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ICE CONTROL STRUCTURE ON THE NORTH PLATTE RIVER

A hydraulic model study

P. H. Burgi
Engineering and Research Center
Bureau of Reclamation

December 1971

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The investigation and results of a hydraulic river model study using polyethylene plastic to simulate river float ice is described. Modifications to an existing river ice control structure are recommended as a result of the study. The conclusions recommend: (1) channel cross-section modifications to improve the flow conditions at the control structure site, (2) two-channel constriction designs which could be used downstream of the control structure to increase the water surface elevation and decrease the flow velocity at the control structure site, and (3) several modifications to the control structure which would improve the ice retention capability.

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ICE CONTROL STRUCTURE ON THE NORTH PLATTE RIVER

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by

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Hydraulics Branch
Division of General Research
Engineering and Research Center
Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION
Rogers C. B. Morton, Secretary
Ellis L. Armstrong, Commissioner

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PURPOSE

The purpose of the investigation was to optimize the design of the existing ice control structure in a limited time. Although three prototype boom configurations were tested, field modifications were impossible after the onset of the winter season.

CONCLUSIONS

1. Although the ice simulation was not complete, the use of materials such as polyethylene to simulate ice in hydraulic models affords considerable insight into the hydrodynamic aspects of ice cover formation.

2. The removal of the rocky protrusion on the riverbed at Station 9+00 will improve the riverflow characteristics at the control structure.

3. Placement of a submerged overflow sill or a jetty-constriction downstream of the control structure is necessary to pool the water, thus reducing the Froude number in the area of the control structure.

4. The 14-ft (4.27-m) cable sag retains the ice cover more satisfactorily than the larger 45-ft (13.72-m) sag. This results in an increase in the cable tension, on the order of twice that of the 45-ft (13.72-m) sag.

5. The "upstream V" configuration of the control structure boom provided a more stable ice cover than the parabolic boom configuration.

6. The boom configuration with the 6-inch (15.24-cm) bottom spikes retained more ice than that with no bottom spikes. The 12-inch (30.48-cm) bottom spikes showed little improvement over the 6-inch (15.24-cm) spikes.

7. The 80-foot (24.4-m) spacing between booms appeared to be more satisfactory than the larger spacings. Due to the absence of shore ice in the model, the effects of the boom spacing are difficult to evaluate.

APPLICATION

Although this investigation was limited to a specific reach of the North Platte River, the conclusions of the report could be applied to other river reaches of the North Platte and other alluvial rivers. The results are encouraging, but more investigations related to river ice control structures are needed to more fully understand the hydrodynamic processes involved.

INTRODUCTION

The North Platte River experiences ice cover formation every winter and at times ice jams are formed. The ice formation process is typical of that occurring on most rivers in cold regions.

In the fall of 1966, the North Platte River Projects Office initiated an experimental prototype study of an ice control structure on the North Platte River (Figure 1). The operation of the control structure (log boom) was expected to create an ice cover artificially by capturing float ice, resulting in an ice cover which would progress upstream from the boom in a predetermined area. In the fall of 1968, the first prototype log boom was installed 7 river-miles (11.26 km) upstream of Casper, Wyoming. The immediate objective of the log boom installation was to reduce the amount of slush ice flowing into the area of Red Butte Village, a small residential development upstream of Casper.

Prototype Ice Control Structure

The ice control structure has been placed across the North Platte River each winter from 1968 to 1970. The cable and spike configurations have been modified several times. The timbers, illustrated in Figure 2A, are 12 ft (3.66 m) long, 14 inches (35.56 cm) high, 15 inches (38.10 cm) wide at the top, and 20 inches (50.80 cm) wide at the base. The original spikes extended 12 inches (30.48 cm) above the timbers and curved 12 inches (30.48 cm) below the timbers (as shown in the figure). The spikes served as a rake in preventing float ice from passing over or under the timbers. Moss in the shallow river was caught by the lower spikes (Figure 2B) and caused the boom to float low in the water. The spikes were cut off the bottom of the upstream boom and shortened to 6-inch (15.24-cm) straight spikes on the bottom of the downstream boom.

The control structure includes four anchor blocks, two on each shore approximately 72 ft (22.86 m) apart. At present, two 1-inch (2.54-cm) cables span the river and the 12-ft (3.66-m) timbers are attached to the cables by 3-ft (0.91-m) lengths of 3/8-inch (0.95-cm) chain.

Previous Investigations

Groat [1]*, as early as 1918, used a hydraulic model to study ice diversion using paraffin to simulate float

*Numbers in brackets designate references at end of text.

ice. Several investigators [2, 3, 4], have used hydraulic models as a tool to better understand ice processes on rivers and reservoirs. Materials such as wax, paraffin, wood, and polyethelyne have been used to simulate ice.

There are two areas of similitude involved in modeling ice porcesses [5, 6]. One area involves the modeling of individual ice floes in a river where the internal properties of the ice are neglected and the similitude is based on hydrodynamic considerations. The other area involves the modeling of the ice properties. Very seldom are the two areas completely independent of each other. One area usually dominates, and in the case of ice cover formation on rivers, the hydrodynamic considerations may dominate the formation process, as in this study.

THE INVESTIGATION

The Model

A 1,500-ft (457.2-m) reach of the North Platte River was represented in a laboratory model at a 1:24 undistorted scale. This included a river distance of 900 ft (274 m) upstream and 600 ft (182 m) downstream from the existing log boom site. The "riverbed" was constructed of concrete using field river cross sections taken at 100-ft (30.48-m) intervals along a baseline running parallel to the river. The river reach under study consisted of a wide bend. When placed in an existing flume, the bend resulted in an oblique angle of flow at the upstream end of the river reach. A rock baffle directed the flow down the model in a manner similar to the actual flow in the river (Figure 3). Model discharge was measured with a 90° V-notch weir at the upstream end of the flume. The water surface elevation was controlled by an adjustable tailgate at the downstream end of the flume. Two point gages were used. One gage was placed at Station 12+00 to set the water surface elevation downstream of the log boom. The other gage was installed at Station 4+00 to measure the increase in water surface elevation as the ice cover progressed upstream from the log boom.

Ice was simulated in the model with 1/8-inch (0.32-cm) hemispherical particles of low-density polyethylene plastic "ice," with a specific gravity of 0.910-0.925 (Figure 4A). A 9-ft (2.74-m) long hopper with a capacity of 10 cubic ft (0.28 m^3) was constructed to feed the "ice" onto the surface of the water. The hopper included a 1-inch (2.54-cm) diameter plexiglass rod with eight 1/8-inch (0.32-cm) protrusions spaced symmetrically around the circumference of the rod and running the full length of the hopper. The rod was placed in the bottom of the hopper and rotated by an electric motor (Figure 4B) to agitate the "ice" particles. An adjustable gate at the bottom of the hopper controlled the rate of application of the "ice." A wire screen basket was installed at the downstream end of the flume to collect the "ice" used during the tests.

Test Procedure

A uniform test procedure was adopted throughout the testing program. Each test run was set up with a flow representing 940 cfs[1] (26.60 m^3/sec) in the prototype river reach. The appropriate water surface elevation 5145.20 was then set at Station 12+00 by adjusting the model tailgate. The "ice" was stored in 50-gallon (0.19-m^3) drums containing water which kept the plastic wet at all times. (This wetting procedure was found to be necessary by Pariset, Hausser, and Gagnon [3] and verified by the author, in order to keep the absorptive property of the plastic stable.) Once the flow parameters of the river were established the hopper was filled with the wet "ice" and the actual run started. Although the ice feed rate was not calibrated, visual control kept the feed rate as even as possible for all test runs (approximately 20-30 inch^3/min (328-492 cc/min) model units). Discharge and point gage measurements were recorded at various times throughout the runs. Photographs indicated the upstream progress of the ice cover and its relative thickness. The test runs were usually terminated when the ice cover stopped progressing upstream. This was usually accompanied by a significant amount of "ice" passing under the ice cover and control structure. In order to measure the relative tension of various boom configurations, a load cell was attached to the upstream boom cable for all test runs and the tension recorded continuously on a strip chart. The quantity of "ice" that had accumulated in the screen basket at the downstream end of the model during a test run was removed from the basket and measured. This is recorded on the data sheets as "ice lost."

The "ice" that was retained by the boom system was then released down the river, collected in the basket, and the quantity measured. These volumes of "ice" as well as other test data are presented in Data Sheets 1 through 19 in the Appendix.

Model Verification

There was concern, while constructing the model, as to the finish needed on the concrete to adequately simulate the field riverbed roughness. Studies to verify the acceptability of the model were conducted. The model discharge and water surface elevation at Station 12+00 were established (Q = 1,050 cfs, (29.72 m^3/sec),

[1] All dimensions refer to the prototype scale, unless otherwise noted.

elevation at 12+00 = 5144.98) to simulate flow data from the prototype when the boom was installed with no ice present. Model data indicated that the water surface elevation at Station 4+00 was approximately 0.14 ft (0.043 m) below that of the prototype river for a water surface elevation of 5144.98 at Station 12+00. Therefore, a decision was made to artificially increase the water surface at Station 12+00 by using the tailgate to compensate for the error in riverbed roughness. The water surface was raised until the slope term in the Manning equation was decreased sufficiently to compensate for the low "n" value. This adjusted model tailwater, which amounted to approximately 0.012 ft (0.37 cm) (model) increase in water surface elevation at Station 12+00 decreasing to zero at Station 4+00, was used throughout the testing program.

Once the model was corrected, surface velocities were measured in the model and compared to the prototype velocities under the same flow conditions. The model velocities were approximately 4 percent below the prototype data.

In general, when "ice" was applied to the model, the cover would not progress upstream from the control structure as well as in the prototype. Due to the relatively high Froude number involved in this reach of the river ($Fr = 0.17$), the ice cover formation is considered very unstable. The mechanism of ice cover formation in the prototype appears to be based on extension of the shore ice across the river. In the model, the absence of the freezing process between "ice" particles eliminates the possibility of shore ice formation, thus greatly reducing the structural strength of the model ice cover.

Although the ice simulation is not complete, a great deal of insight with regard to the hydrodynamic aspects of ice cover formation can be attained with the use of such models. The use of materials such as polyethylene to simulate ice in hydraulic models affords a means of investigating ice formation processes under normal hydraulic laboratory conditions.

TEST RESULTS

As shown by the data sheets in the appendix, various boom configurations were tested (Runs 1 through 13) as well as two tests with higher tailwaters than that of the prototype (Runs 14 and 15). To evaluate the lack of shore ice in the model, large sheets of polyethylene were cut to simulate the shore ice status at the control structure site immediately before the ice cover closed at the boom and started to progress upstream (Runs 16 and 17). Two types of artificial constrictions were placed downstream of the ice control structure in order to pool the water (Runs 18 and 19).

Channel Modifications

Channel cross sections.—The channel cross section for Station 9+00, which corresponds to the location of the present ice control structure site, is shown in Figure 5. A view showing the riverbed contours in May of 1970 is shown in Figure 6. The rocky protrusion of the riverbed in the left center of the cross section interferes with the uniformity of the flow under the control structure. As the ice cover thickens at the control structure, the effective area of the left third of the cross section decreases rapidly, forcing the river discharge into the right channel of the cross section (Figure 7A). The intense white area on the left side of the river is the thick ice cover. The flow is concentrated on the right side carrying the "ice" under the control structure.

Although the cross section at Station 8+00 favors the right side, there is a definite improvement in the uniformity of "ice" retention by the control structure at Station 8+00 relative to that at Station 9+00 (Figure 7B).

The removal of the rocky protrusion in the cross section at Station 9+00 will improve the flow characteristics under the control structure and, as a result of the increased cross sectional area, reduce the velocity at the section.

Velocity and Froude number considerations.—Bryce and Berry [7] found on the Niagara River that with water velocities greater than 2.5 fps (0.76 m/sec) where the river averaged 30 ft (9.14 m) deep, the ice cover was unstable. They agreed with Kivisild's [8] upper limit of $Fr = 0.08$, where:

$$Fr = \frac{V}{\sqrt{gD}}$$

for ice cover stability. Michel [9] states that the maximum average flow velocity to insure a stable cover should be 1.0 fps (0.30 m/sec) for a river depth of 5 ft (1.52 m). The average flow velocity at cross section 9+00 is 1.7 fps (0.52 m/sec) for a river discharge of 940 cfs (26.60 m^3/sec) at an average depth of 3.1 feet (0.95 m). This yields $Fr = 0.17$, well above the $Fr = 0.08$ recommended by Kivisild. Removing the rock protrusion and artificially raising the water surface 1.5 ft (0.46 m) will result in an average velocity of 1.0 fps (0.30 m/sec) and a Froude Number of 0.079 at Station 9+00. Placement of a submerged overflow sill or jetty downstream of the control structure would be necessary to pool the water and increase the depth.

Ice Control Structure Modifications

Cable sag.—Boom configurations with 14-ft (4.27-m) and 45-ft (13.72-m) cable sag were tested. In general, the runs with cable sag of 14 ft (4.27 m) retained more "ice" than those with a 45-ft (13.72-m) cable sag (Figure 8).

Cable tension.—The tension on the cable with a 14-ft (4.27-m) cable sag was approximately twice as great as for the cable with a 45-ft (13.72-m) sag (Figure 9). Because there was no freezing process present in the model studies and because the drag on the underside of the ice cover may not have been simulated, the cable tension data could only be used in a qualitative sense in comparing various model boom configurations.

Cable configuration.—Runs with the "upstream V" configuration, Figure 10, resulted in more stable ice covers than the simple parabolic design. They released a comparatively small amount of "ice" downstream. The "upstream V" configuration (45° to the shoreline) takes advantage of the increased stability of the ice cover resulting from the wedging of the float ice between the boom and the riverbanks.

The run with the booms of the control structure close together (Figure 10C) resulted in a more stable ice cover between the booms than that of the run with a 55-ft (16.76-m) spacing between the booms (Figure 10D).

Spike design.—The orientation of 12-inch (30.48-cm) spikes on the underside of the timbers in the downstream direction, compared to the prototype original upstream orientation, did not appear to make any difference in the ice cover formation (Figure 11). Figure 12 illustrates the various spike configurations used in the model investigations.

The 12-inch (30.48-cm) spike showed a slight improvement over a shorter 6-inch (15.24-cm) spike (Figures 13A and 13B).

The 6-inch (15.24-cm) spike proved to be more effective than no spike at all (Figures 13C and 13D).

Alternate openings in upstream boom.—Run No. 12 had alternate timbers in the upstream boom removed to test the effectiveness of open spaces in the boom (Figure 14A). The thick "ice" initially retained by the control structure eventually started to move quite easily through the open spaces in the upstream boom (Figure 14B). Complete failure of the ice cover soon followed (Figure 14C). The presence of shore ice might have resulted in a somewhat more stable ice cover.

Spacing between booms.—Three spacings between the ice control structure booms, 80 ft (24.38 m), 155 ft (47.27 m), and 290 ft (88.39 m), were tested (Figure 15). The "ice" progressed upstream from the control structure approximately the same distance for all three configurations. The 80-ft (24.38-m) spacing configuration allowed the "ice" to close off and thicken between the booms, whereas the runs with larger spacings never closed off. Although the actual surface area of the ice cover was greater for the run with the 290-ft (88.39-m) spacing, the volume of "ice" retained was greater for the 80-ft (24.38-m) spacing. Run No. 9 with the 80 ft (24.38-m) spacing appeared more stable than the other two spacings; however, the absence of shore ice formation in the model precludes any firm decision with regard to boom spacing.

By pooling the water, thus reducing the Froude number, the possibility of using only one boom should be considered for any future installations.

Shore ice effect.—Figure 16 illustrates two runs using the same flow parameters and boom configuration; however, one had shore ice represented by large sheets of polyethylene. The polyethylene sheets were cut to represent a shore ice configuration in the field as shown in Figure 17A. The shore ice resulted in a more stable ice cover which progressed upstream further than the run without shore ice.

Figure 17B indicates the ability of the model control structure to backup the float ice instead of allowing it to flow under the structure. The density of the polyethylene particles was 0.92 g/cm^3. Figure 17C indicates how float ice in the field initially passes under the control structure. The close-off of the ice cover at the prototype structure is achieved by the shore ice bridging the river instead of float ice backing up at the control structure. This phenomenon did not occur in the model investigations. It appears that some of the field float ice approaches the density of water (1.0 g/cm^3) which would float lower in the water and therefore have a tendency to float under the control structure at high velocities.

The tendency of the shore ice in the prototype river to "funnel" the float ice into the apex of the parabola appears to add to the field problem of establishing an ice cover early after float ice develops in the river. The "upstream V" configuration of the control structure would alleviate this tendency.

Artificial Channel Constrictions

Two artificial constrictions were tested in the model. The constrictions were located at Station 10+50, some 50 feet (15.24 m) downstream from the control structure.

Opposing jetty constriction.—The first constriction, Figure 18, consisted of an opposing jetty which reduced the river's width from 210 ft (64.0 m) to 56 ft (15.07 m) at the water surface. This increased the water surface elevation at the control structure site by 1.0 ft (0.30 m) and resulted in an ice cover formation similar to Run No. 15 when the tailgate was used to increase the depth (Figure 19).

The jetties were designed to overtop at a discharge of approximately 1,500 cfs (42.45 m^3/sec), allowing the constriction to pass larger discharges during the spring and summer months without greatly increasing the velocities through the narrow constriction. The model jetties were made of concrete with a top width representing 5 ft (1.52 m) in the prototype river and a 2:1 side-slope. The jetties were placed 45 ft (13.72 m) apart on the bed of the river. Crest elevation of the jetties was 5146.25 with the crest sloping upward toward the shores at 1:50.

Velocities were measured in the area of the constriction with a propeller-type miniflowmeter. Velocities shown in Figure 20 were recorded at 0.6 of the depth. In the constriction, the velocities near the bottom were approximately the same as those at 0.6 depth. The velocities in the center of the river were quite intense, reaching 7 fps (2.13 m/sec) 50 ft (15.24 m) downstream from the constriction. This design would require that particular attention be given to armoring of the complete structure and the central part of the downstream channel to prevent the possibility of erosion resulting from the channel alteration. The opposing jetty design would provide for the passage of recreation boats through the control structure site during the summer months.

Submerged overflow sill.—The second type of constriction tested, Figure 21, consisted of a submerged overflow sill. The submerged sill increased the water surface elevation at the control structure site by approximately 0.8 ft (0.24 m) resulting in an ice cover formation similar to Run No. 14, Figure 22. Figure 23 illustrates the improvement in the retention capability of the control structure as the water surface elevation is increased, thus decreasing the Froude number. Runs No. 6, 18, and 19 all had the same boom configuration, location, and downstream water surface elevation.

The model sill was made of concrete and had a prototype crest width of 1 ft (0.30 m) at an elevation of 5144.66. The sides were sloped at 2:1.

Velocities were also measured in the area of the overflow sill in the same manner as with the opposing jetty (Figure 24). The velocities were greater than 5 fps (1.52 m/sec) along the downstream toe of the sill; however, the velocities returned to the normal river velocities some 50 to 75 ft (15.24-22.86 m) downstream from the sill. The submerged overflow sill will be susceptible to sediment deposition in the upstream pool, thus reducing the effective cross sectional area. The shallow clearance, about 11 inches (27.9 cm) at 940 cfs (26.60 m^3/sec), over the sill may present some difficulties for recreational boating in the area of the control structure.

To observe the movement of the ice cover, lines of colored polyethylene particles were dropped at various times over Station 8+00. Figure 25A was taken 24 minutes after the first line was dropped and 79 minutes after the start of the test. Notice how the center of the ice cover has been displaced downstream. Figure 25B was taken 48 minutes after the second line was dropped. Figure 25C was taken 95 minutes after the third line was dropped. Figure 25D was taken 73 minutes after the fourth line was dropped. Notice how the lines bend downstream on the right side of the ice cover in Figure 25D.

REFERENCES

1. Groat, B. F., "Ice Diversion, Hydraulic Models, and Hydraulic Similarity," Transactions of American Society of Civil Engineers, Vol. 82, 1918

2. Cebertowicz, R., "Hydraulic Engineering Structures in the Light of Tests with Models," Translated by Polish Academy of Sciences Institute of Hydraulic Engineering in Gdansk, 1968

3. Pariset, E., Hausser, R., Gagnon, A., "Formation of Ice Covers and Ice Jams in Rivers," Journal of the Hydraulics Division, ASCE, Vol. 91, November 1966

4. Taubmann, Christian, "Model Tests for the design of Ice-Retaining Basin on the Sihl River," Translated from the German Reprint, Schweizerischen Bauzeitung, by Joint Publications Research Service for USBR, Translation No. 853, 10 pp. 1971

5. Tesaker, E., "Ice Problems in Models," River and Harbour Research Laboratory, Technical University of Norway, Bulletin No. 8E, 1966

6. Michel, B., "Ice Pressure on Engineering Structures," Cold Regions Science and Engineering Monograph 111-B1b, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, 79 pp., June 1970

7. Bryce, J. B., Berry, G. T., "Lake Erie–Niagara Ice Boom," Engineering Journal (Canada), Vol. 51, No. 2, February 1968

8. Kivisild, H. R., "Hanging Ice Dams," International Association for Hydraulic Research, Vol. 3, Eighth Congress, Montreal, Canada, 1959

9. Michel, B., "Analysis of Hypotheses Relative to the Formation of Ice Covers in Winter," Department of Civil Engineering, Laval University, Quebec, Canada, 1966, English translation by USBR, Denver, Colorado, No. 697, 1967

