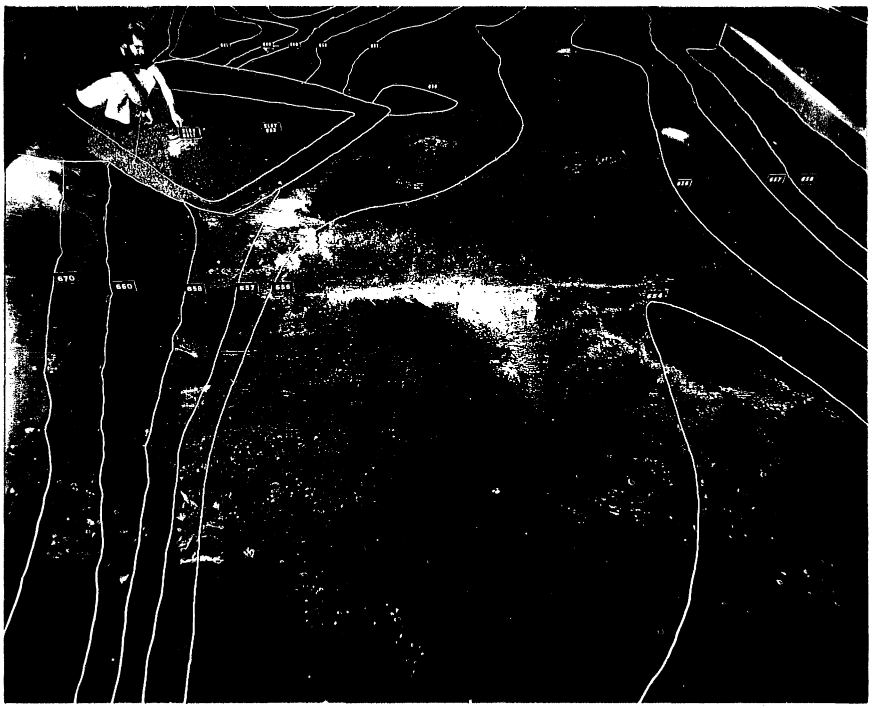


Photo 36 - Discharge Outlet Modification. Flow Condition 10, Q_T = 12,000 cfs, Q_D = 1390 cfs, T.W. = 673.8 ft, Pipes Open = 8, 7, 6 & 5; local scour after 8 hours of flow.

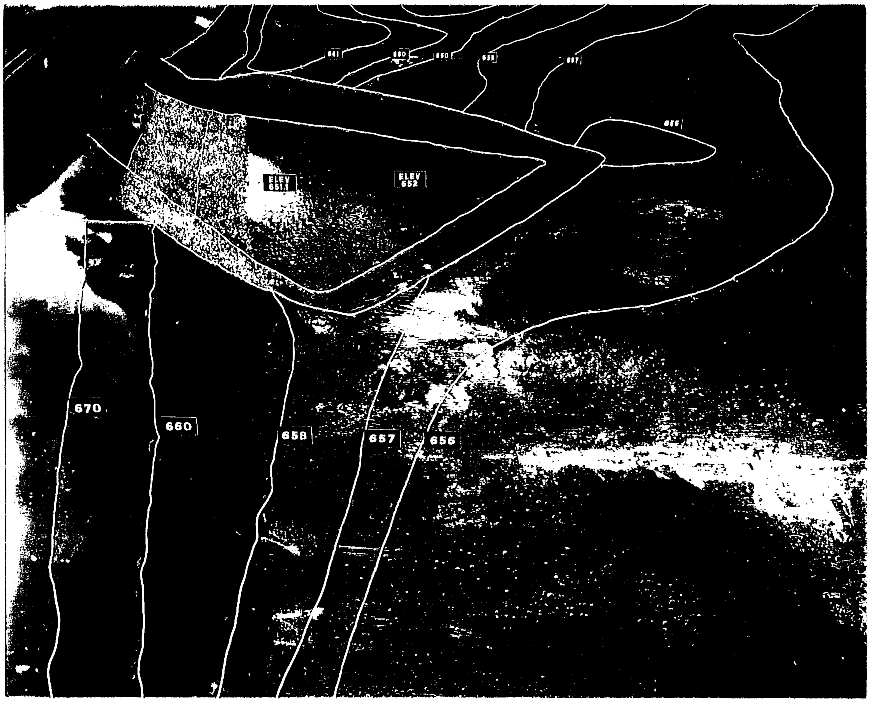


Photo 37 - Discharge Outlet Modification. Flow Condition 10, Q_T = 12,000 cfs, Q_D = 1390 cfs, T.W. = 673.8 ft, Pipes Open = 8, 7, 6 & 5; local scour after 8 hours of flow.

Photo 38 - Discharge Outlet Modification. Flow Condition 10, Q_T = 12,000 cfs, Q_D = 1390 cfs, T.W. = 673.8 ft, Pipes Open = 8, 7, 6 & 5; local scour after 8 hours of flow.