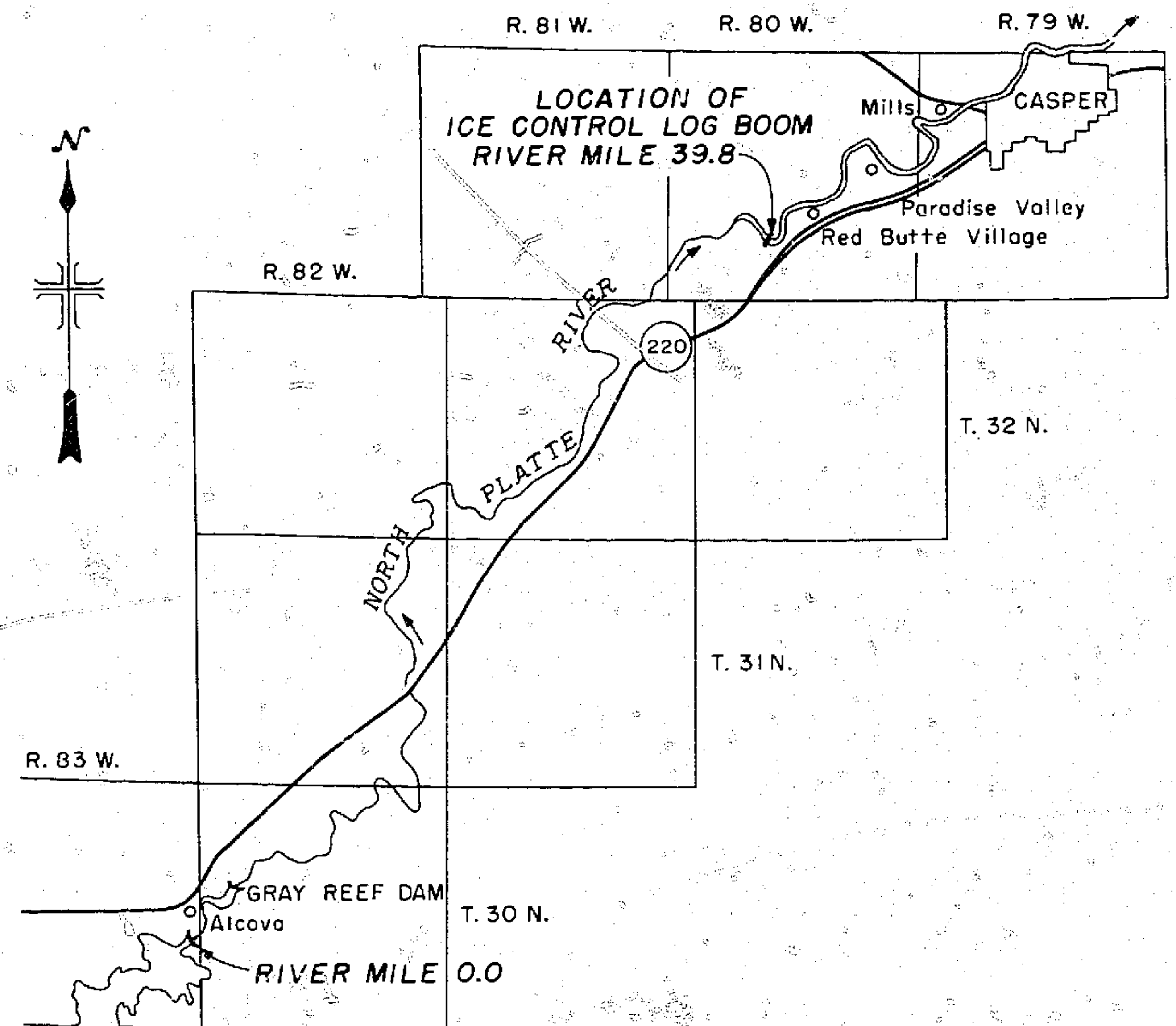
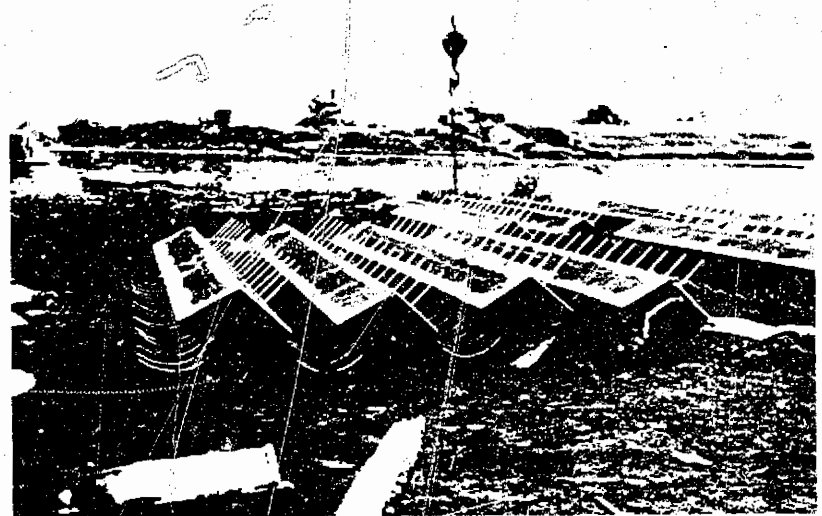
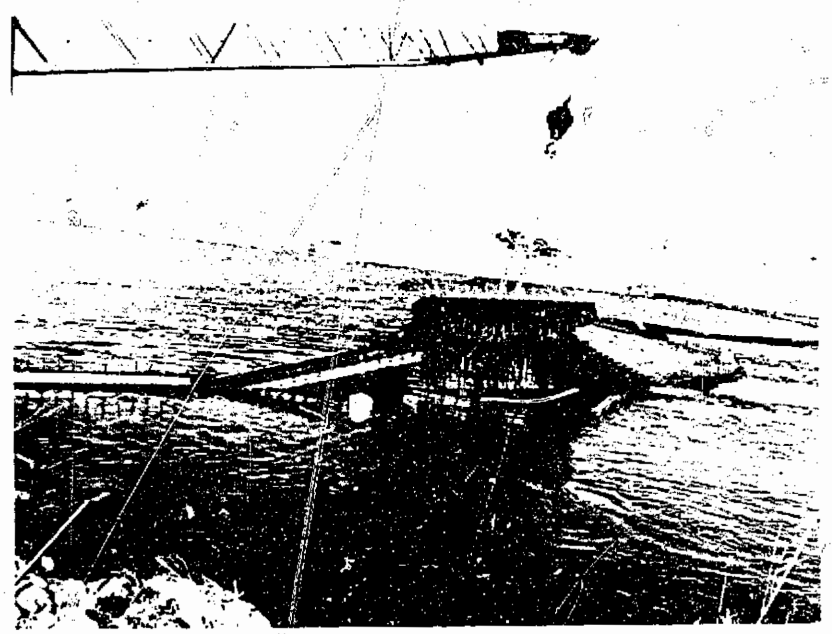


Figure 1. Location map.

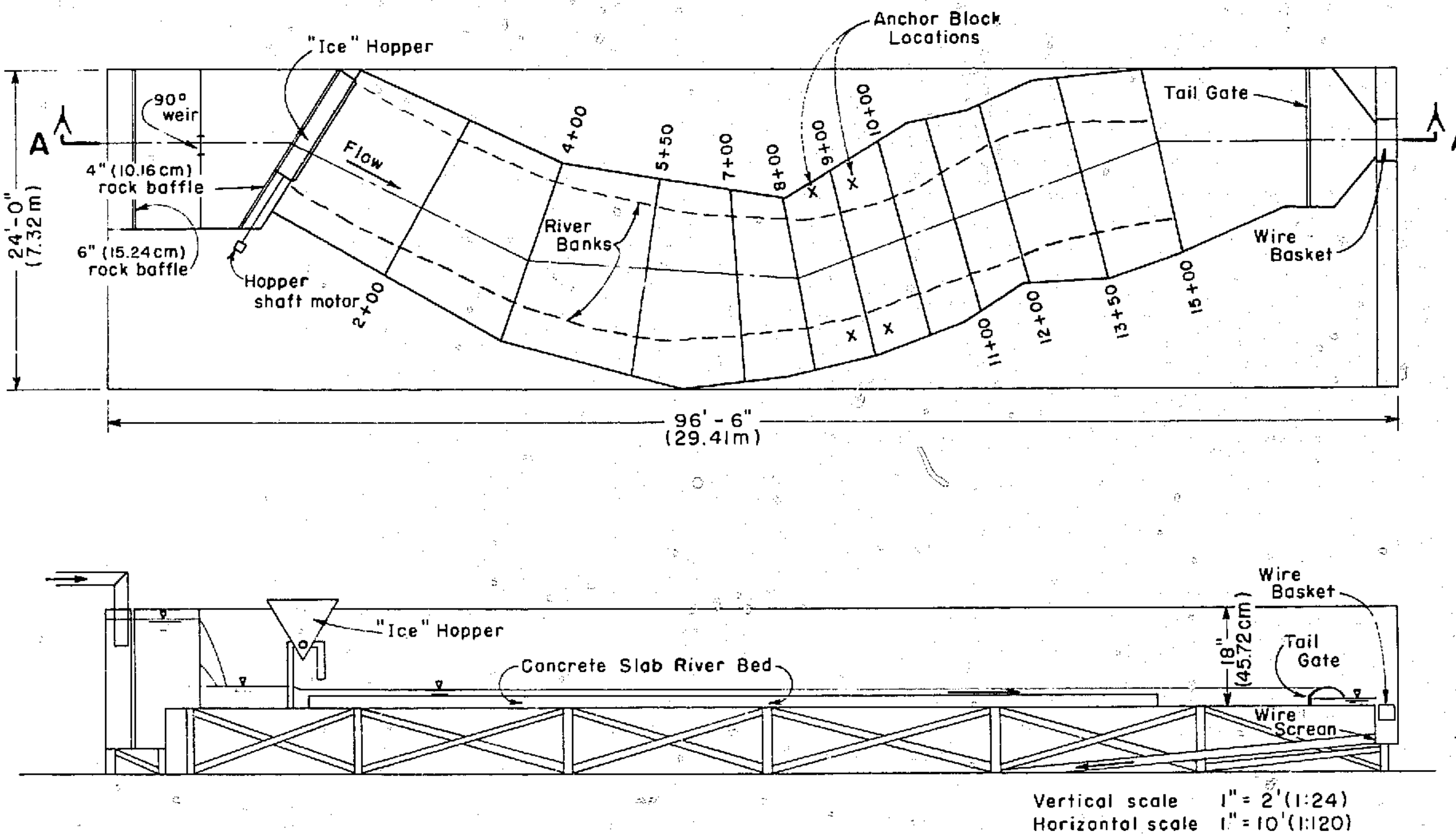


A. Prototype ice control structure timbers ready to be installed. Photo P20-703-5933 NA



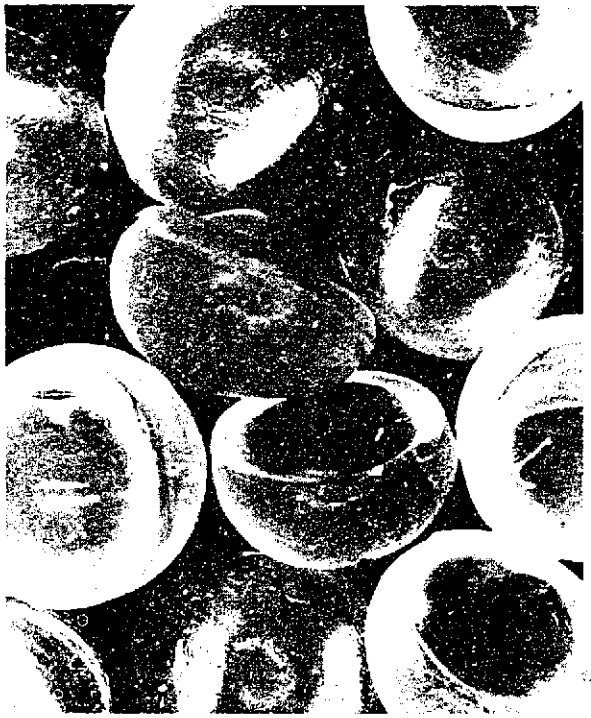
B. Crane lifting one log of the boom for examination of moss accumulation. Photo P20-703-5952 NA

Figure 2. Prototype ice control structure.

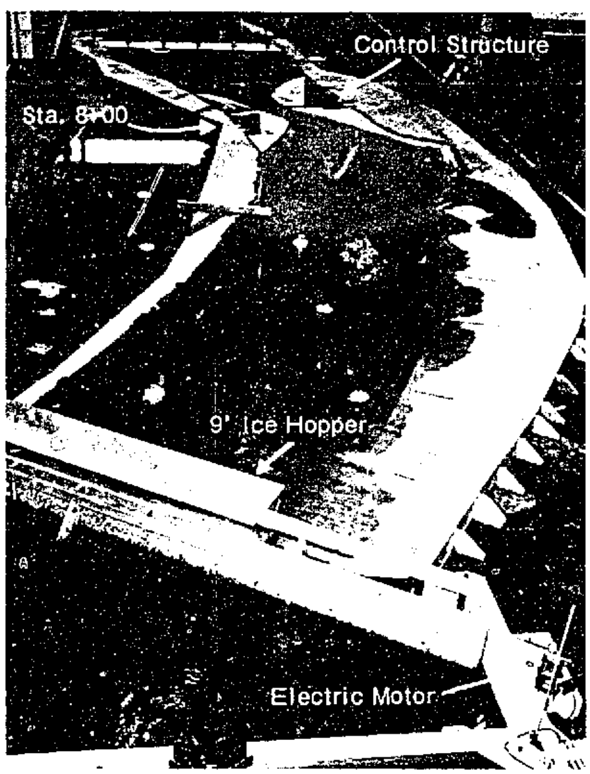


SECTION A-A

Figure 3. Model layout–Ice control structure, North Platte River.

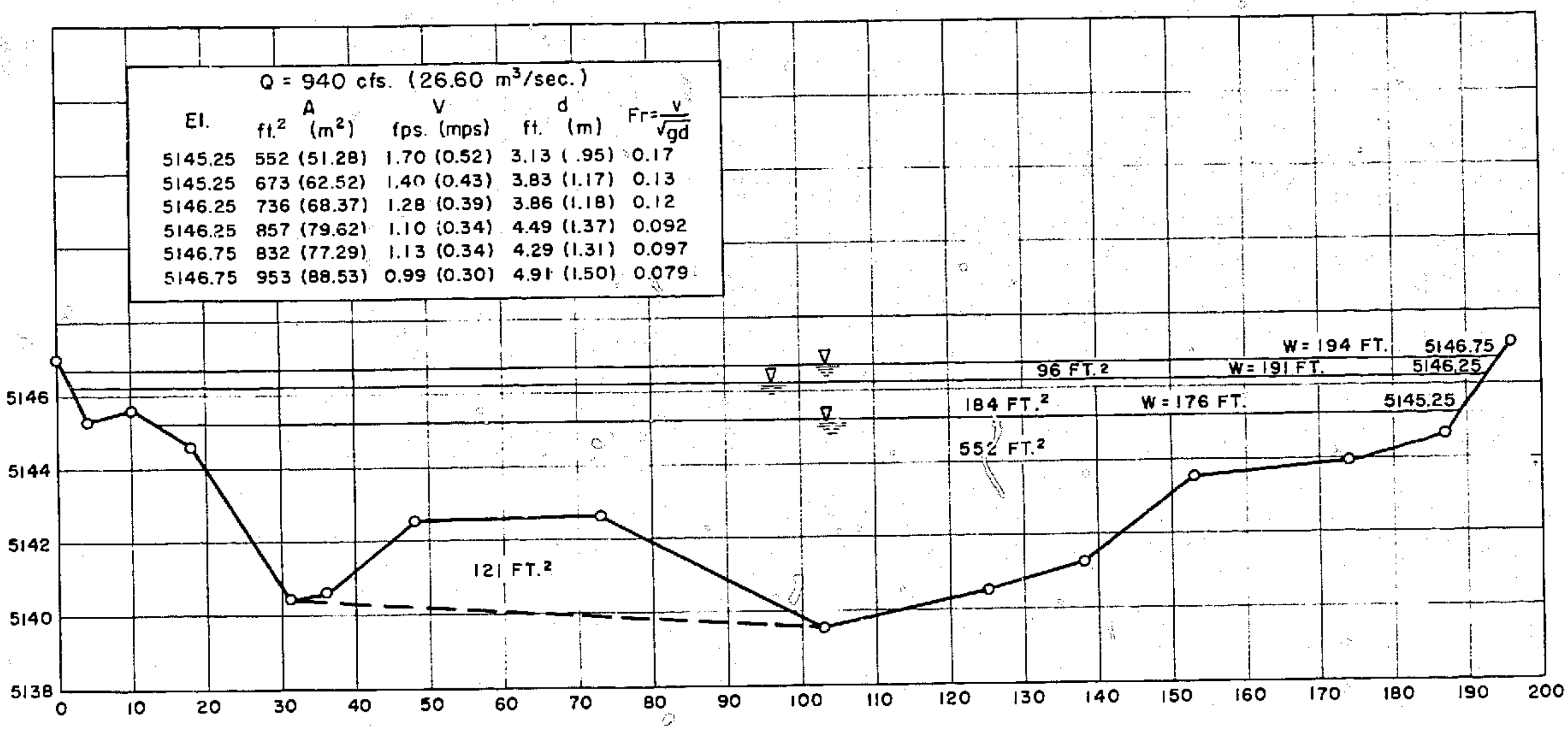


A. One-eighth-inch (0.32-cm) polyethylene particles used in the investigation. Photo P20-D-70151



B. View of model looking downstream. Photo P20-D-70161

Figure 4. North Platte River model.



Q = 940 cfs. (26.60 m³/sec.)

El.	A ft.²	A (m²)	V fps.	V (mps)	d ft.	d (m)	$Fr = \frac{v}{\sqrt{gd}}$
5145.25	552	(51.28)	1.70	(0.52)	3.13	(.95)	0.17
5145.25	673	(62.52)	1.40	(0.43)	3.83	(1.17)	0.13
5146.25	736	(68.37)	1.28	(0.39)	3.86	(1.18)	0.12
5146.25	857	(79.62)	1.10	(0.34)	4.49	(1.37)	0.092
5146.75	832	(77.29)	1.13	(0.34)	4.29	(1.31)	0.097
5146.75	953	(88.53)	0.99	(0.30)	4.91	(1.50)	0.079

Figure 5. Cross section–Sta. 9+00.

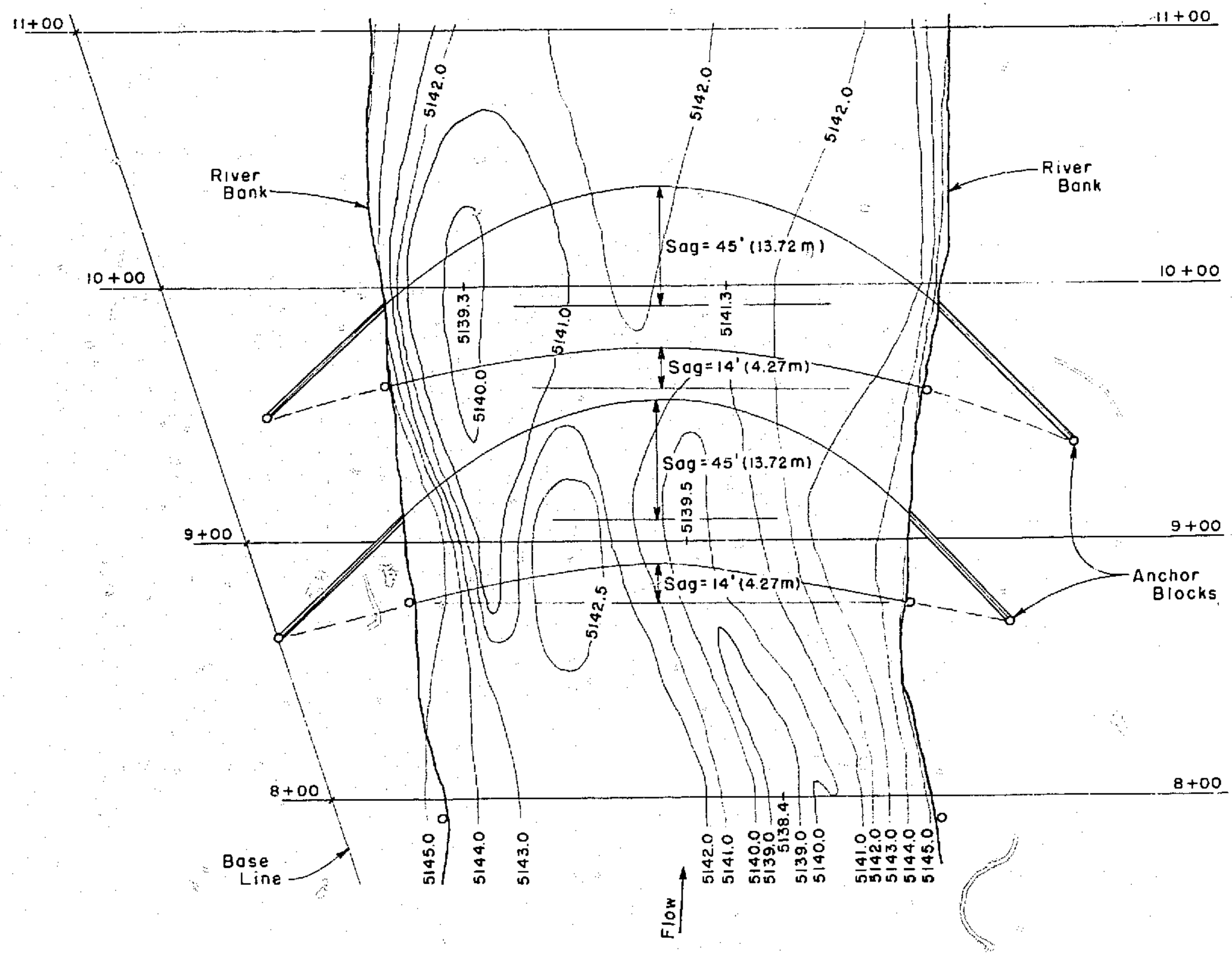
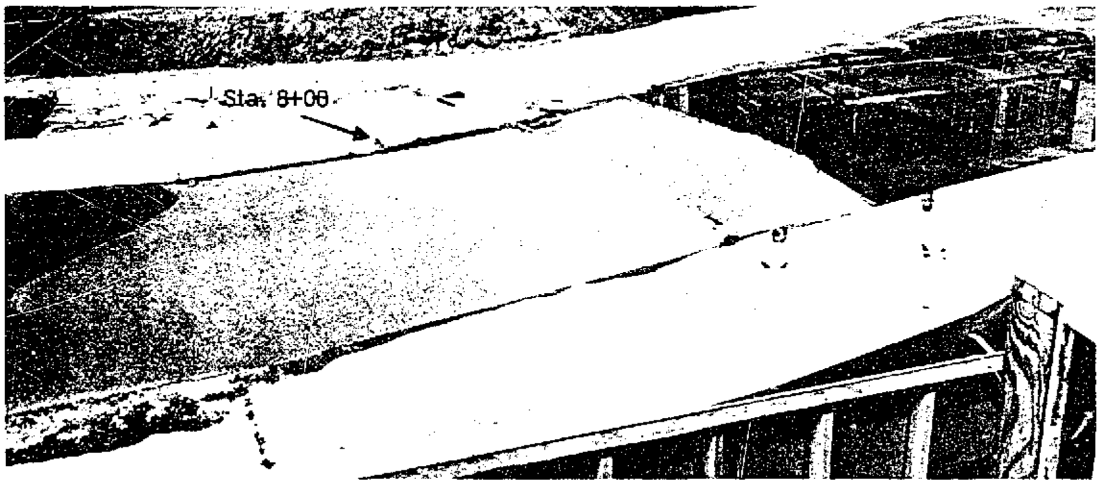
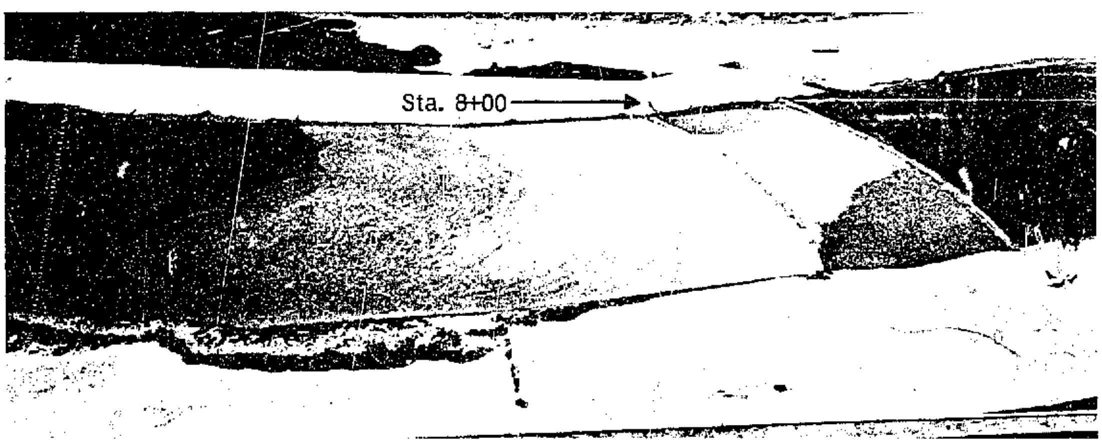


Figure 6. Riverbed contours at site of control structure.

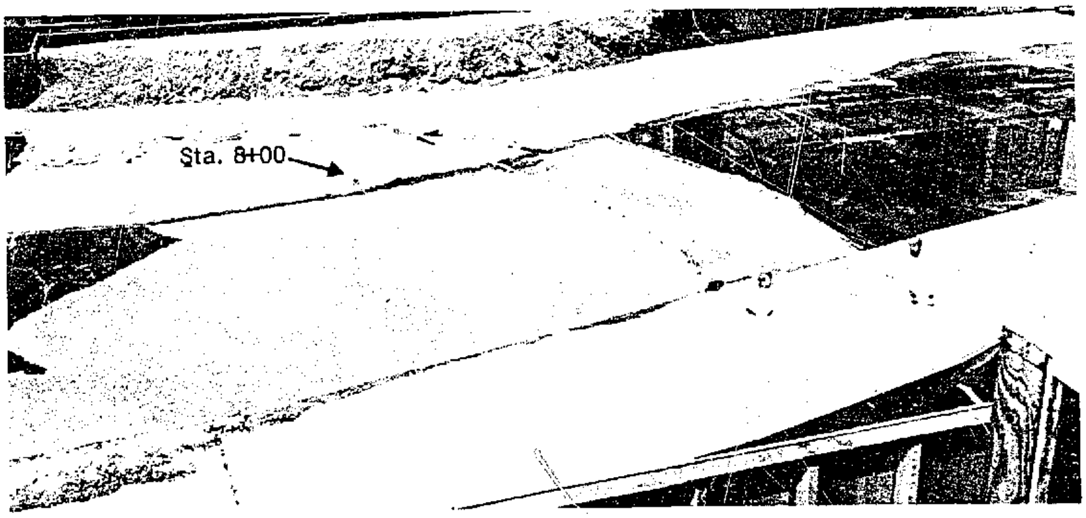


A. Run No. 6, upstream boom at Sta. 9+00. Note ice escaping under right side of upstream boom. Photo P20-D-70140

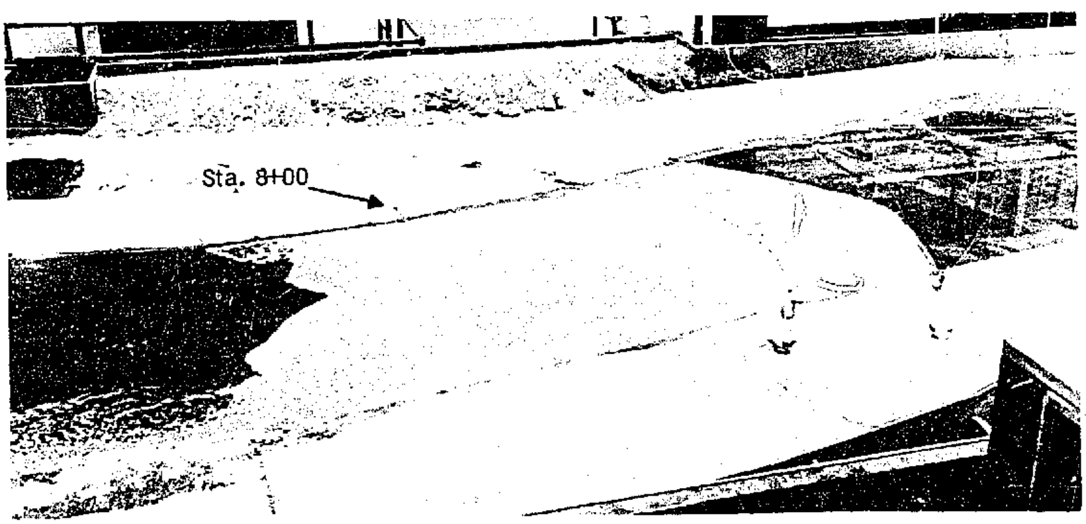


B. Run No. 9, upstream boom at Sta. 8+00. Note improved thickness of ice indicated by light area on photograph. Photo P20-D-70145

Figure 7. Location of ice control structure.



A. Run No. 6, 14-foot (4.21-m) cable sag. Photo P20-D-70139



B. Run No. 5, 45-foot (13.72-m) cable sag. Photo P20-D-70137

Figure 8. Effect of cable sag.

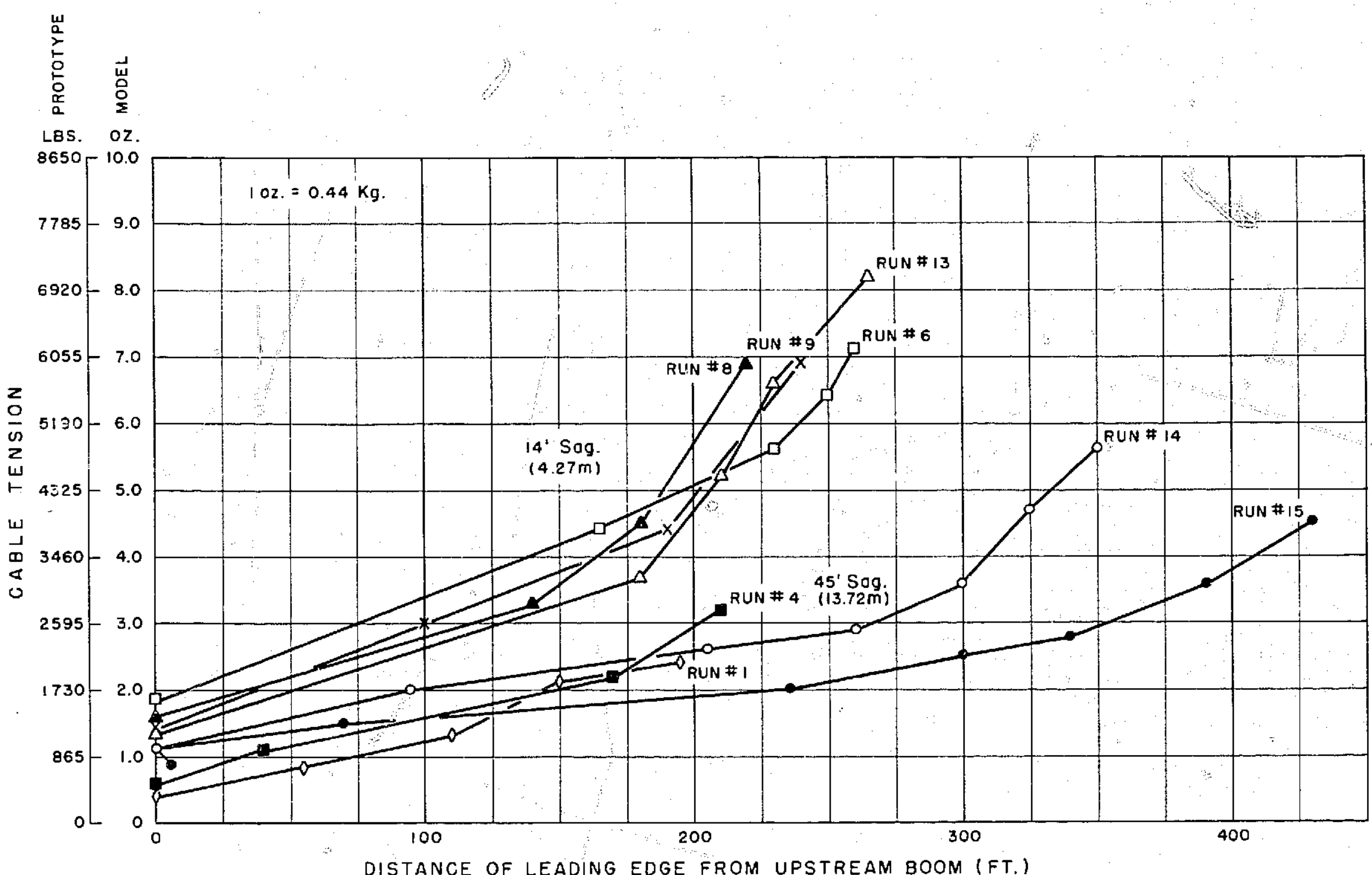
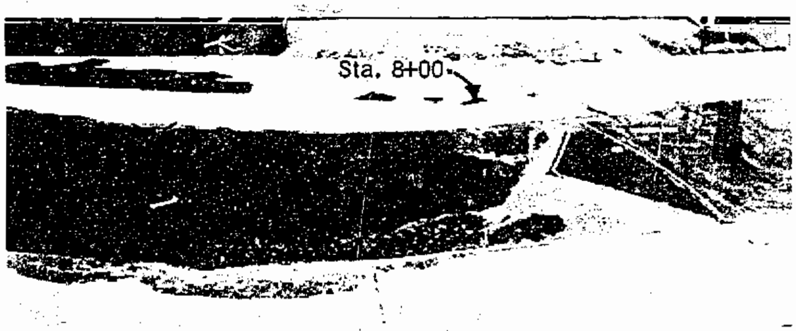
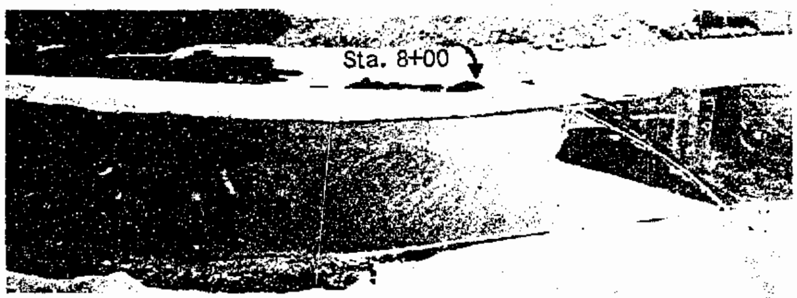


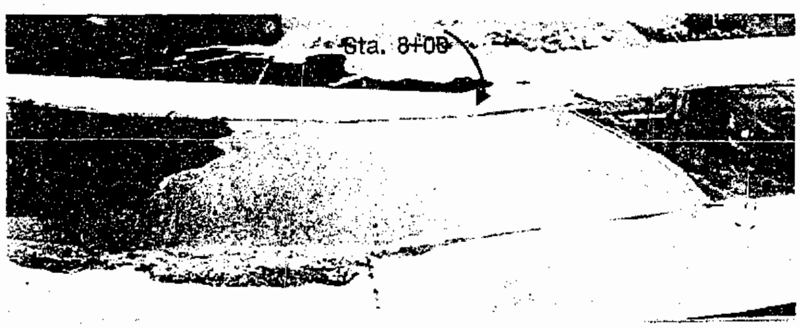
Figure 9. Upstream boom cable tensions.



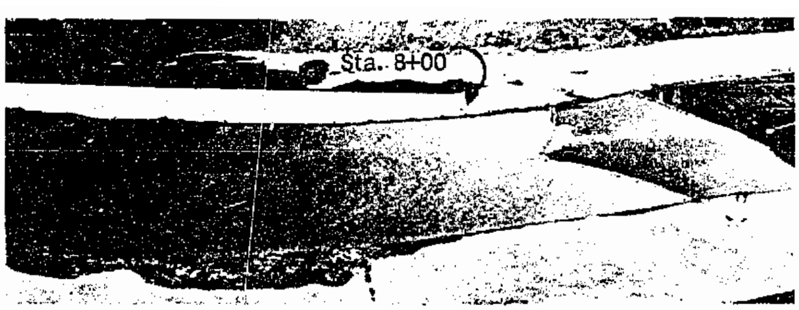
A. Run No. 11, model time—10 minutes. Photo P20-D-70148



B. Run No. 11, model time—109 minutes. Photo P20-D-70149

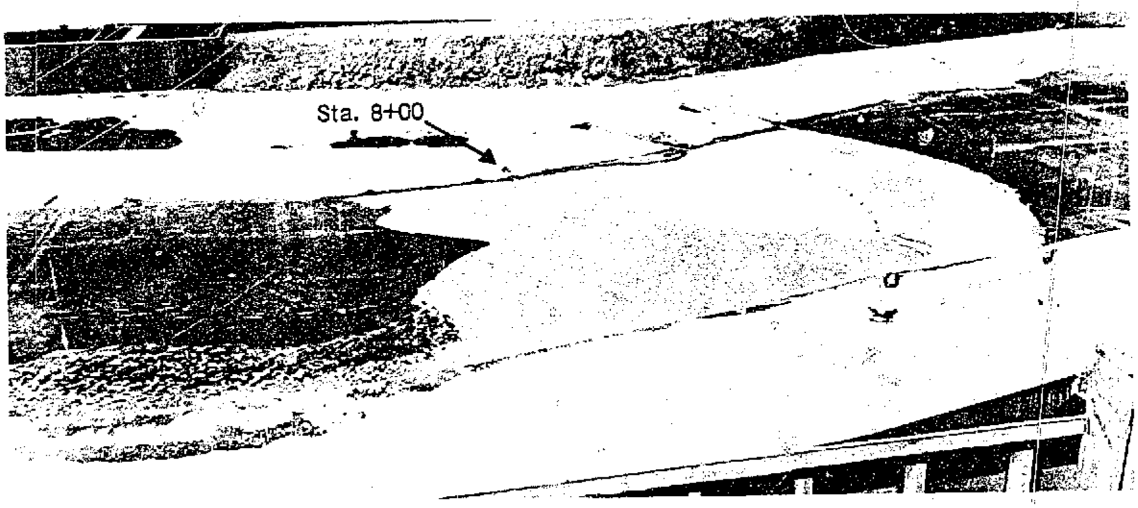


C. Run No. 11, model time—194 minutes. Photo P20-D-70150

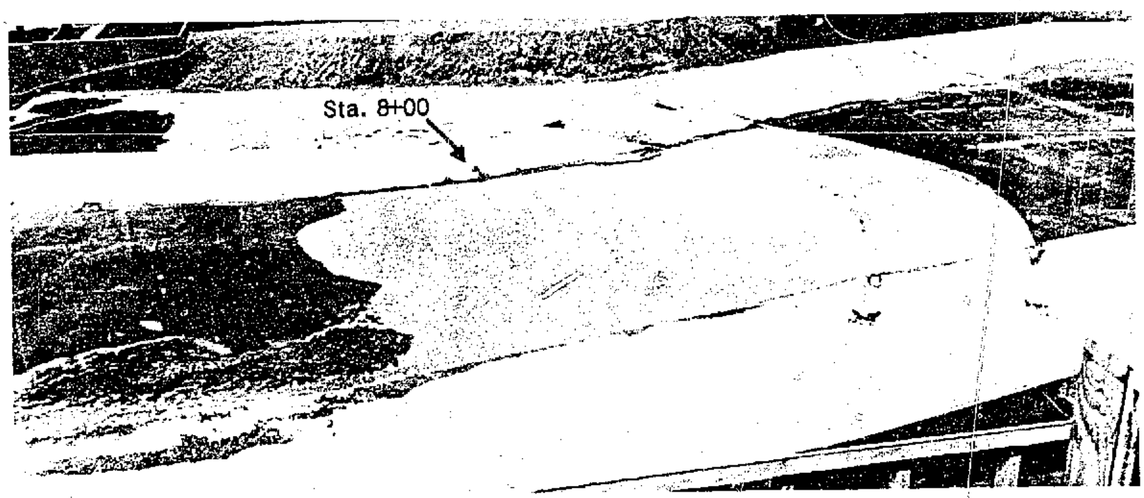


D. Run No. 10, model time—257 minutes. Cable spacing—55 feet. Photo P20-D-70147

Figure 10. Control structure with "upstream V" configuration

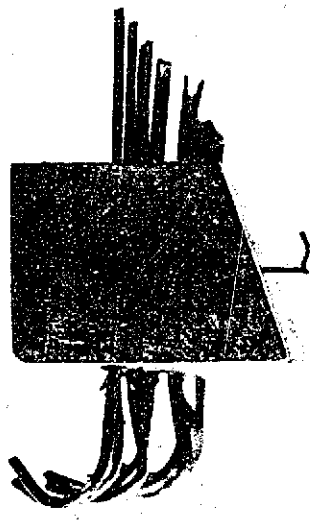


A. Run No. 1, 12-inch (30.48-cm) spike oriented upstream. Note: Timbers only in center half of upstream boom. Photo P20-D-70133

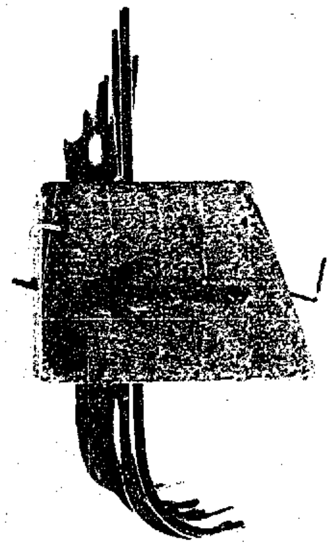


B. Run No. 2, 12-inch (30.48-cm) spike oriented downstream. Note: Timbers only in center half of upstream boom. Photo P20-D-70134

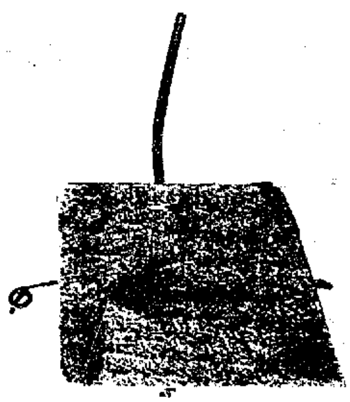
Figure 11. Effect of 12-inch spike orientation.



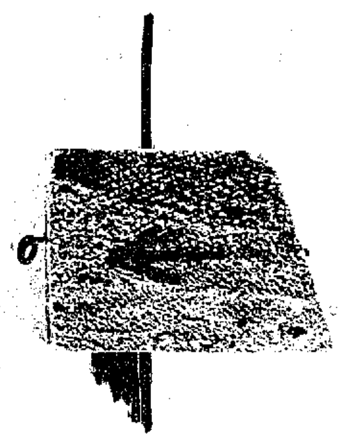
A. Timber Configuration No. 1, 12-inch (30.48-cm) spikes oriented downstream.



B. Timber Configuration No. 2, 12-inch (30.48 cm) spikes oriented upstream.

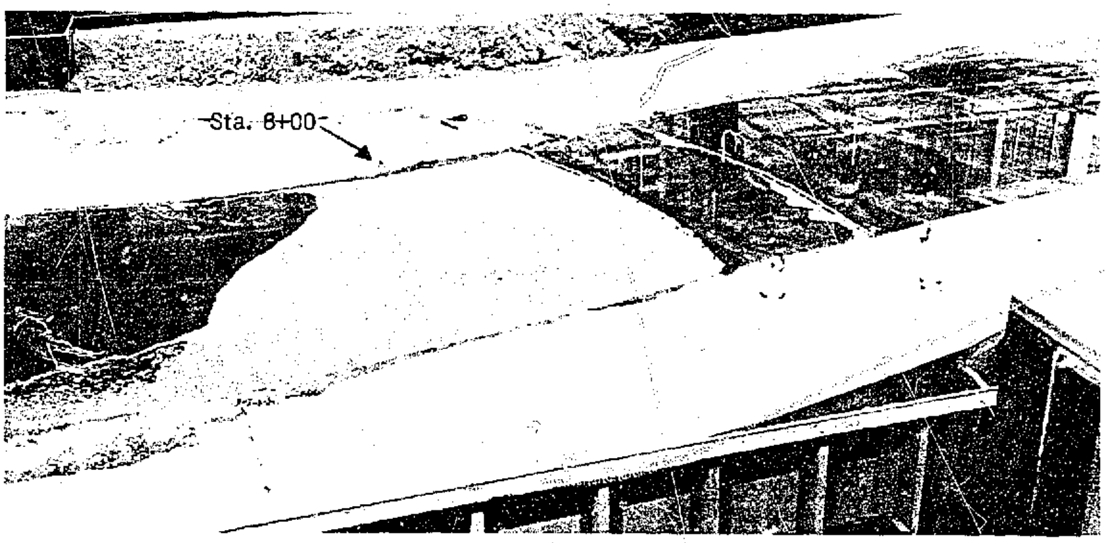


C. Timber Configuration No. 3, no spikes.

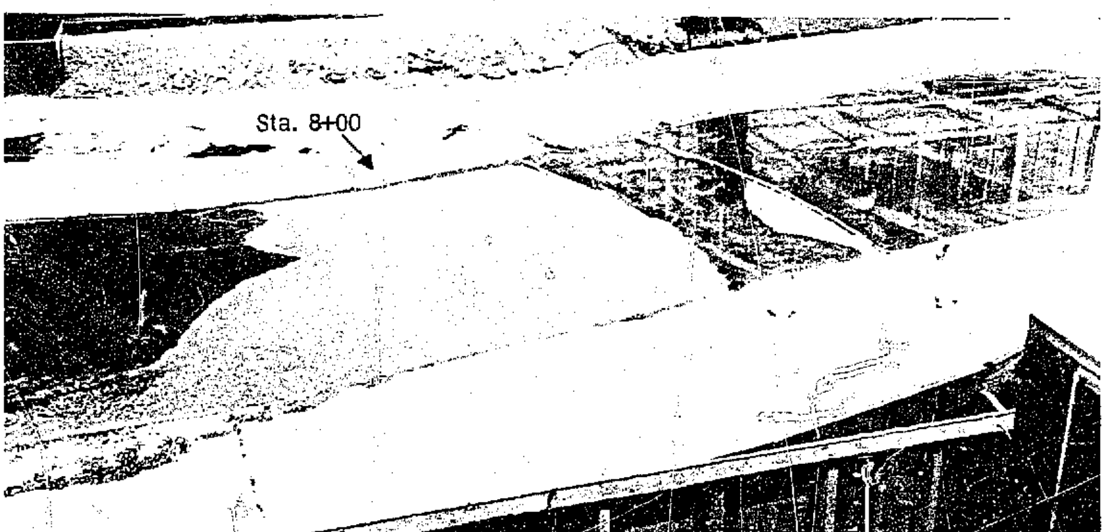


D. Timber Configuration No. 4, 6-inch (15.24-cm) spikes.

Figure 12. Timber spike configurations. Top Photo P20-D-70146, bottom Photo P20-D-70155

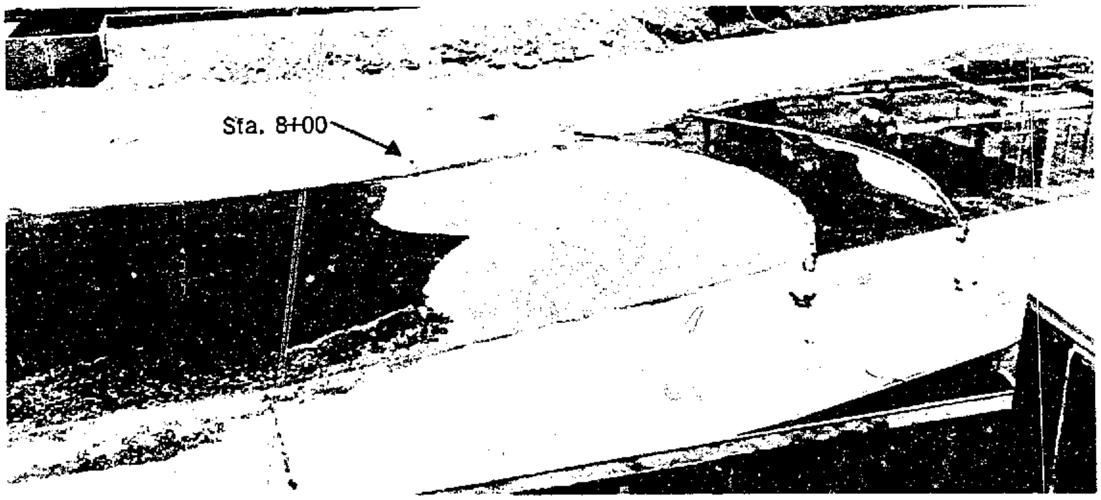


A. Run No. 6, 6-inch (15.24-cm) spikes on upstream boom. Photo P20-D-70138

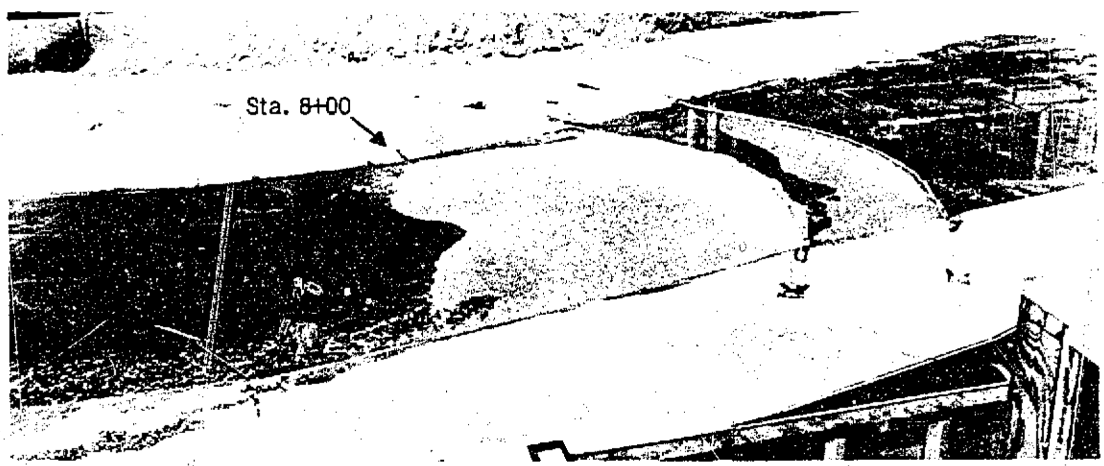


B. Run No. 7, 12-inch (30.48-cm) spikes on upstream boom. Photo P20-D-70142

Figure 13. Effect of upstream boom spike configuration.

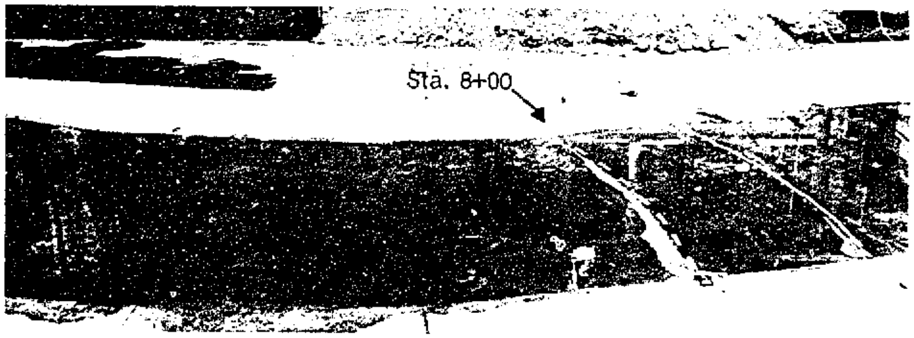


C. Run No. 4, 40-foot cable sag, 6-inch (15.24-cm) spikes on upstream boom. Photo P20-D-70136

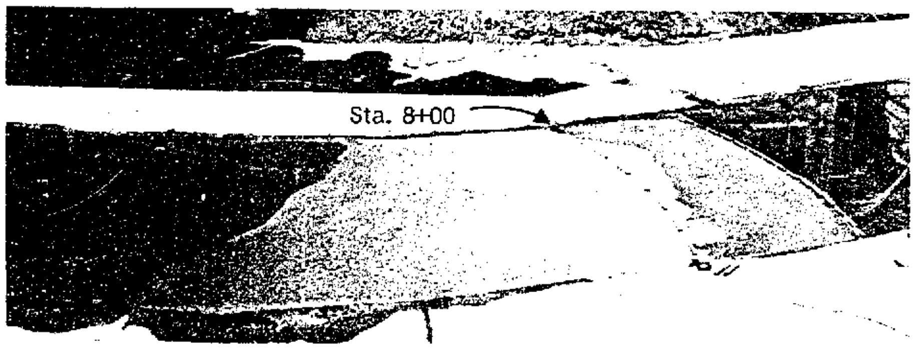


D. Run No. 5, 43-foot cable sag, no spikes on upstream boom. Photo P20-D-70135

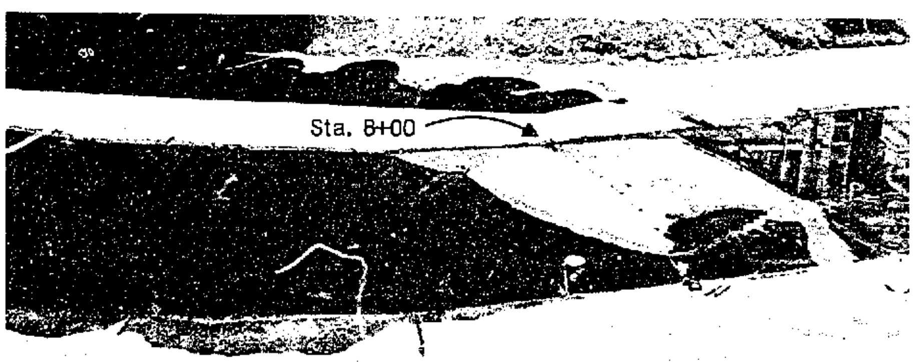
Figure 13. Effect of upstream boom spike configuration.



A. Run No. 12, alternate openings of timbers in upstream boom. Photo P20-D-70152

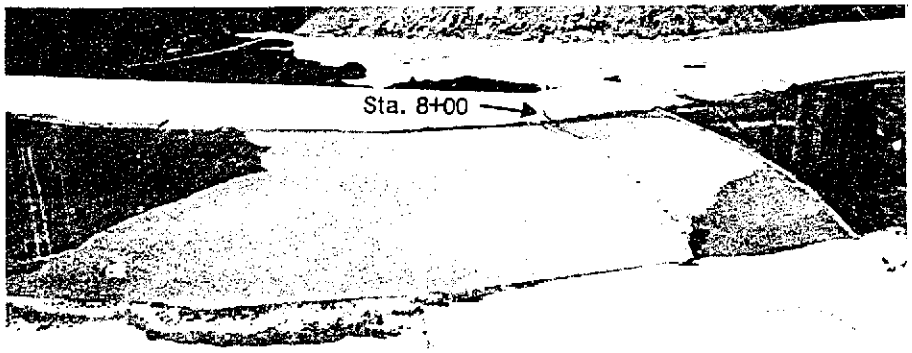


B. Run No. 12, thick ice passing through openings in upstream boom. Photo P20-D-70153

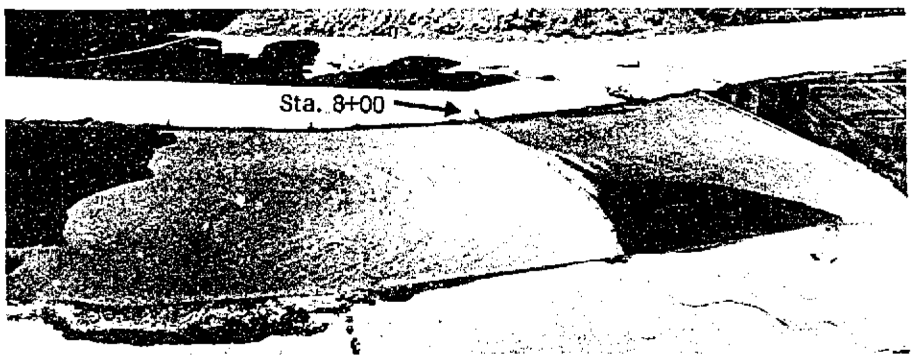


C. Run No. 12, failure of ice cover around right side of control structure. Photo P20-D-70154

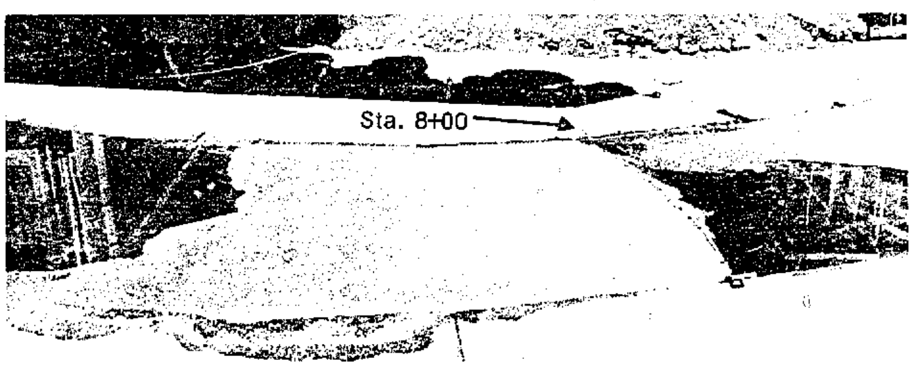
Figure 14. Effect of alternate openings in upstream boom.



A. Run No. 9, 80-foot (24.38-m) space between booms. Photo P20-D-70145

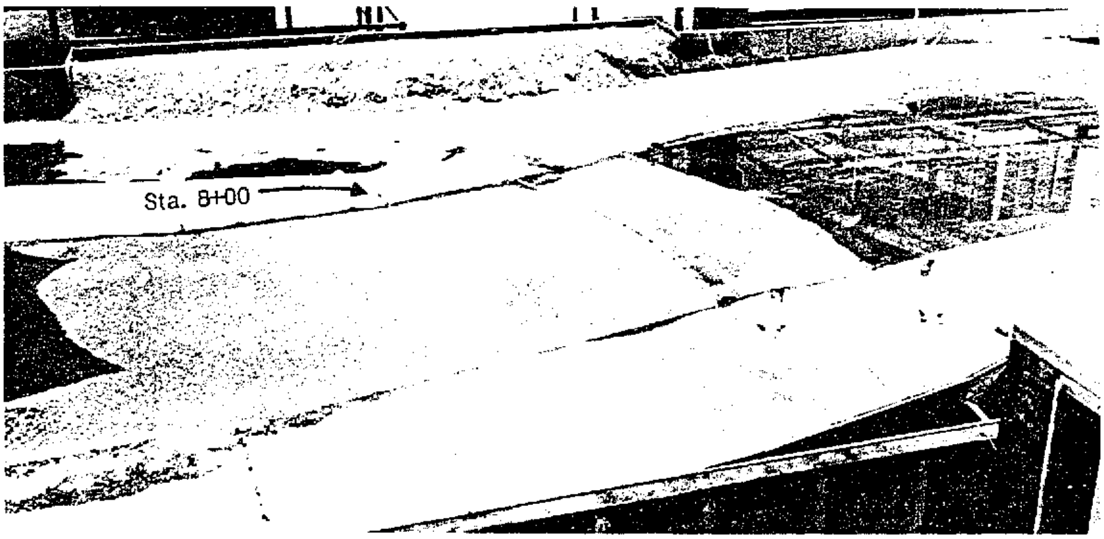


B. Run No. 8, 155-foot (47.24-m) space between booms. Photo P20-D-70144

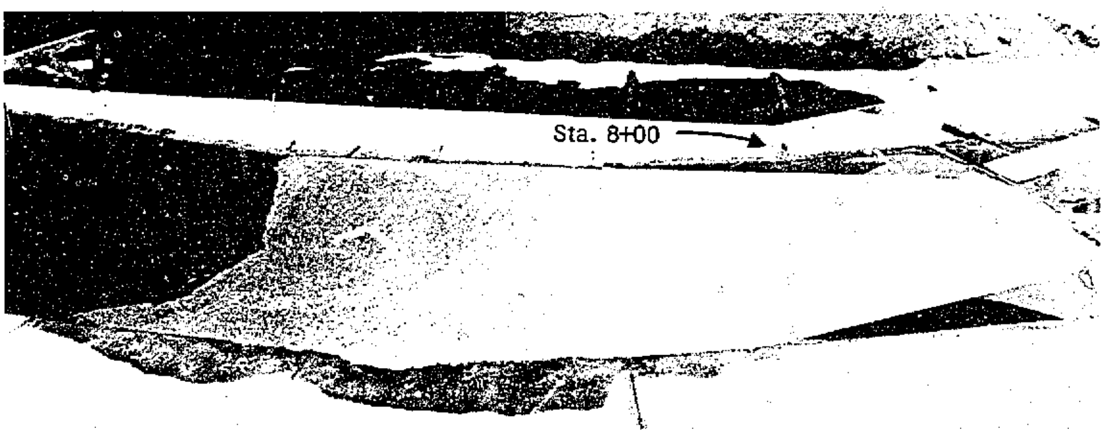


C. Run No. 13, 290-foot (88.39-m) space between booms. Photo P20-D-70156

Figure 15. Effect of boom spacing.

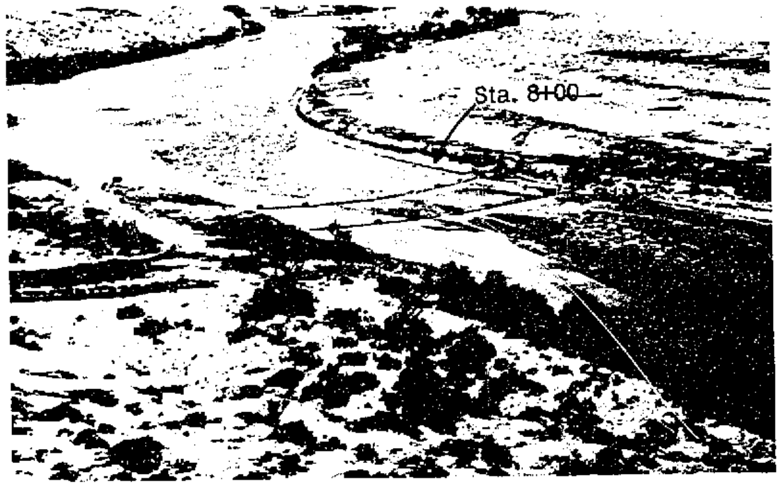


A. Run No. 7, no shore ice. Photo P20-D-70143

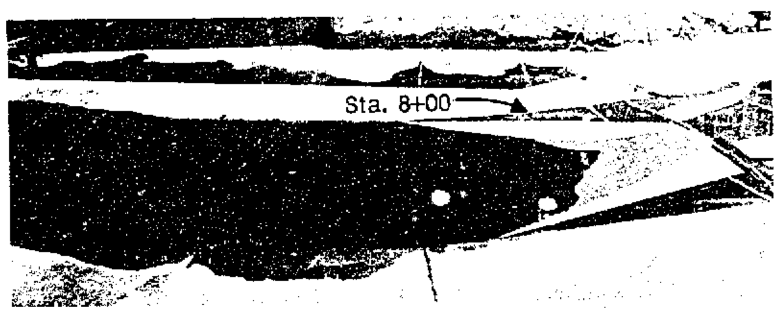


B. Run No. 16, shore ice present. Note improvement in retention capability of control structure with shore ice. Photo P20-D-70160

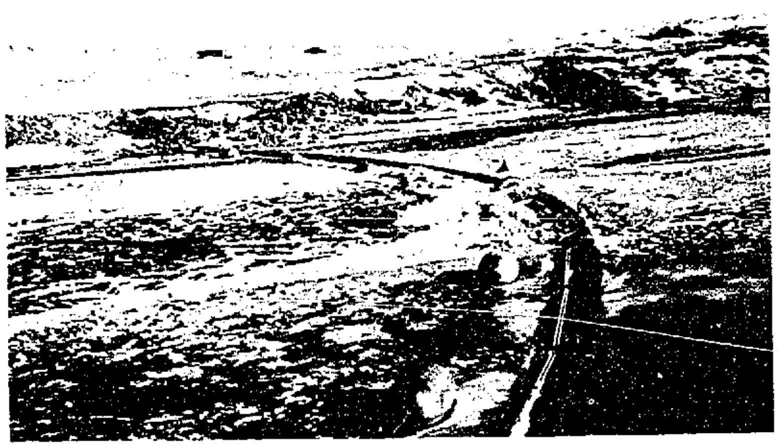
Figure 16. Improvement in model ice cover progression as a result of shore ice.



A. Upstream view of prototype ice control structure. Note shore ice formation in area of control structure. Photo P20-703-1186

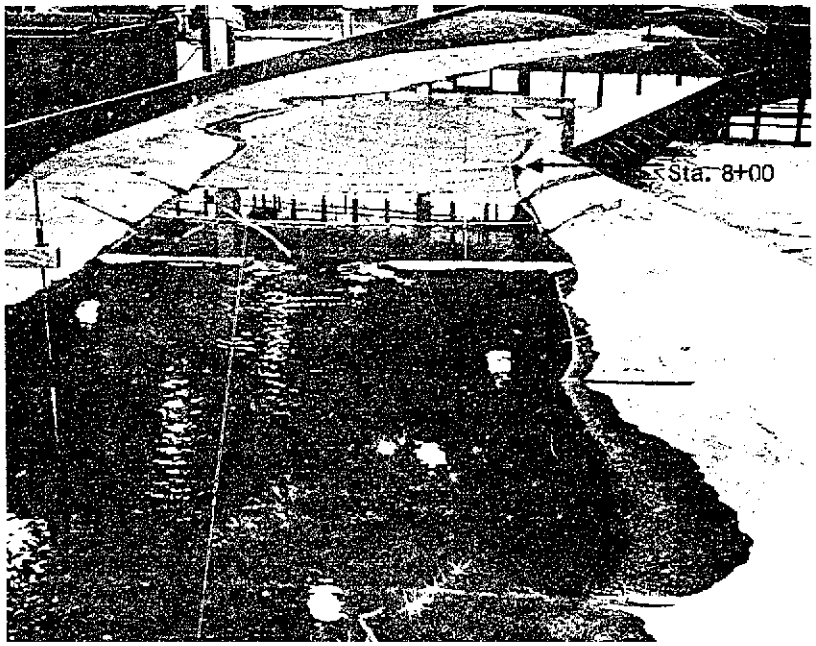


B. Run No. 17, Note float ice retained at upstream boom between shore ice. Photo P20-D-70159

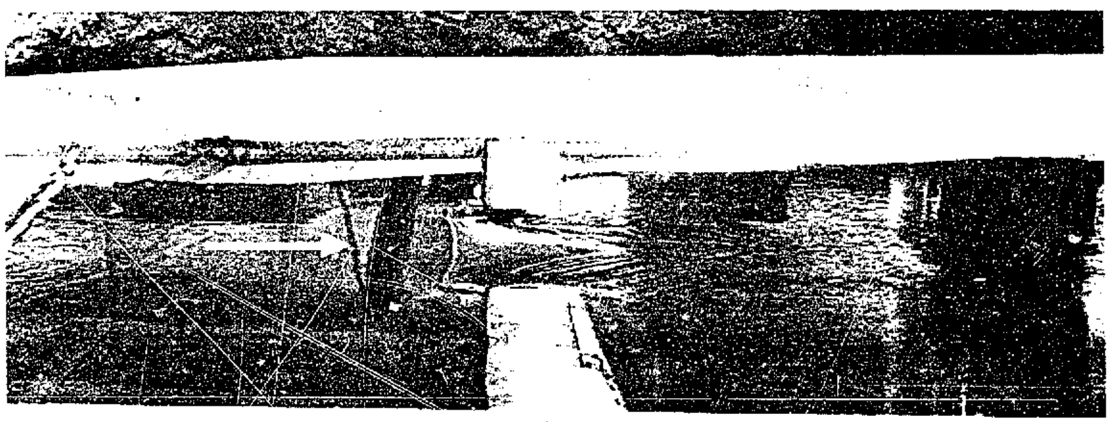


C. Ice control structure. Note float ice in center passing under upstream boom. Photo P20-703-1183

Figure 17. Shore ice formation.

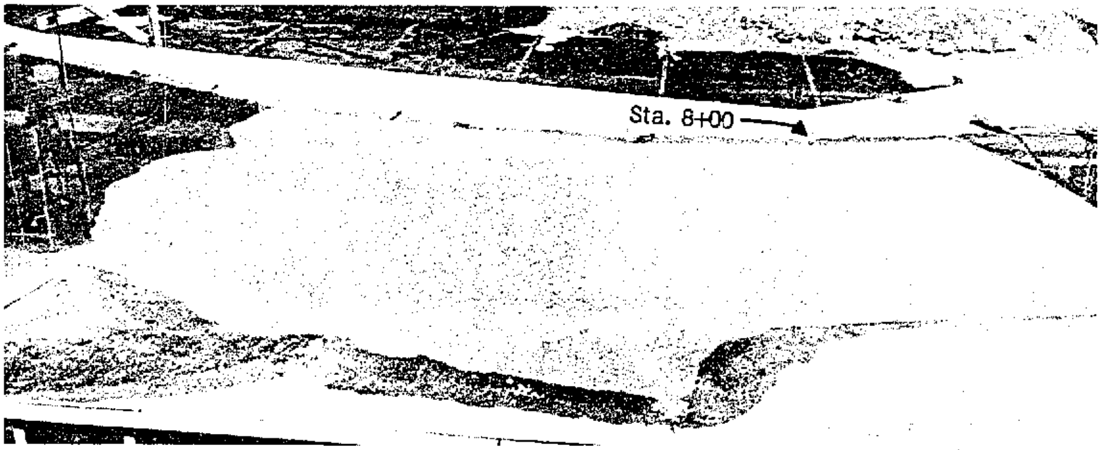


A. Run No. 18, model view looking upstream at opposing jetty constriction and ice cover. Photo P20-D-70164

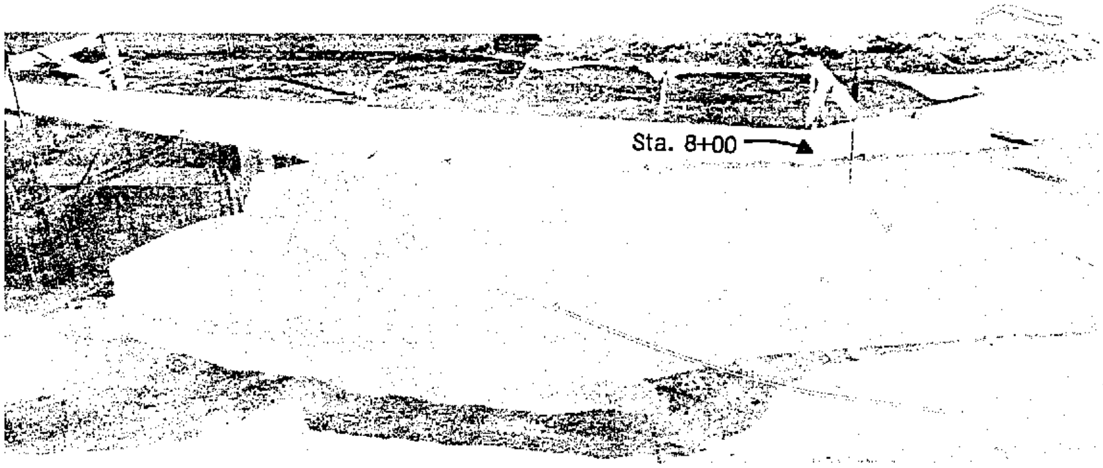


B Run No. 18, side view of constricted flow. Note difference in upstream and downstream water surfaces. Photo P20-D-70173

Figure 18. Opposing jetty constriction.



A. Run No. 15, ice cover progressed to Sta. 5+00. Water surface elevation at Sta. 12+00 artificially set 1.0 foot higher than normal. Photo P20-D-70158



B. Run No. 18, ice cover progressed to Sta. 5+30. Opposing jetty used to increase water surface elevation. Photo P20-D-70162

Figure 19. Ice cover progression—Opposing jetty.

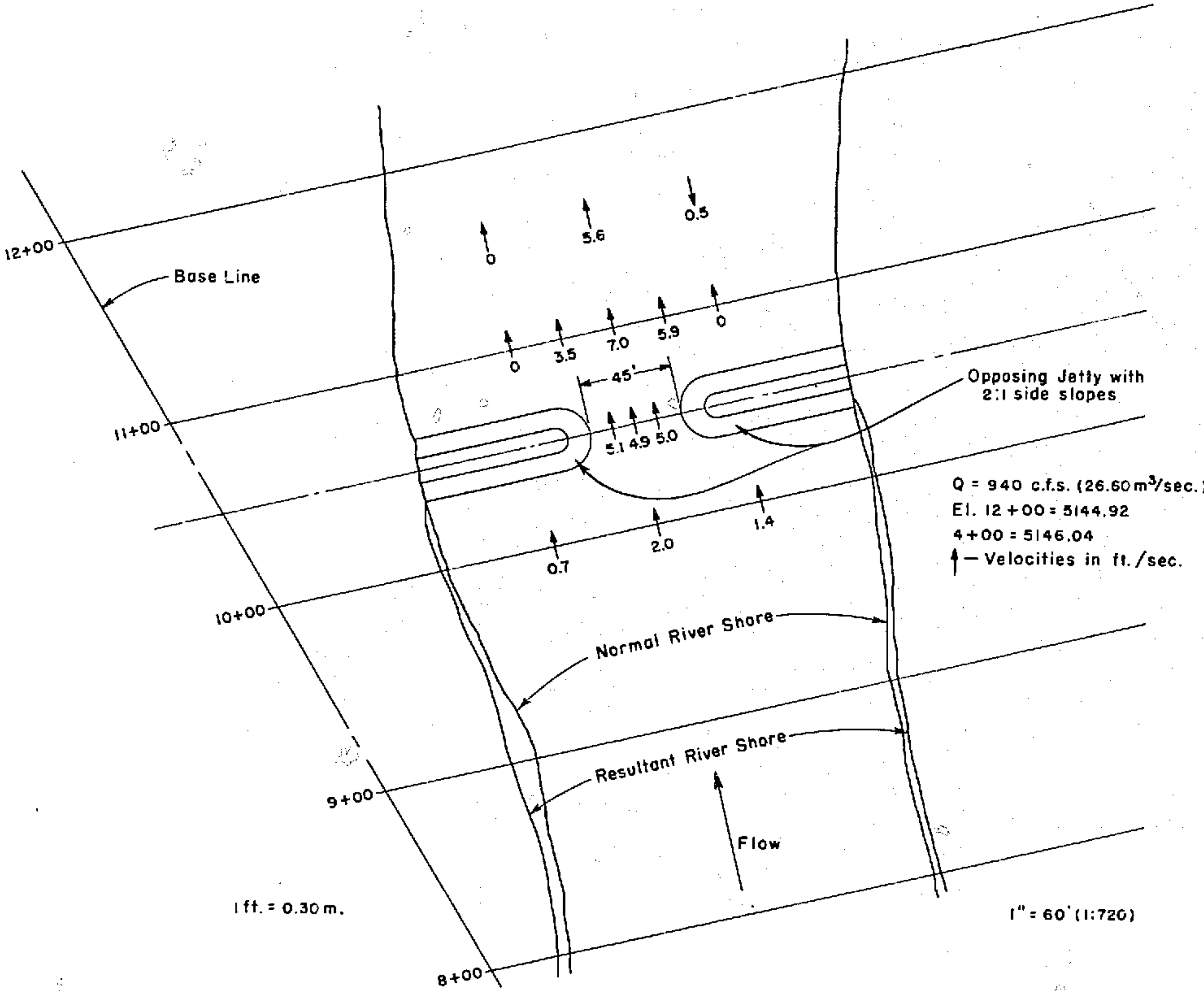
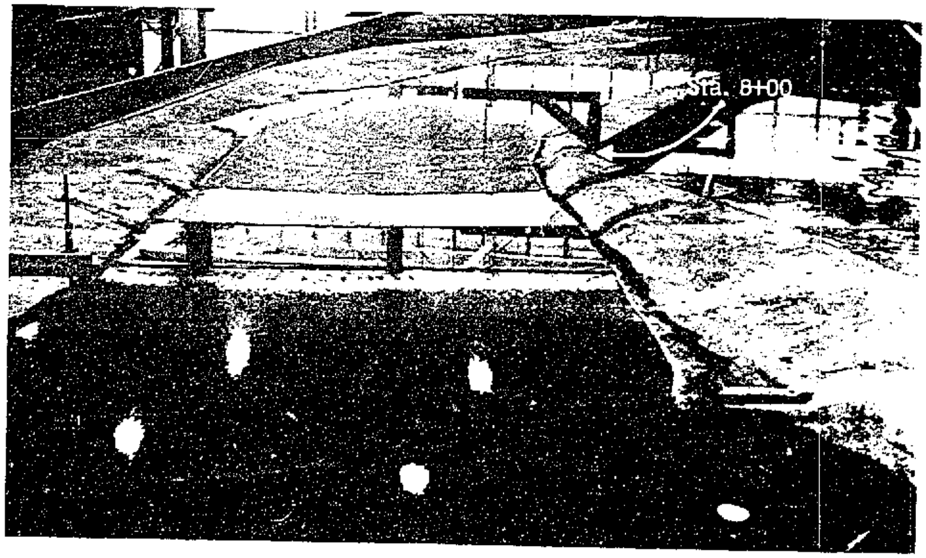
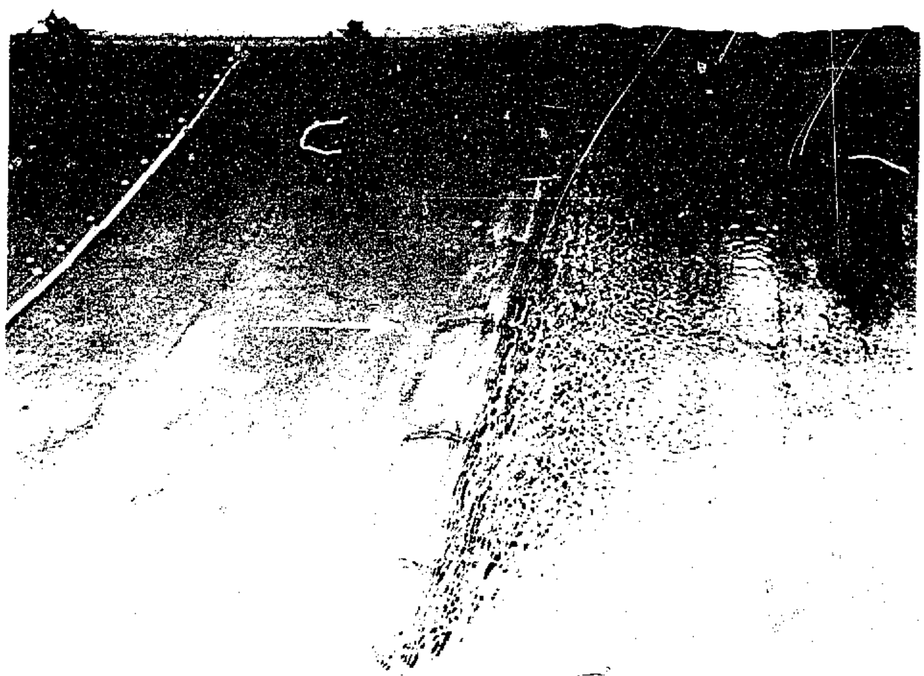


Figure 20. River velocities near opposing jetty.

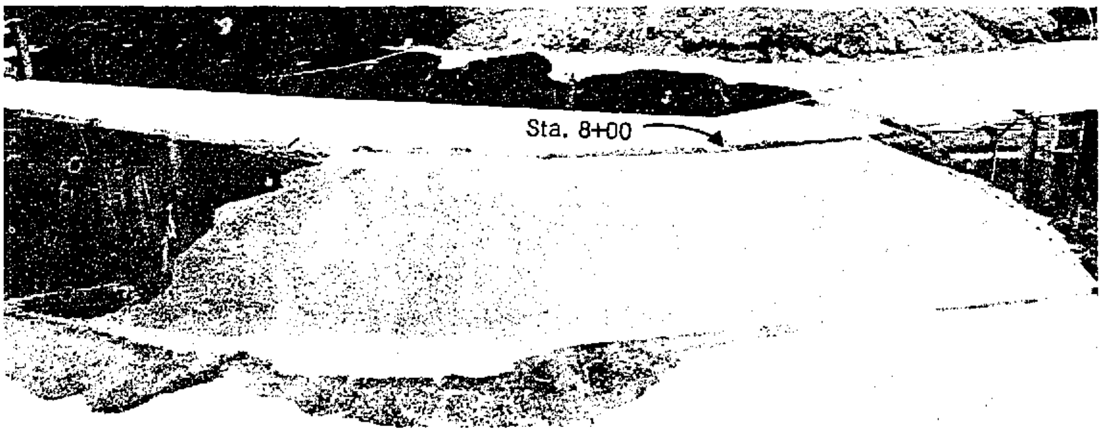


A. Run No. 19, model view looking upstream at submerged overflow sill and ice cover. Photo P20-D-70165

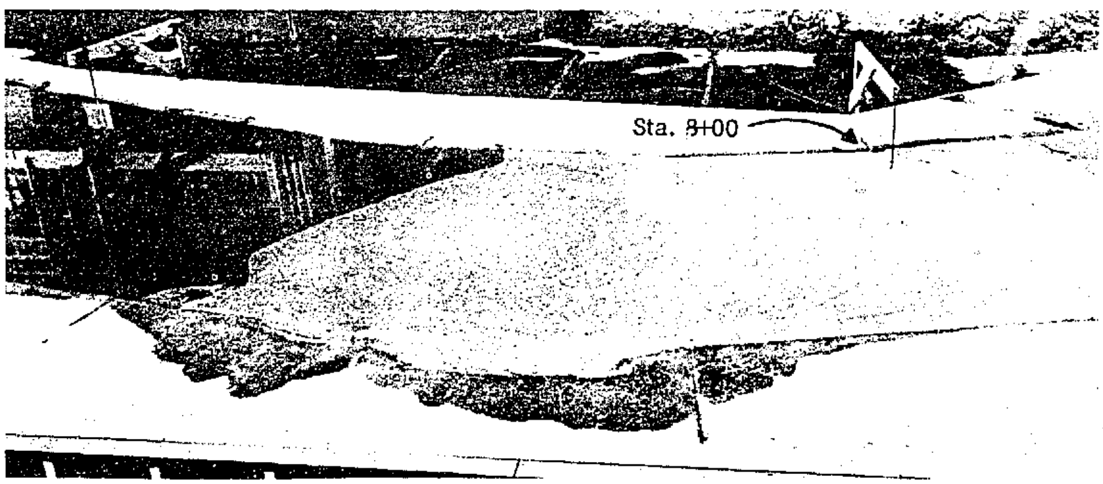


B. Run No. 19, side view of submerged overflow sill. Photo P20-D-70166

Figure 21. Submerged overflow sill constriction.

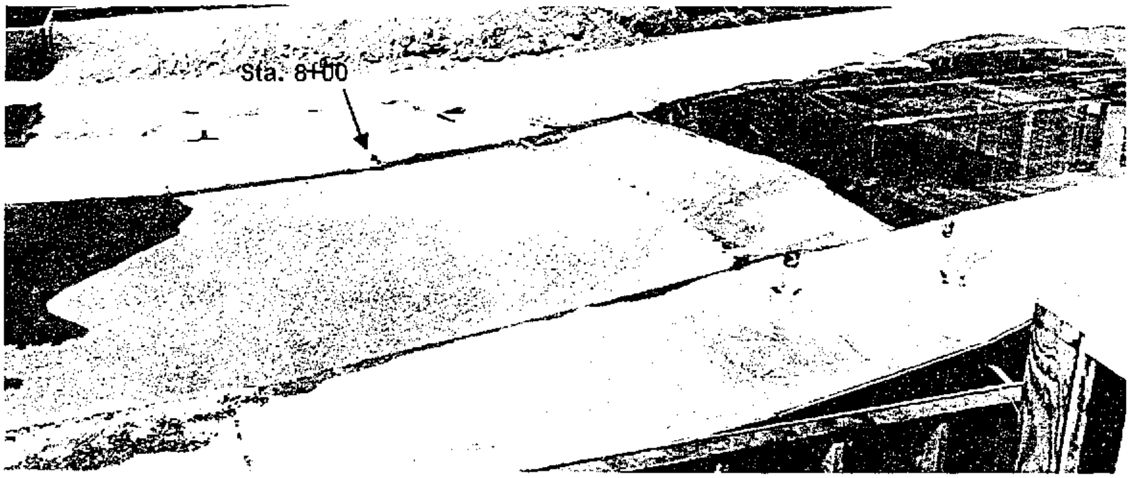


A. Run No. 14, ice cover progressed to Sta. 5+80. Water surface at Sta. 12+00 artificially set 0.7 foot higher than normal. Photo P20-D-70157

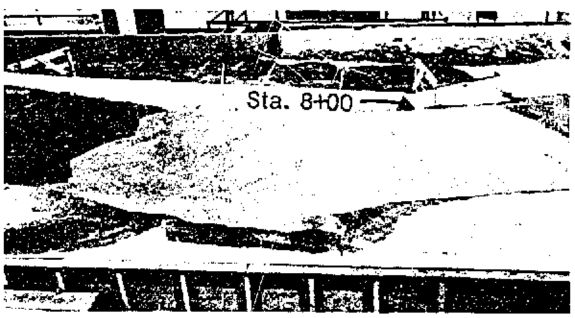


B. Run No. 19, ice cover progressed to Sta. 5+80. Submerged overflow sill used to increase water surface elevation. Photo P20-D-70172

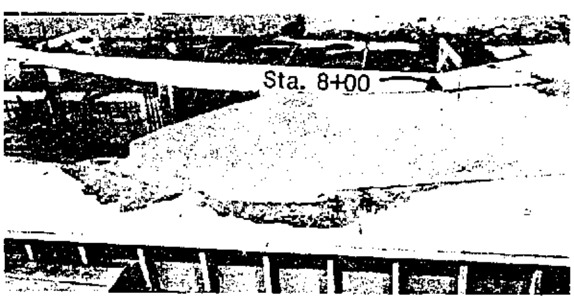
Figure 22. Ice cover progression--Submerged overflow sill.



A. Run No. 6, normal riverflow. Photo P20-D-70141



B. Run No. 18, water surface elevation increased by 1.0 foot (opposing jetty). Left Photo P20-D-70162, right Photo P20-D-70163



C. Run No. 19, water surface elevation increased by 0.7 foot (submerged overflow sill). Left Photo P20-D-70172, right Photo P20-D-70171

Figure 23. Comparison of retention capabilities.

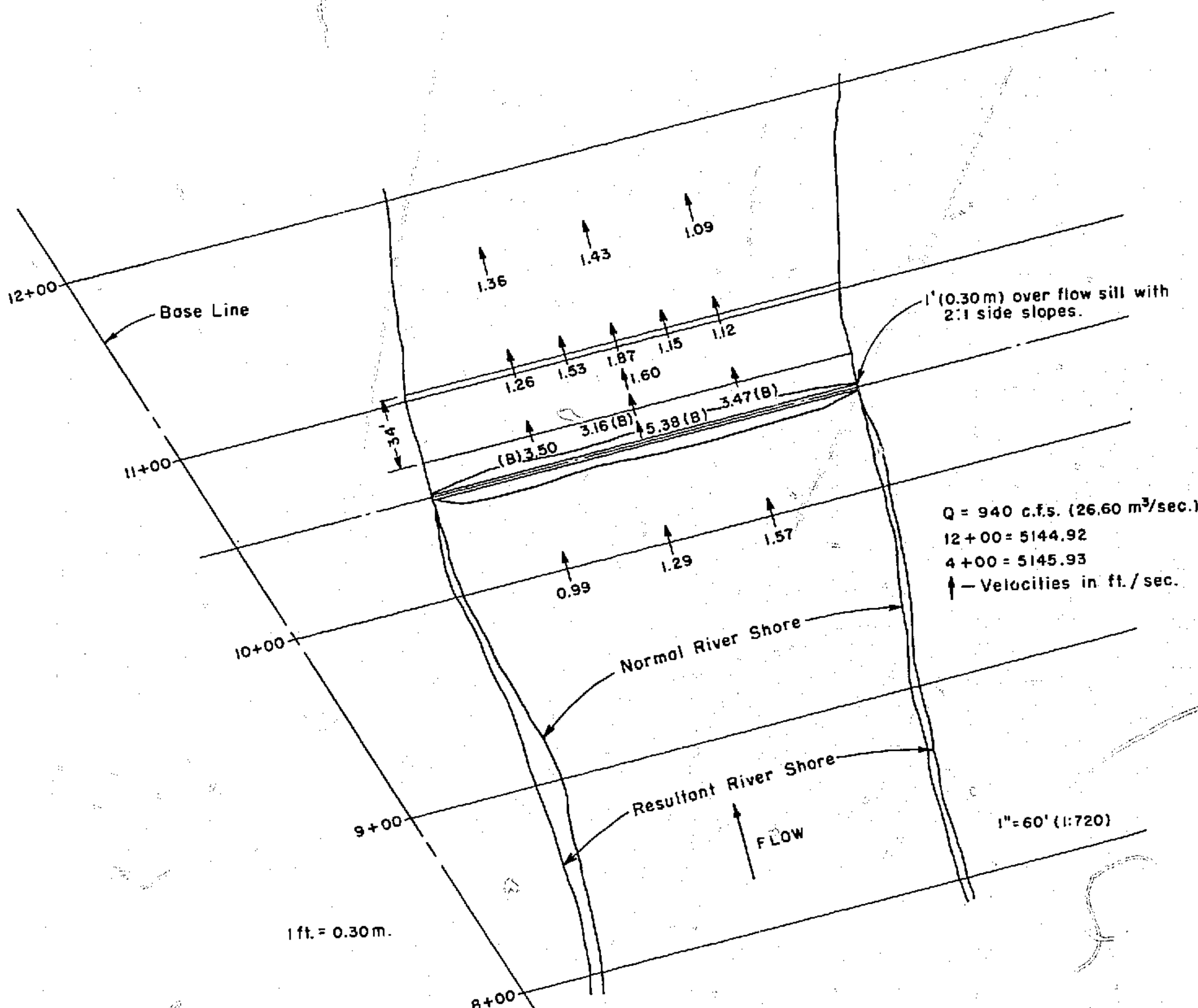
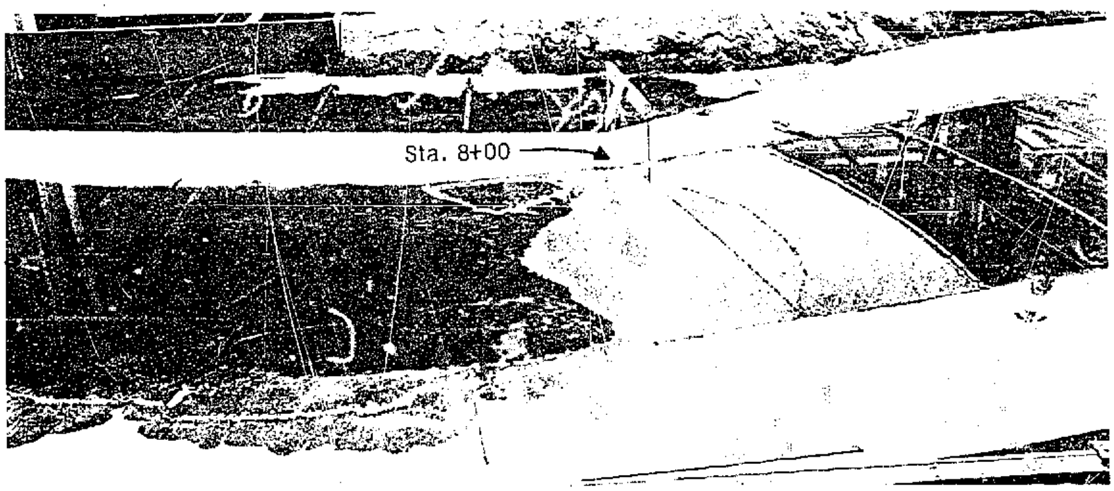
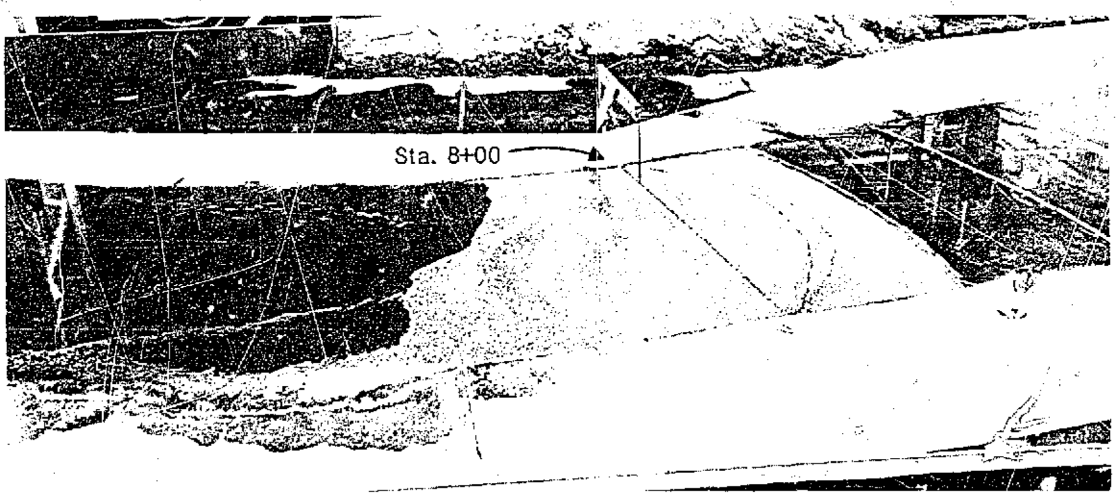


Figure 24. River velocities near submerged overflow sill.

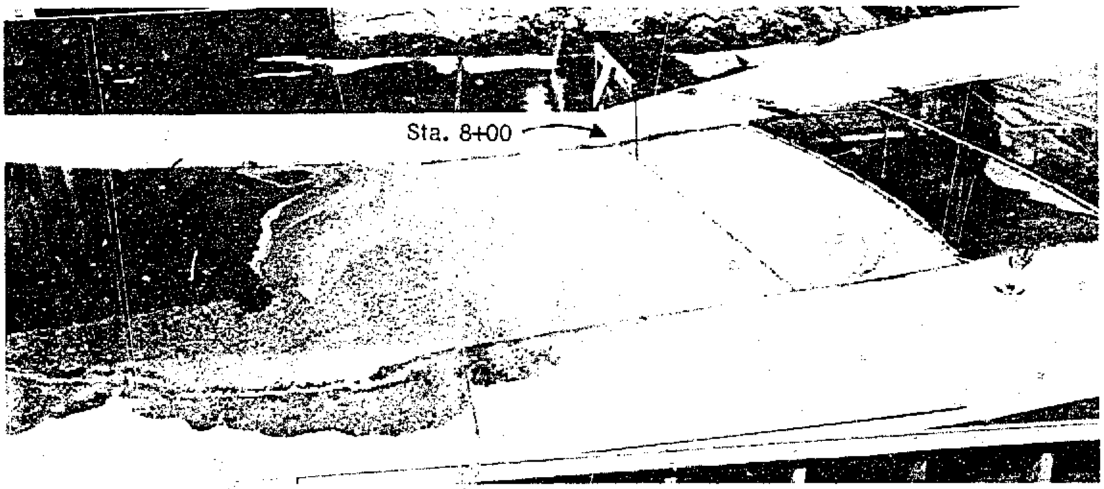


A. Run No. 19, model time–79 minutes. Photo P20-D-70167

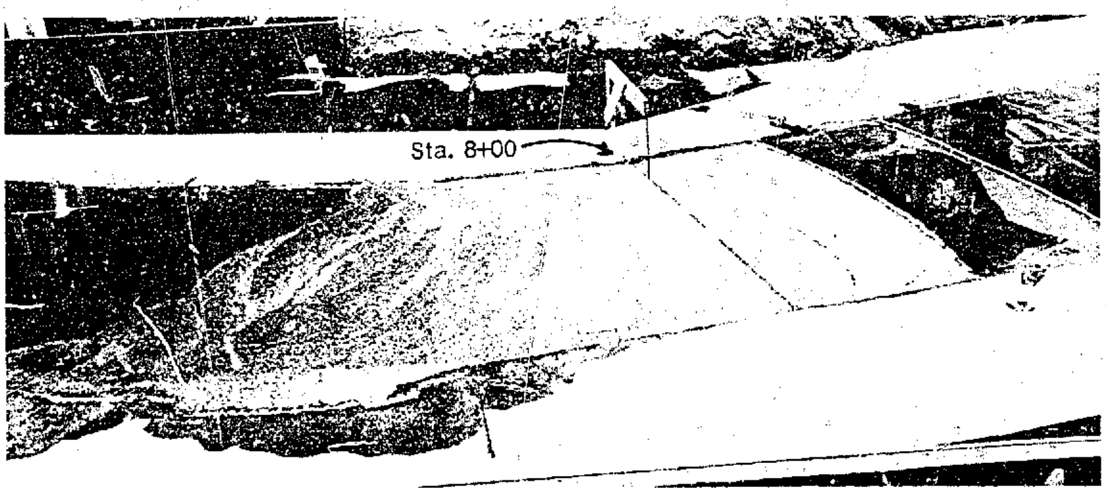


B. Run No. 19, model time–127 minutes. Photo P20-D-70168

Figure 25. Ice cover movement.



C. Run No. 19, model time—222 minutes. Photo P20-D-70169

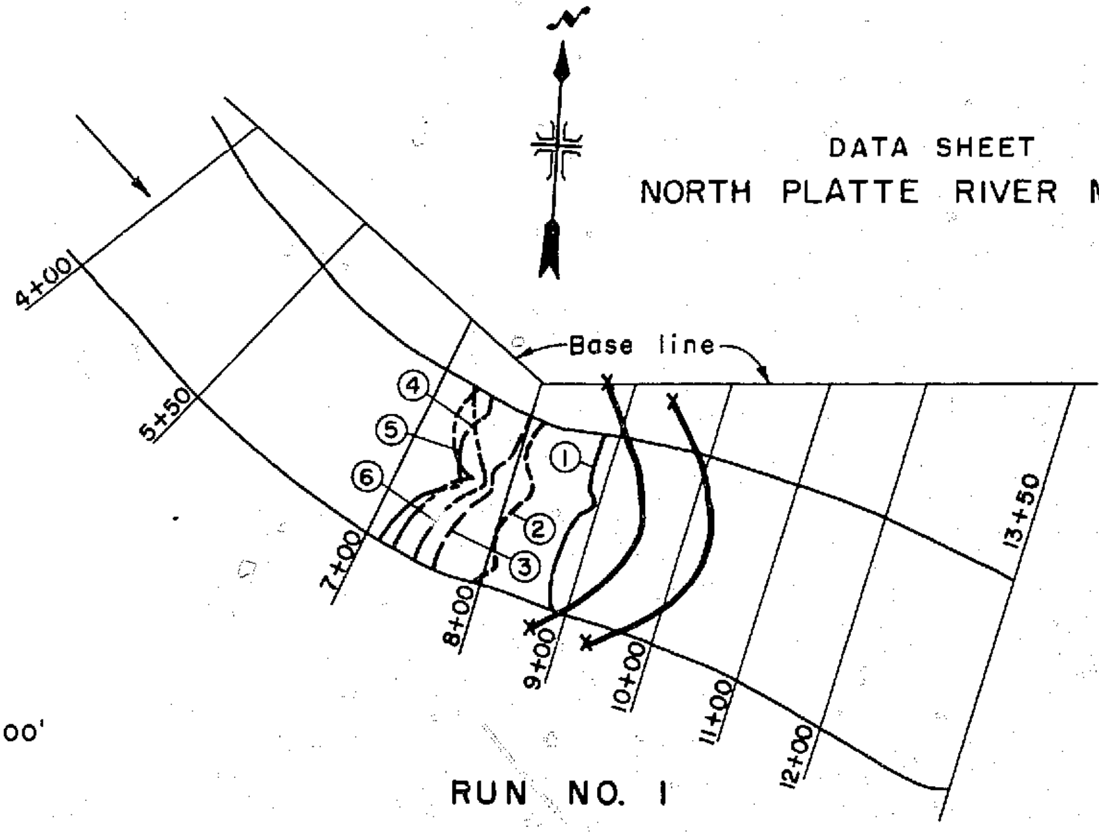


D. Run No. 19, model time—295 minutes. Photo P20-D-70170

Figure 25. Ice cover movement.

APPENDIX

DATA SHEET
NORTH PLATTE RIVER MODEL



RUN NO. 1

Time[+] (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.43	0.4(11.3)
23	1	5145.47	0.8(22.7)
36	2	5145.51	1.3(36.9)
52	3	5145.53	1.9(53.9)
98	4	5145.60	2.5(70.9)
119	5	5145.60	2.5(70.9)
*155	6	5145.60	2.4(68.0)

[+] Time from start of ice flow
* Ice stopped

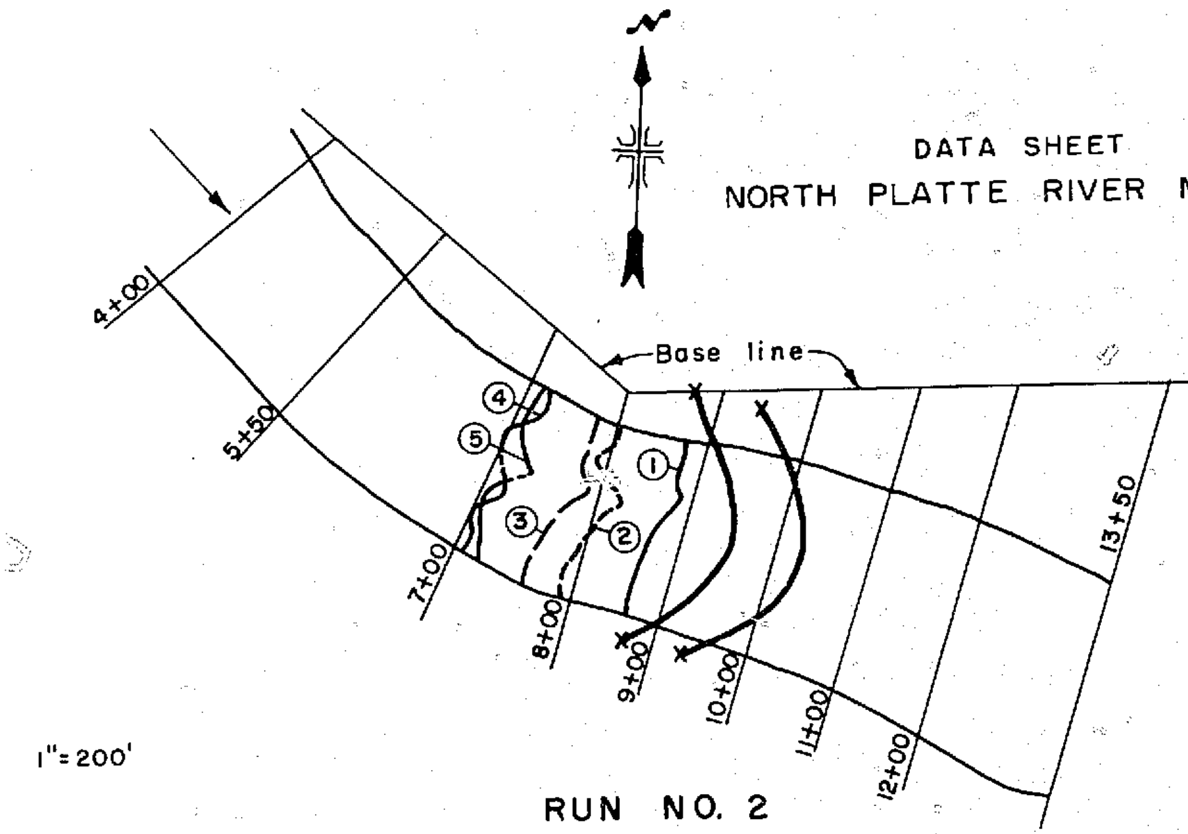
I. FLOW PARAMETERS
(Prototype Units)
Q 940 cfs Elev. Sta. 12+00 5146.19
(26.60 m^3/s)
V 2.0 ft/sec (0.61 m/sec) Fr = 0.20
D 3.0 ft (0.91 m)

II. BOOM CONFIGURATION
Sag 45' (13.7 m)
Timber configuration:

	No. of timbers	configuration
Upstream	9	#2
Downstream	19	#2

III. ICE COVER DATA
(Model Units)
Time 140 min.
Surface Area 14,140 $in.^2$ (91,226 cm^2)
Volume 4,420 $in.^3$ (72,444 cm^3)
Avg. ice thickness 0.313 in. (0.80 cm)
Ice Lost 1,770 $in.^3$ (29,010 cm^3)

DATA SHEET
NORTH PLATTE RIVER MODEL



1"= 200'

RUN NO. 2

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.35	0.5(14.2)
37	1	5145.39	0.8(22.7)
60	2	5145.42	1.3(36.9)
104	3	5145.47	2.1(59.5)
157	4	5145.54	2.7(76.5)
*175	5	5145.55	2.8(79.4)

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs (26.60 m^3/s) Elev. Sta. 12+00 5145.19

V 2.0 ft/sec (0.61 m/sec) Fr = 0.20

D 3.0 ft (0.91 m)

II. BOOM CONFIGURATION

Sag 45' (13.7 m)

Timber configuration:

	No. of timbers	configuration
Upstream	9	#1
Downstream	19	#1

III. ICE COVER DATA
(Model Units)

Time 157 min.

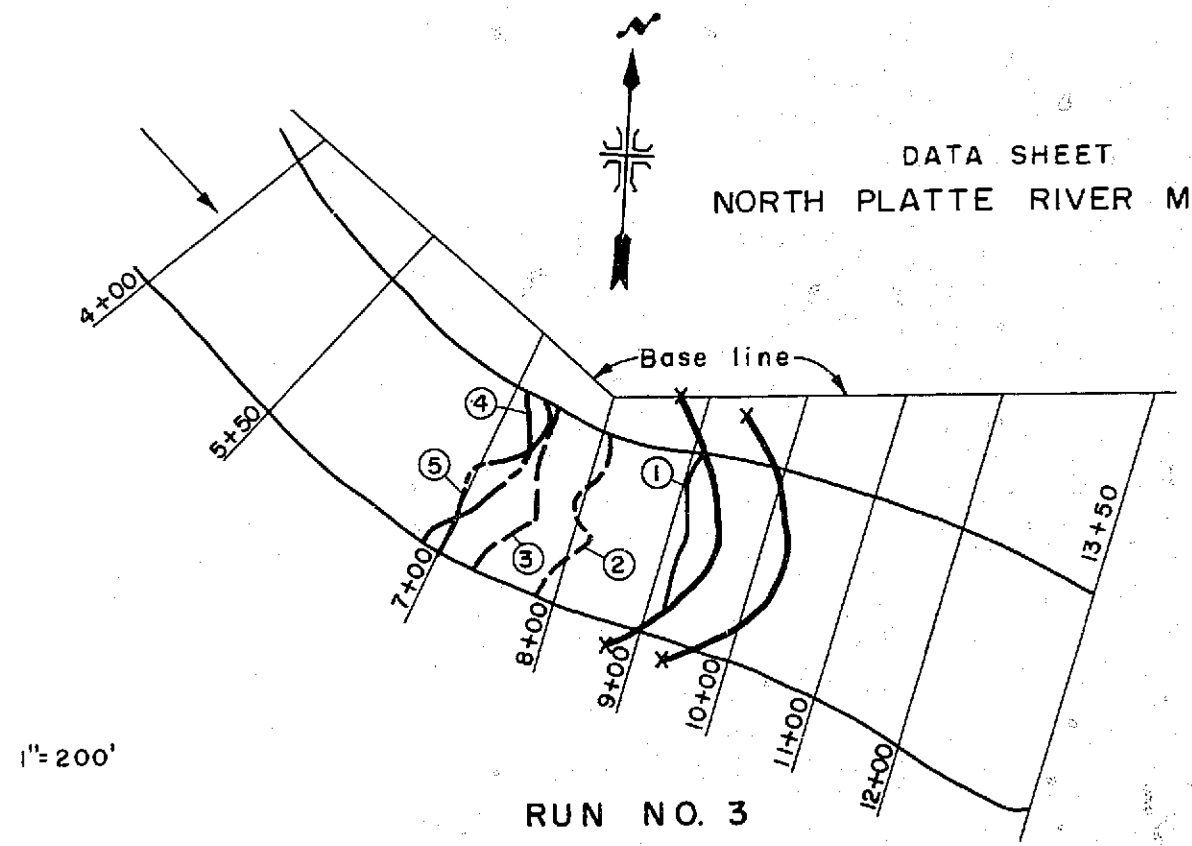
Surface Area 15,250 $in.^2$ (98,363 cm^2)

Volume 4,130 $in.^3$ (67,691 cm^3)

Avg. ice thickness 0.271 in. (0.69 cm)

Ice Lost 590 $in.^3$ (9,670.1 cm^3)

DATA SHEET
NORTH PLATTE RIVER MODEL



RUN NO. 3

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.36	0.4(11.3)
20	1	5145.40	0.5(14.2)
45	2	5145.43	1.4(39.7)
87	3	5145.52	2.4(68.0)
115	4	5145.55	2.6(73.7)
*129	5	5145.55	2.7(76.5)

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs Elev. Sta. 12+00 5145.19
(26.60 m^3/s)
V 2.0 ft/sec (0.61 m/sec) Fr = 0.20
D 3.0 ft (0.91 m)

II. BOOM CONFIGURATION

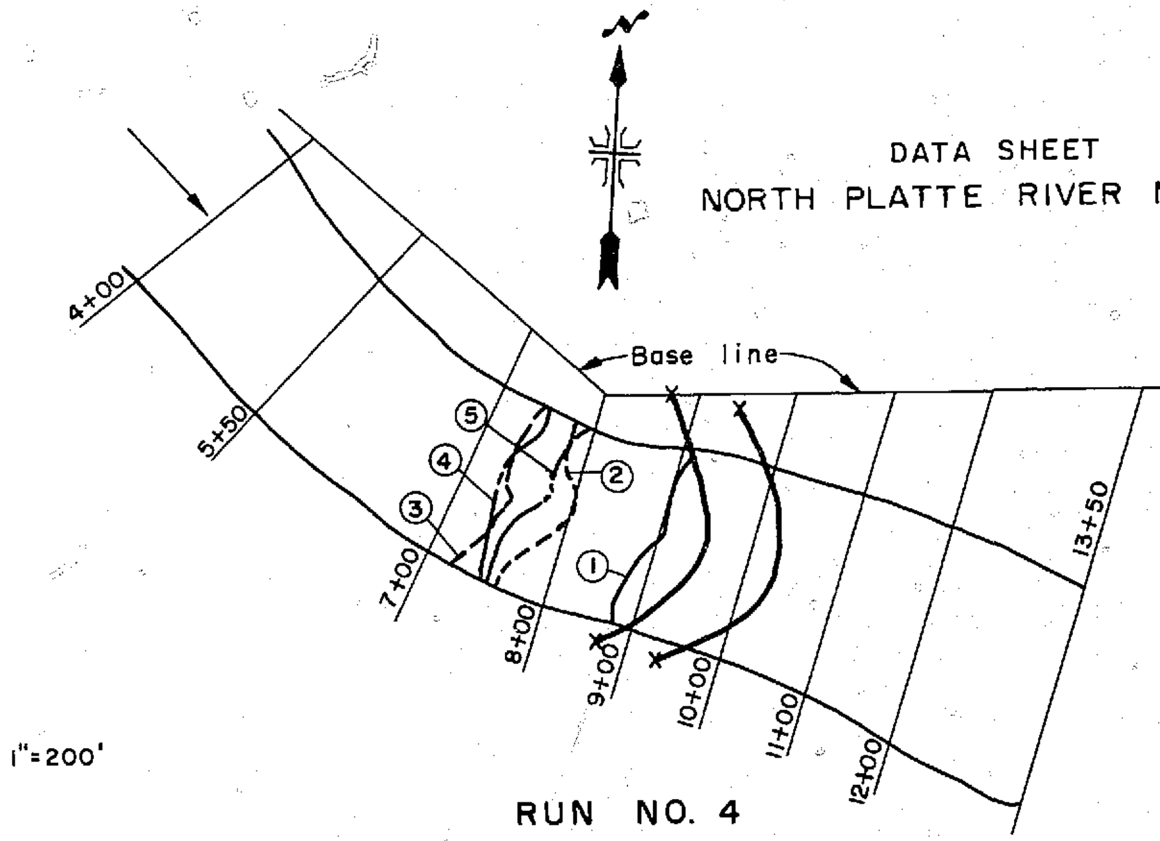
Sag 45' (13.7 m)
Timber configuration:

	No. of timbers	configuration
Upstream	9	#3
Downstream	19	#2

III. ICE COVER DATA
(Model Units)

Time 128 min.
Surface Area 15,380 in.^{2} (99,201 cm^2)
Volume 4,520 in.^{3} (74,083 cm^3)
Avg. ice thickness 0.294 in. (0.75 cm)
Ice Lost 1,770 in.^{3} (29,010 cm^3)

DATA SHEET
NORTH PLATTE RIVER MODEL



RUN NO. 4

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.41	0.6(17.0)
22	1	5145.42	1.1(31.2)
43	2	5145.48	2.1(59.5)
80	3	5145.53	3.1(87.9)
103	4	5145.57	3.5(99.2)
*118	5	5145.57	3.2(90.7)

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs Elev. Sta. 12+00 5145.19
(26.60 m^3/s)
V 2.0 ft/sec (0.61 m/sec) Fr = 0.20
D 3.0 ft (0.91 m)

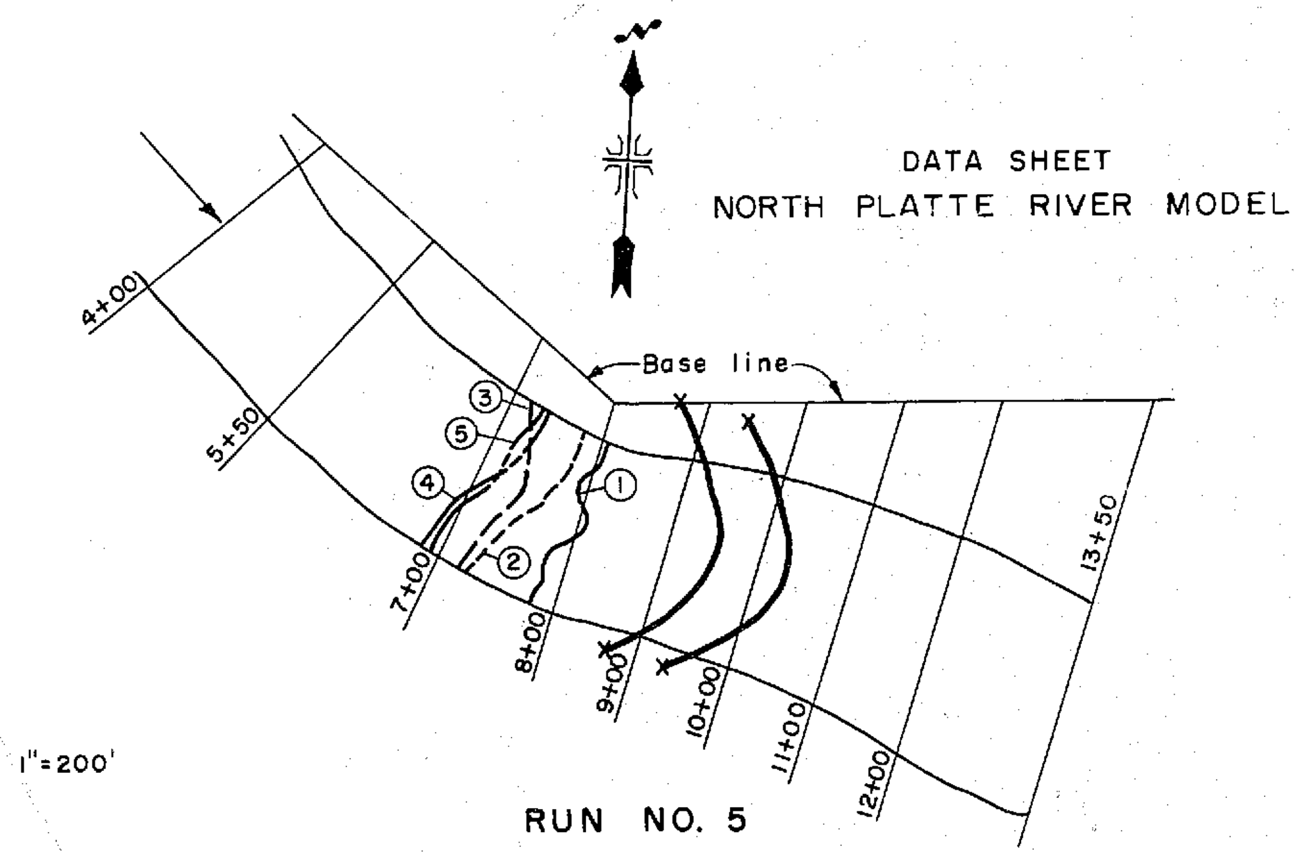
II. BOOM CONFIGURATION

Sag 40' (12.2 m)
Timber configuration:

	No. of timbers	configuration
Upstream	17	#3
Downstream	19	#1

III. ICE COVER DATA
(Model Units)

Time 115 min.
Surface Area 14,500 $in.^2$ (93,525 cm^2)
Volume 3,930 $in.^3$ (64,413 cm^3)
Avg. ice thickness 0.271 in. (0.69 cm)
Ice Lost 1,770 $in.^3$ (29,010 cm^3)



RUN NO. 5

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.48	0.6(17.0)
35	1	5145.51	1.5(42.5)
62	2	5145.55	2.1(59.5)
99	3	5145.59	2.7(76.5)
138	4	5145.60	3.0(85.0)
*162	5	5145.63	3.0(85.0)

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs Elev. Sta. 12+00 5145.20
(26.60 m^3/s)

V 2.0 ft/sec (0.61 m/sec) Fr = 0.20

D 3.0 ft (0.91 m)

II. BOOM CONFIGURATION

Sag 43' (13.1 m)

Timber configuration:

	No. of timbers	configuration
Upstream	17	#4
Downstream	19	#1

III. ICE COVER DATA
(Model Units)

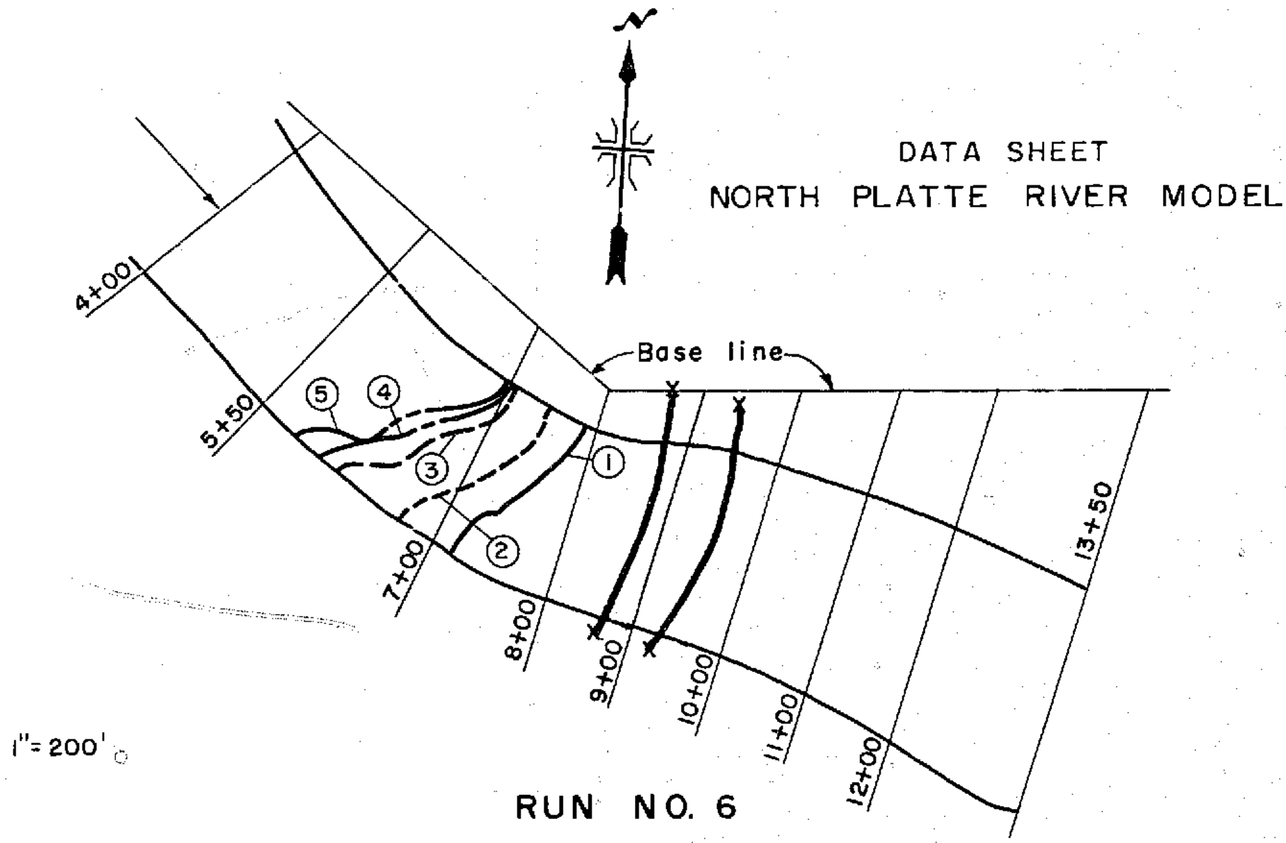
Time 155 min.

Surface Area 15,380 in^2 (99,201 cm^2)

Volume 4,010 $in.^3$ (65,724 cm^3)

Avg. ice thickness 0.261 in. (0.66 cm)

Ice Lost 590 $in.^3$ (9,670 cm^3)



RUN NO. 6

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.51	1.9(53.9)
26	1	5145.53	1.9(53.9)
42	2	5145.54	4.4(124.7)
84	3	5145.57	5.6(158.8)
122	4	5145.60	6.4(181.4)
*196	5	5145.65	6.7(189.9)

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs (26.60 m³/s) Elev. Sta. 12+00 5145.21

V 2.0 ft/sec (0.61 m/sec) Fr = 0.20

D 3.0 ft (0.91 m)

II. BOOM CONFIGURATION

Sag 14' (4.27 m)

Timber configuration:

	No. of timbers	configuration
Upstream	15	#4
Downstream	17	#1

III. ICE COVER DATA
(Model Units)

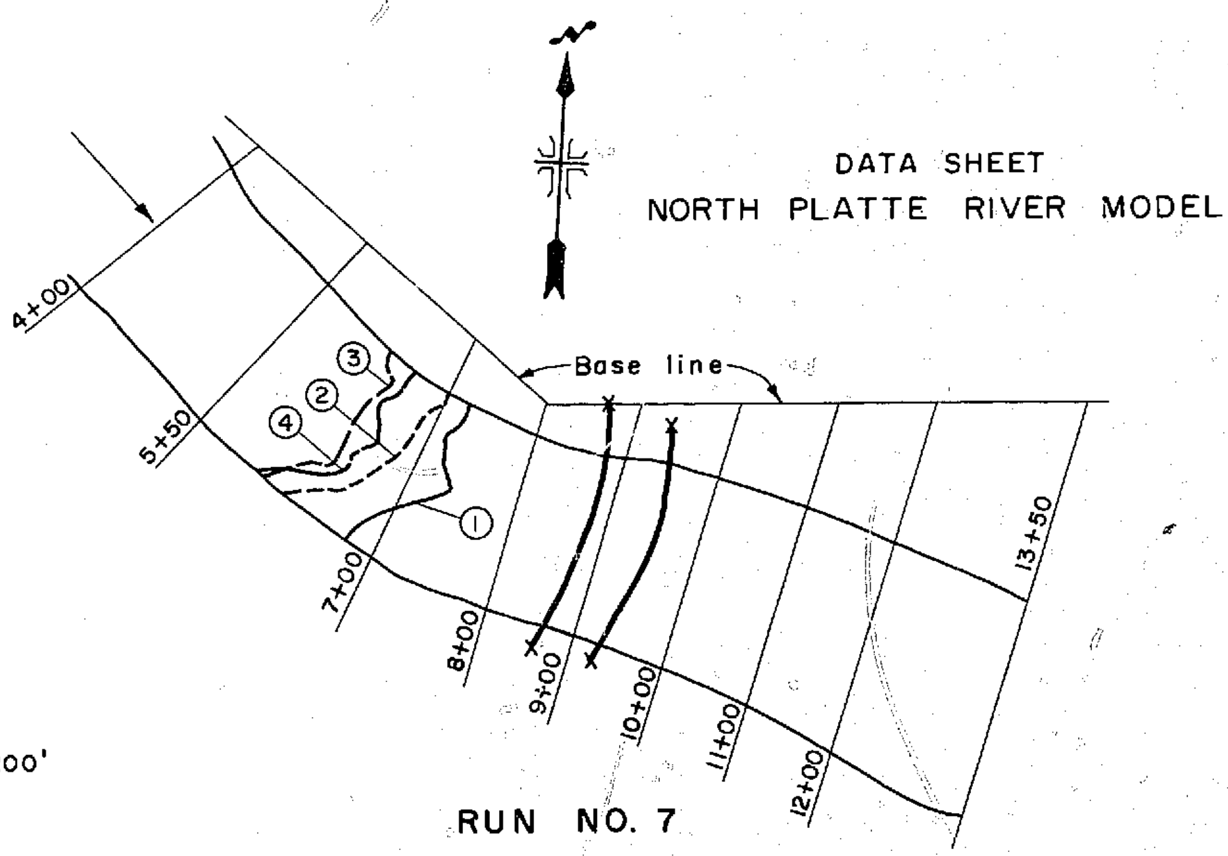
Time 196 min.

Surface Area 17,380 in.^{2} (112,101 cm^2)

Volume 4,280 in.^{3} (70,149 cm^3)

Avg. ice thickness 0.246 in. (0.62 cm)

Ice Lost 590 in.^{3} (9,670 cm^3)



RUN NO. 7

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.51	2.2(62.4)
34	1	5145.54	4.6(130.4)
76	2	5145.61	6.3(178.6)
112	3	5145.66	7.5(212.6)
*124	4	5145.66	7.2(204.1)

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs Elev. Sta. 12+00 5145.19
(26.60 m^3/s)
V 2.0 ft/sec (0.61 m/sec) Fr = 0.20
D 3.0 ft (0.91 m)

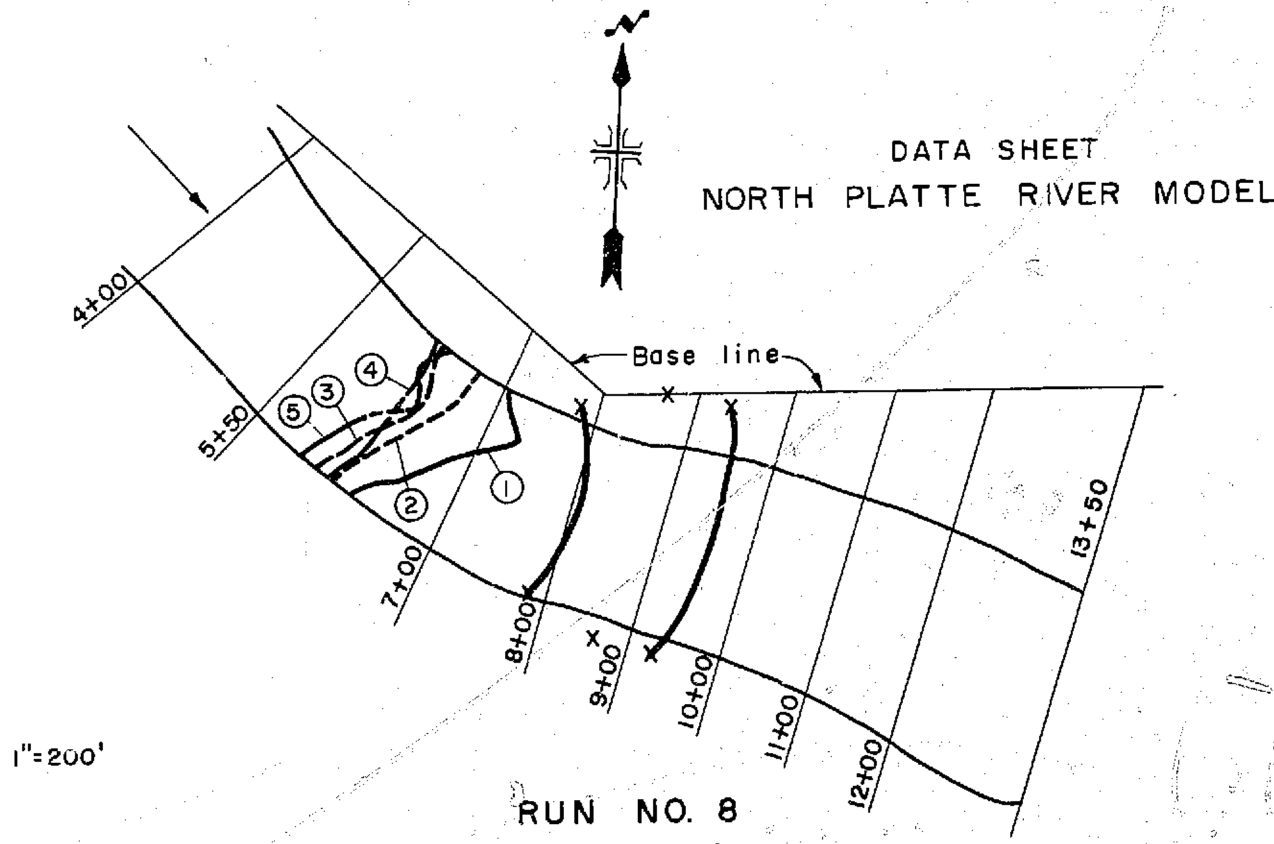
II. BOOM CONFIGURATION

Sag 14' (4.27 m)
Timber configuration:

	No. of timbers	configuration
Upstream	15	#1
Downstream	17	#4

III. ICE COVER DATA
(Model Units)

Time 112 min.
Surface Area 17,900 $in.^2$ (115,455 cm^2)
Volume 4,280 $in.^3$ (70,149 cm^3)
Avg. ice thickness 0.239 in. (0.61 cm)
Ice Lost 1,180 $in.^3$ (19,340 cm^3)



RUN NO. 8

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.48	1.6(45.4)
31	1	5145.53	3.3(93.6)
51	2	5145.55	4.5(127.6)
72	3	5145.59	5.6(158.8)
128	4	5145.65	7.0(198.5)
*142	5	5145.65	6.6(187.1)

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs (26.60 m³/s) Elev. Sta. 12+00 5145.21

V 2.0 ft/sec (0.61 m/sec) Fr = 0.20

D 3.0 ft (0.91 m)

II. BOOM CONFIGURATION

Sag 12' (3.66 m)

Timber configuration:

	No. of timbers	configuration
Upstream	15	#4
Downstream	17	#1

III. ICE COVER DATA
(Model Units)

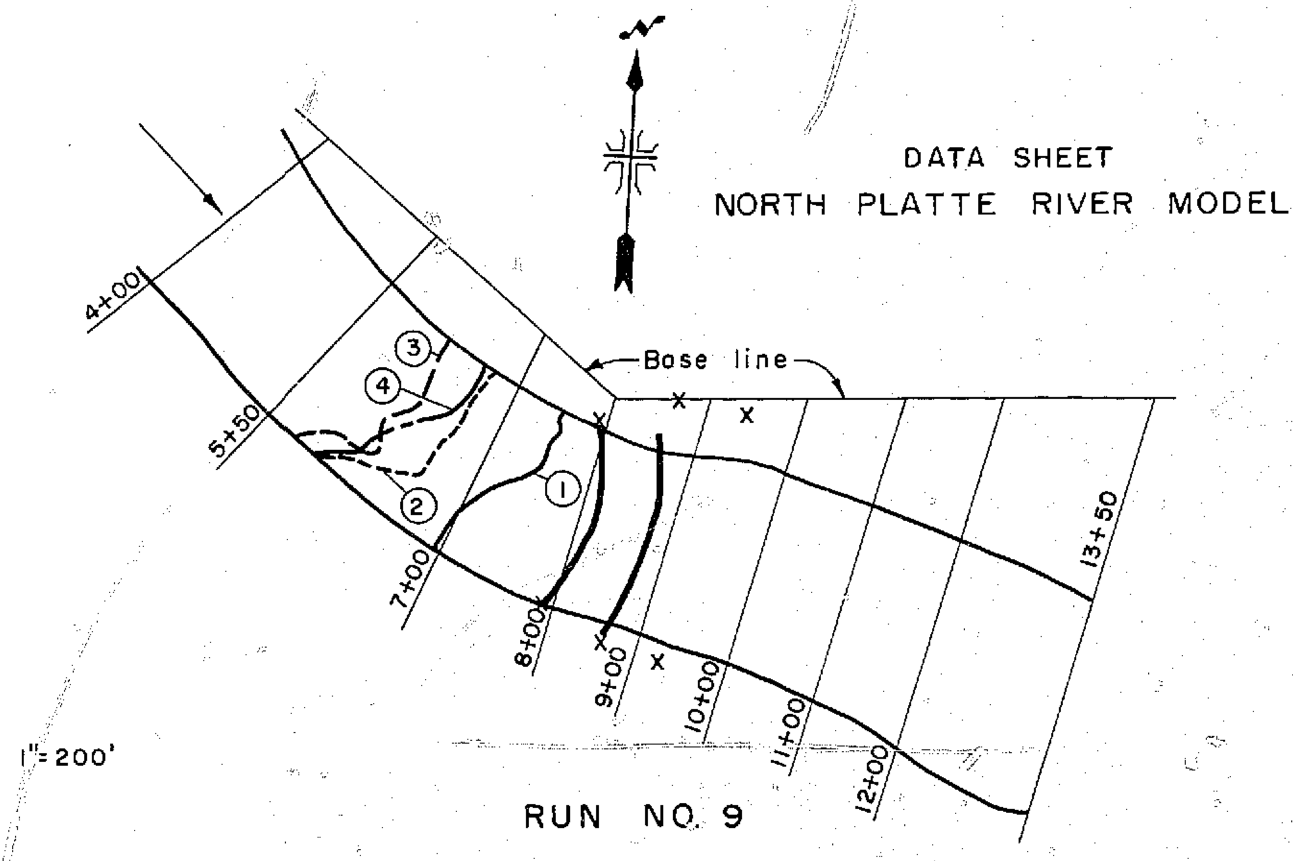
Time 126 min.

Surface Area 17,250 in.^{2} (111,263 cm^2)

Volume 4,100 in.^{3} (67,199 cm^3)

Avg. ice thickness 0.238 in. (0.60 cm)

Ice Lost 295 in.^{3} (4,835 cm^3)



RUN NO. 9

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.48	1.5(42.5)
23	1	5145.51	3.0(85.0)
51	2	5145.55	4.4(124.7)
113	3	5145.63	6.0(170.1)
*147	4	5145.65	5.9(167.3)

*•Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs Elev. Sta. 12+00 5145.21
(26.60 m^3/s)

V 2.0 ft/sec (0.61 m/sec) Fr = 0.20

D 3.0 ft (0.91 m)

II. BOOM CONFIGURATION

Sag 14' (4.27 m)

Timber configuration:

	No. of timbers	configuration
Upstream	15	#4
Downstream	16	#1

III. ICE COVER DATA
(Model Units)

Time 139 min.

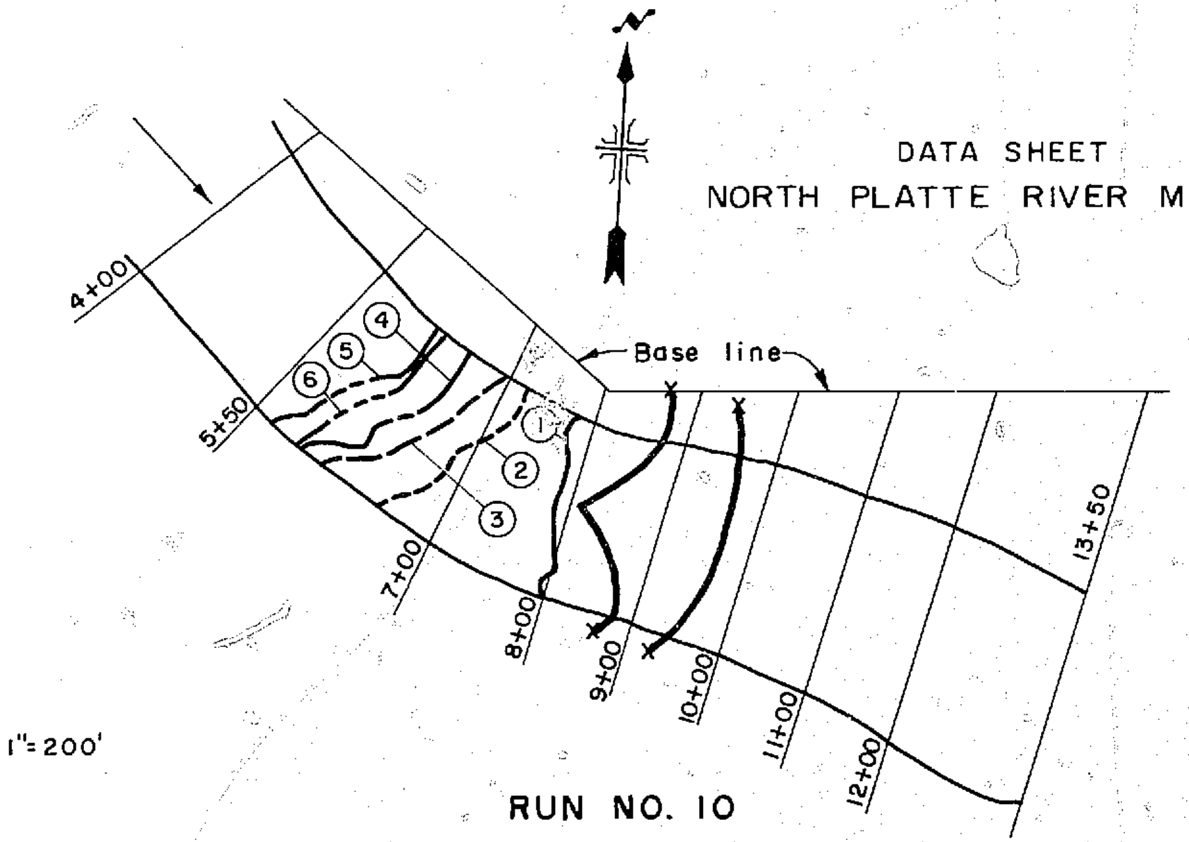
Surface Area 15,620 $in.^2$ (100,749 cm^2)

Volume 5,020 $in.^3$ (82,278 cm^3)

Avg. ice thickness 0.321 in. (0.82 cm)

Ice Lost 295 $in.^3$ (4,835 cm^3)

DATA SHEET
NORTH PLATTE RIVER MODEL



RUN NO. 10

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.53	1.3(36.9)
30	1	5145.57	1.7(48.2)
53	2	5145.58	2.3(65.2)
78	3	5145.60	2.8(79.4)
122	4	5145.65	3.2(90.7)
222	5	5145.72	4.4(124.7)
*266	6	5145.72	4.4(124.7)

*Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs Elev. Sta. 12+00 5145.19
(26.60 m^3/s)
V 2.0 ft/sec (0.61 m/sec) Fr = 0.20
D 3.0 ft (0.91 m)

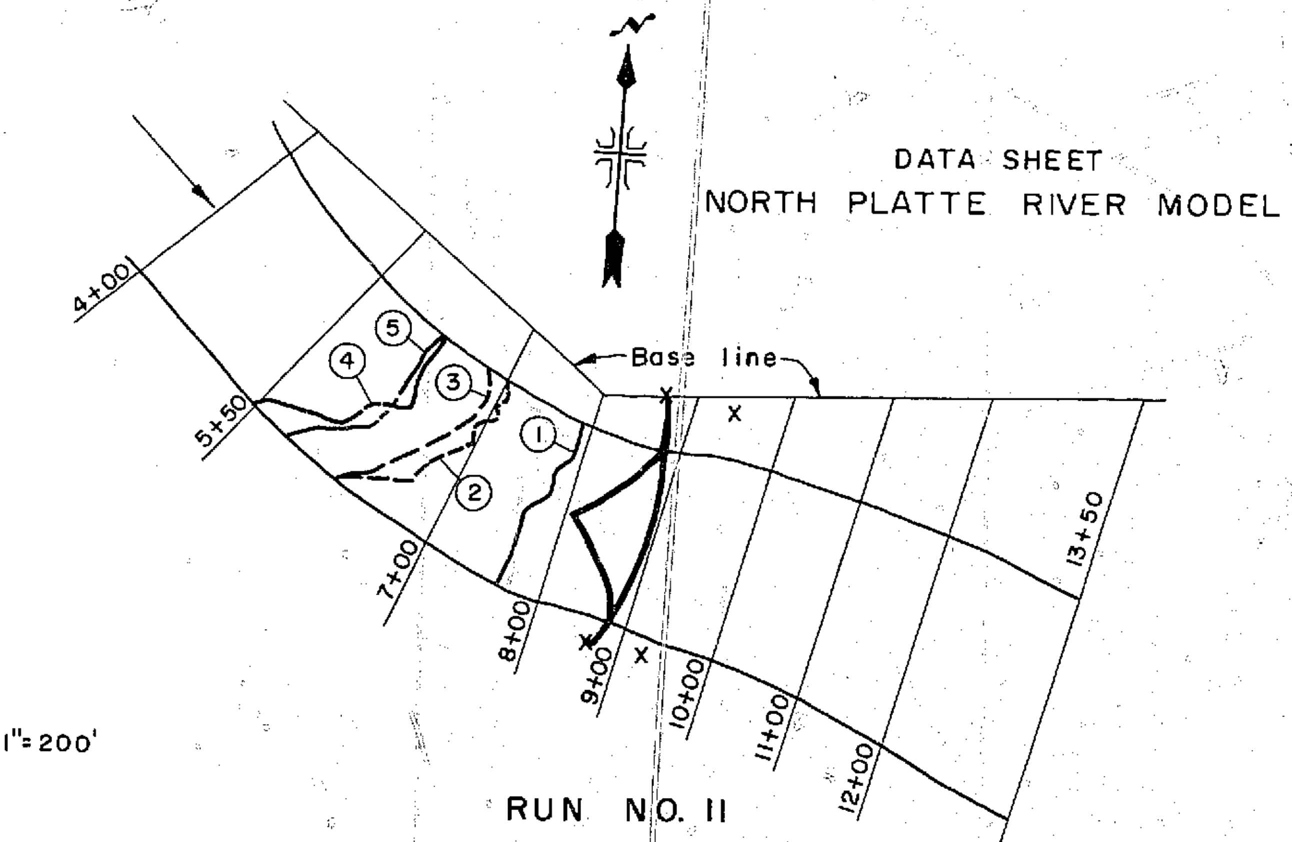
II. BOOM CONFIGURATION

Sag 14' (D.S. Boom) (4.27 m)
Timber configuration:

	No. of timbers	configuration
Upstream	17	#4
Downstream	17	#1

III. ICE COVER DATA
(Model Units)

Time 257 min.
Surface Area 20,220 in.^{2} (130,491 cm^2)
Volume 5,270 in.^{3} (86,375 cm^3)
Avg. ice thickness 0.26 in. (0.66 cm)
Ice Lost 197 in.^{3} (3,229 cm^3)



RUN NO. II

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.55	2.0(56.7)
21	1	5145.57	2.9(82.2)
56	2	5145.60	3.6(102.1)
83	3	5145.61	4.2(119.1)
170	4	5145.66	5.2(147.4)
*194	5	5145.69	5.3(150.3)

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs Elev. Sta. 12+00 5145.21
(26.60 m^3/s)
V 2.0 ft/sec (0.61 m/sec) Fr = 0.20
D 3.0 ft (0.91 m)

II. BOOM CONFIGURATION

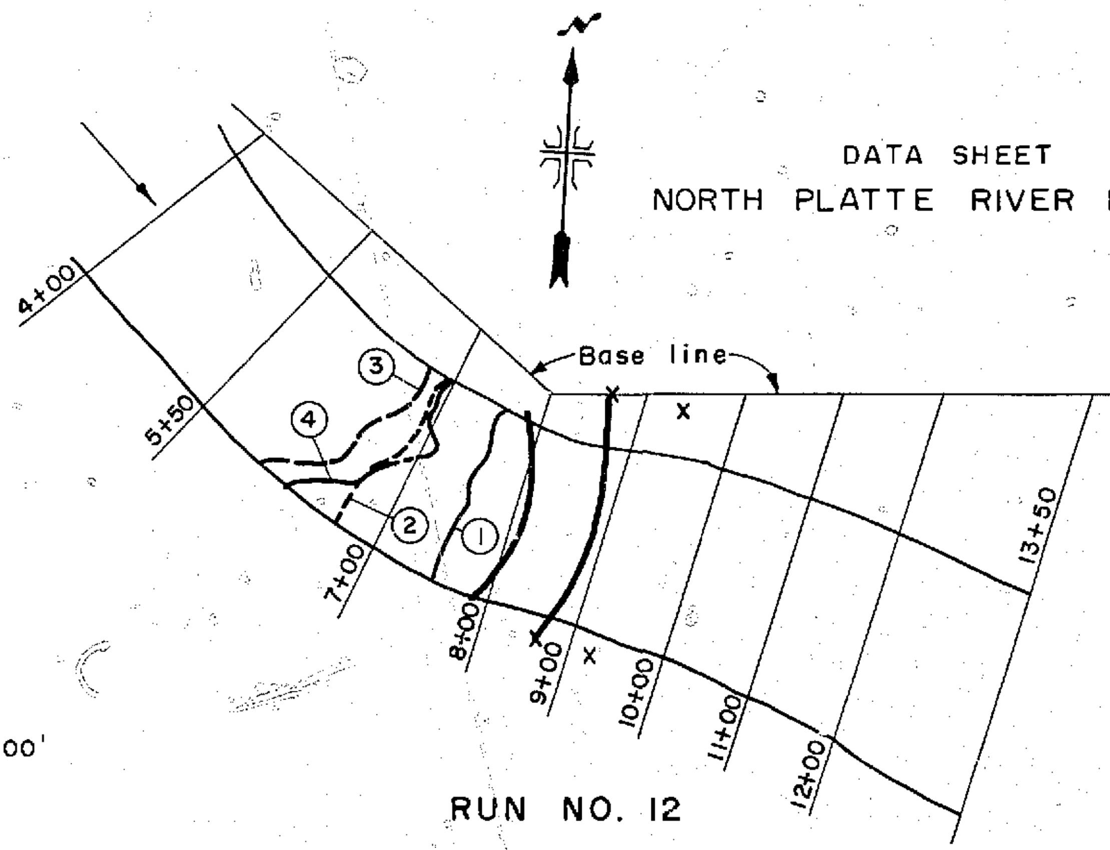
Sag 14' (D.S. Boom) (4.27 m)
Timber configuration:

	No. of timbers	configuration
Upstream	17	#4
Downstream	17	#1

III. ICE COVER DATA
(Model Units)

Time 194 min.
Surface Area 15,500 $in.^2$ (99,975 cm^2)
Volume 4,805 $in.^3$ (78,754 cm^3)
Avg. ice thickness 0.31 in. (0.79 cm)
Ice Lost 148 $in.^3$ (2,426 cm^3)

DATA SHEET
NORTH PLATTE RIVER MODEL



RUN NO. 12

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.43	0.9(25.5)
35	1	5145.46	2.1(59.5)
65	2	5145.48	2.8(79.4)
116	3	5145.54	5.3(150.3)
1[illegible]7	4	5145.55	4.9(138.9)

• Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs (26.60 m^3/s) Elev. Sta. 12+00 5145.21

V 2.0 ft/sec (0.61 m/sec) Fr = 0.20

D 3.0 ft (0.91 m)

II. BOOM CONFIGURATION

Sag 14' (4.27 m)

Timber configuration:

	No. of timbers	configuration
Upstream	7	#4
Downstream	15	#1

III. ICE COVER DATA
(Model Units)

Time 132 min.

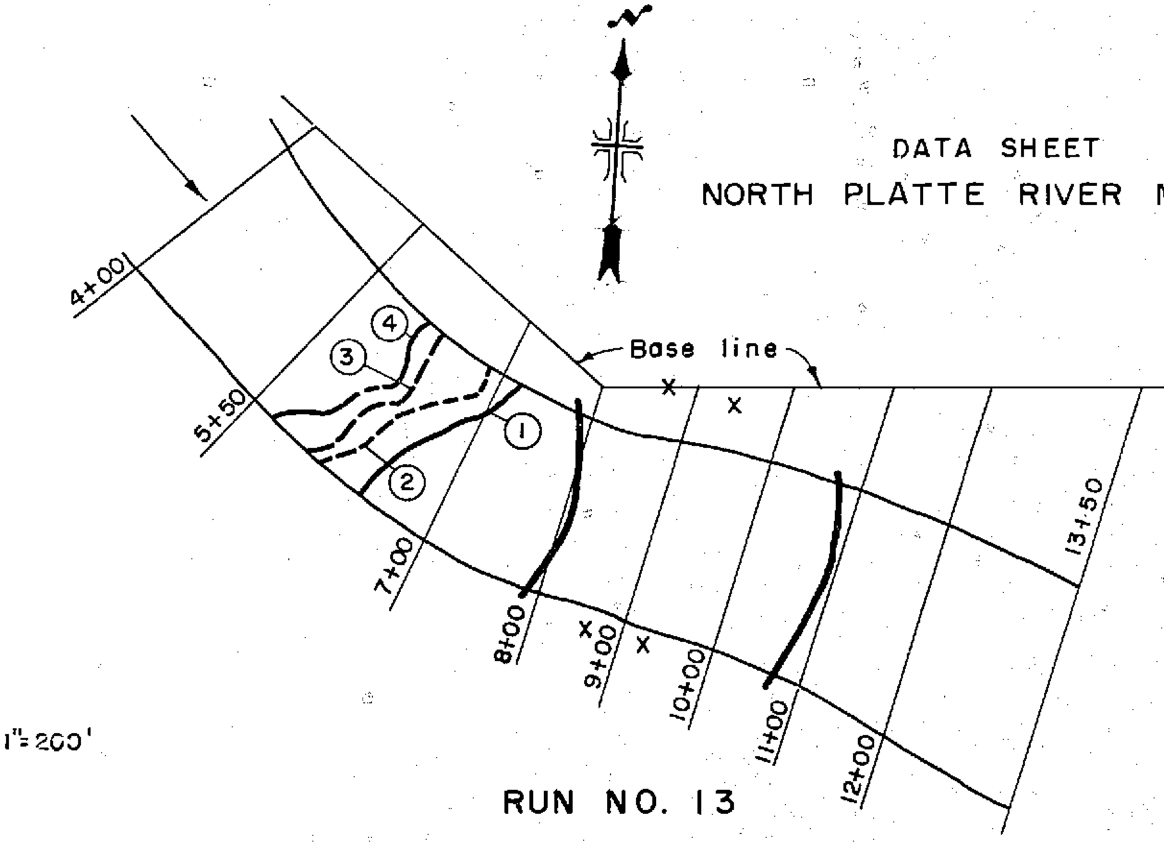
Surface Area 13,130 $in.^2$ (84,689 cm^2)

Volume 2,930 $in.^3$ (48,351 cm^3)

Avg. ice thickness 0.23 in. (0.58 cm)

Ice Lost –

DATA SHEET
NORTH PLATTE RIVER MODEL



RUN NO. 13

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.42	1.4(39.7)
30	1	5145.45	3.7(104.9)
72	2	5145.51	5.4(153.1)
140	3	5145.55	7.0(198.5)
*273	4	5145.65	9.0(255.2)

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs (26.60 m^3/s) Elev. Sta. 12+00 5145.21

V 2.0 ft/sec (0.61 m/sec) Fr = 0.20

D 3.0 ft (0.91 m)

II. BOOM CONFIGURATION

Sag 14' (4.27 m)

Timber configuration:

	No. of timbers	configuration
Upstream	14	#4
Downstream	18	#1

III. ICE COVER DATA
(Model Units)

Time 273 min.

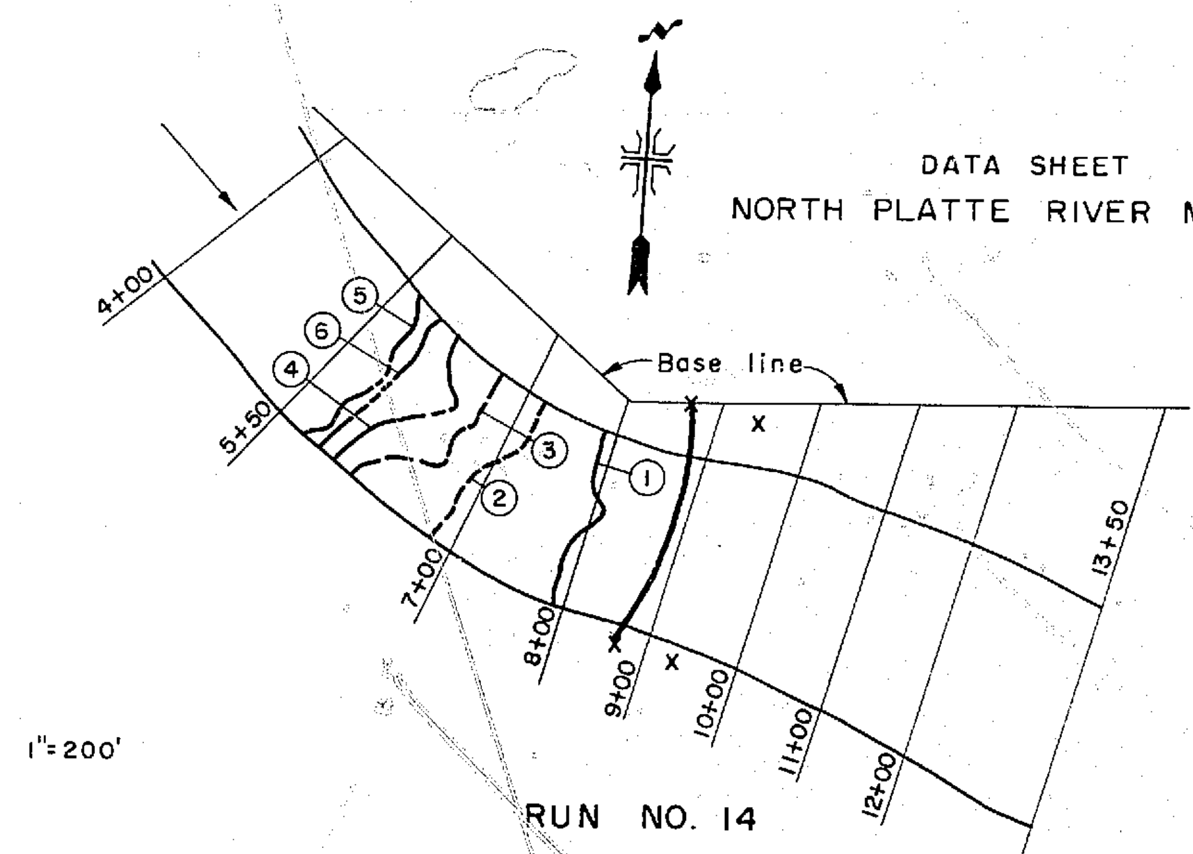
Surface Area 16,650 $in.^2$ (107,393 cm^2)

Volume 4,860 $in.^3$ (79,655 cm^3)

Avg. ice thickness 0.29 in. (0.74 cm)

Ice Lost 516 $in.^3$ (8,456 cm^3)

DATA SHEET
NORTH PLATTE RIVER MODEL



RUN NO. 14

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5146.00	1.1(31.2)
45	1	5146.01	2.0(56.7)
74	2	5146.03	2.6(73.7)
107	3	5146.05	3.0(85.1)
163	4	5146.07	3.8(107.7)
320	5	5146.11	6.0(170.1)
*353	6	5146.12	7.0(198.5)

*•Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs Elev. Sta. 12+00 5145.77
(26.60 m^3/s) (artificially increased by tailgate)

V 1.72 ft/sec (0.52 m/sec) Fr = 0.155

D 3.8 ft (1.16 m)

II. BOOM CONFIGURATION

Sag 14' (4.27 m)

Timber configuration:

	No. of timbers	configuration
Upstream	16	#1
Downstream		

III. ICE COVER DATA
(Model Units)

Time 321 min.

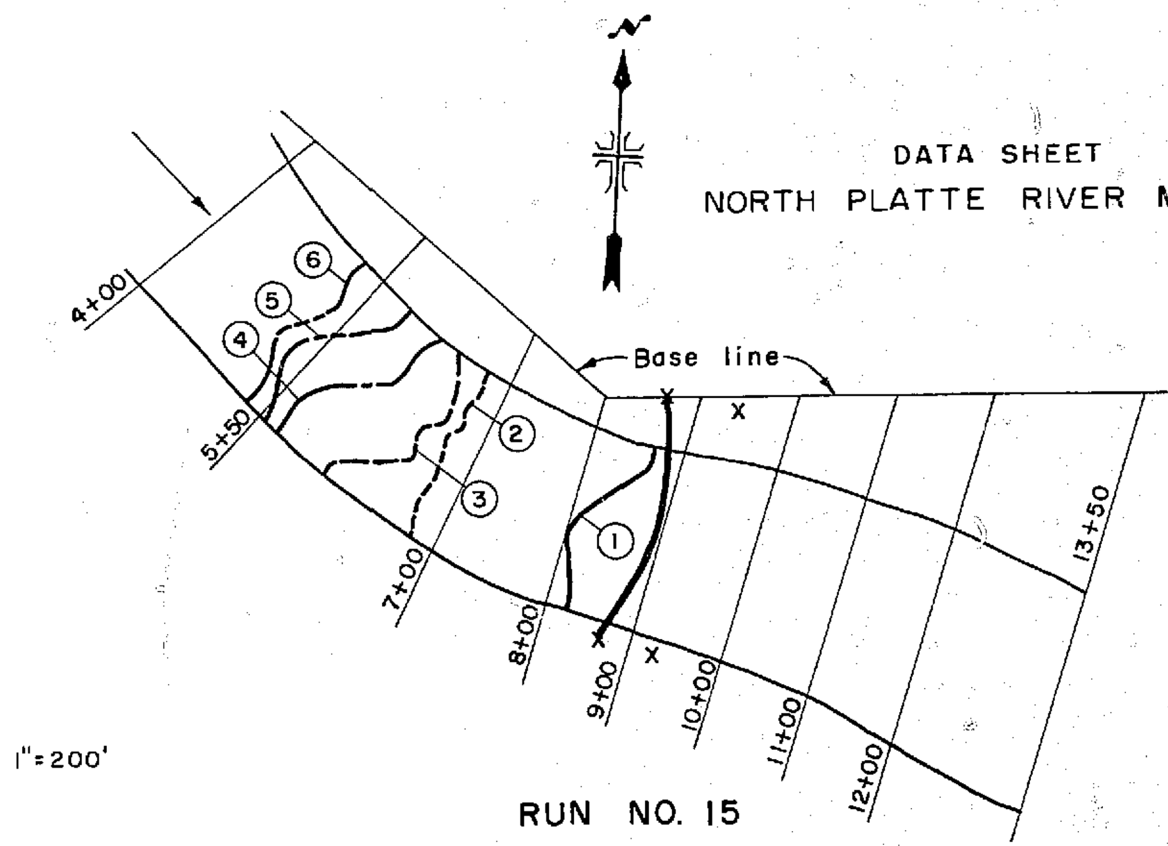
Surface Area 17,650 $in.^2$ (113,843 cm^2)

Volume 5,160 $in.^3$ (84,572 cm^3)

Avg. ice thickness 0.29 in. (0.74 cm)

Ice Lost 590 $in.^3$ (9,670 cm^3)

DATA SHEET
NORTH PLATTE RIVER MODEL



RUN NO. 15

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5146.38	1.1(31.2)
32	1	5146.41	1.5(42.5)
80	2	5146.42	2.0(56.7)
95	3	5146.42	2.1(59.5)
200	4	5146.44	3.0(85.1)
297	5	5146.45	3.9(110.6)
*390	6	5146.49	5.1(144.6)

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs Elev. Sta. 12+00 5146.15
(26.60 m^3/s) (Artificially increased by tailgate)
V 1.58 ft/sec (0.48 m/sec) Fr = 0.136
D 4.2 ft (1.28 m)

II. BOOM CONFIGURATION

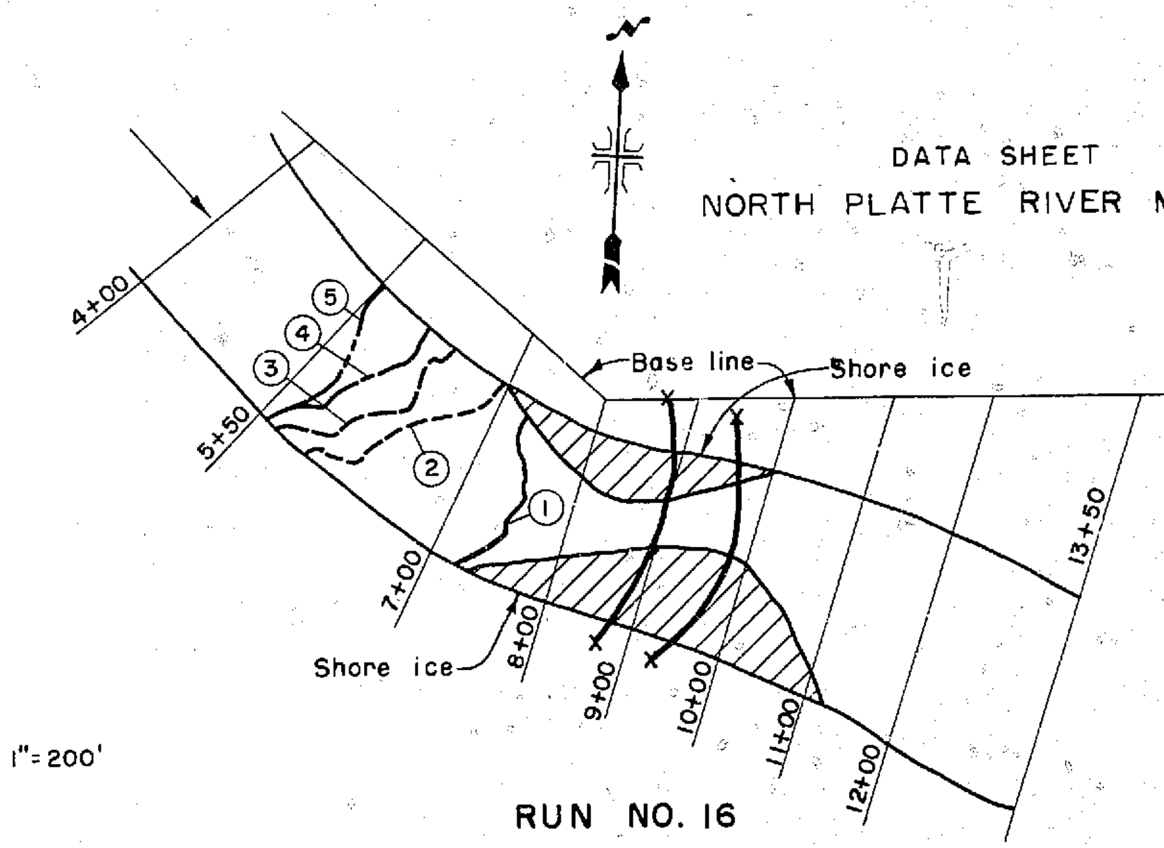
Sag 14' (4.27 m)
Timber configuration:

	No. of timbers	configuration
Upstream	16	#1
Downstream		

III. ICE COVER DATA
(Model Units)

Time 390 min.
Surface Area 22,500 in.^{2} (145,125 cm^2)
Volume 5,900 in.^{3} (96,701 cm^3)
Avg. ice thickness 0.26 in. (0.66 cm)
Ice Lost 0

DATA SHEET
NORTH PLATTE RIVER MODEL



RUN NO. 16

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz (gr)
0		5145.53	-
24	1	5145.54	-
83	2	5145.60	-
138	3	5145.63	-
275	4	5145.72	-
*316	5	5145.83	-

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs (26.60 m^3/s) Elev. Sta. 12+00 5145.22

V 2.0 ft/sec (0.61 m/sec) Fr = 0.20

D 3.0 ft (0.91 m)

II. BOOM CONFIGURATION

Sag 14' (4.27 m)

Timber configuration:

	No. of timbers	configuration
Upstream	15	#1
Downstream	17	#4

III. ICE COVER DATA
(Model Units)

Time -

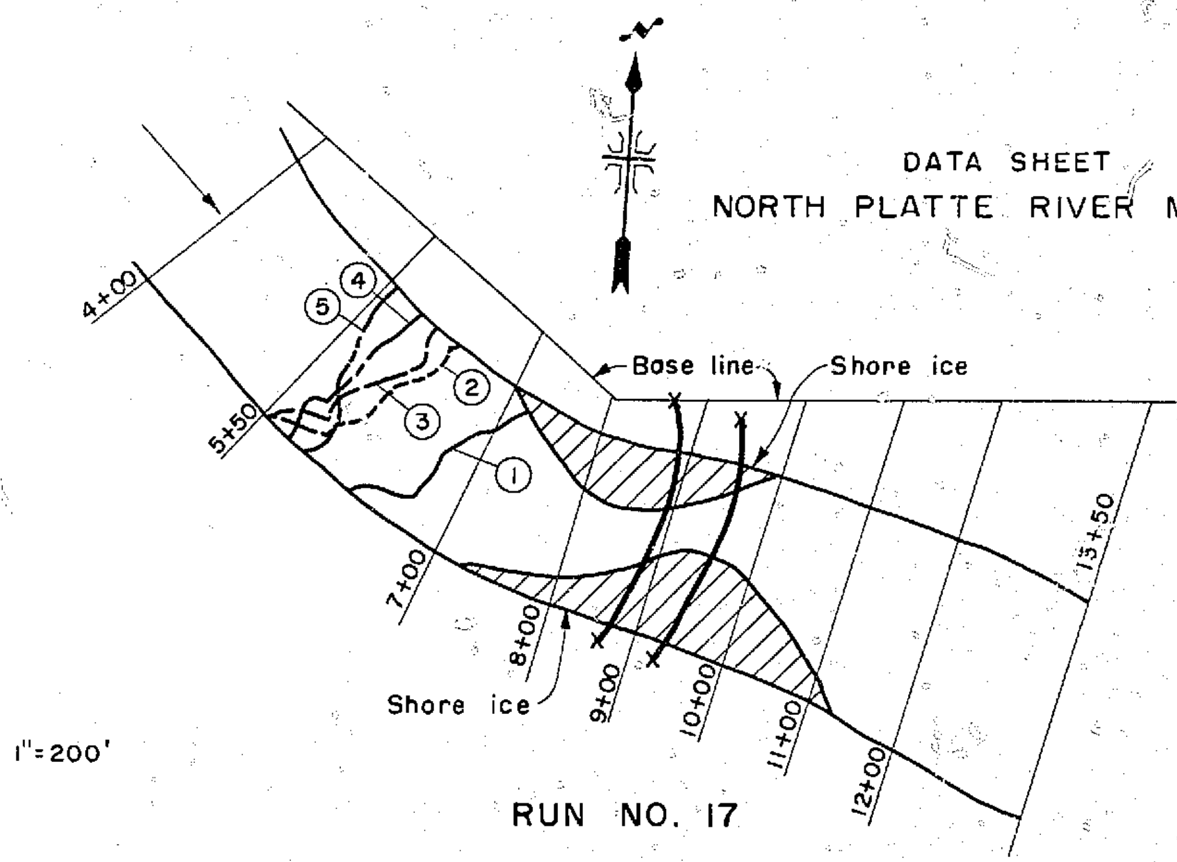
Surface Area -

Volume -

Avg. ice thickness -

Ice Lost -

DATA SHEET
NORTH PLATTE RIVER MODEL



RUN NO. 17

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz
0		5145.53	-
30	1	5145.57	-
107	2	5145.63	-
194	3	5145.71	-
252	4	5145.77	-
*337	5	5145.83	-

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs Elev. Sta. 12+00 5145.21
(26.60 m^3/s)
V 2.0 ft/sec (0.61 m/sec) Fr = 0.20
D 3.0 ft (0.91 m)

II. BOOM CONFIGURATION

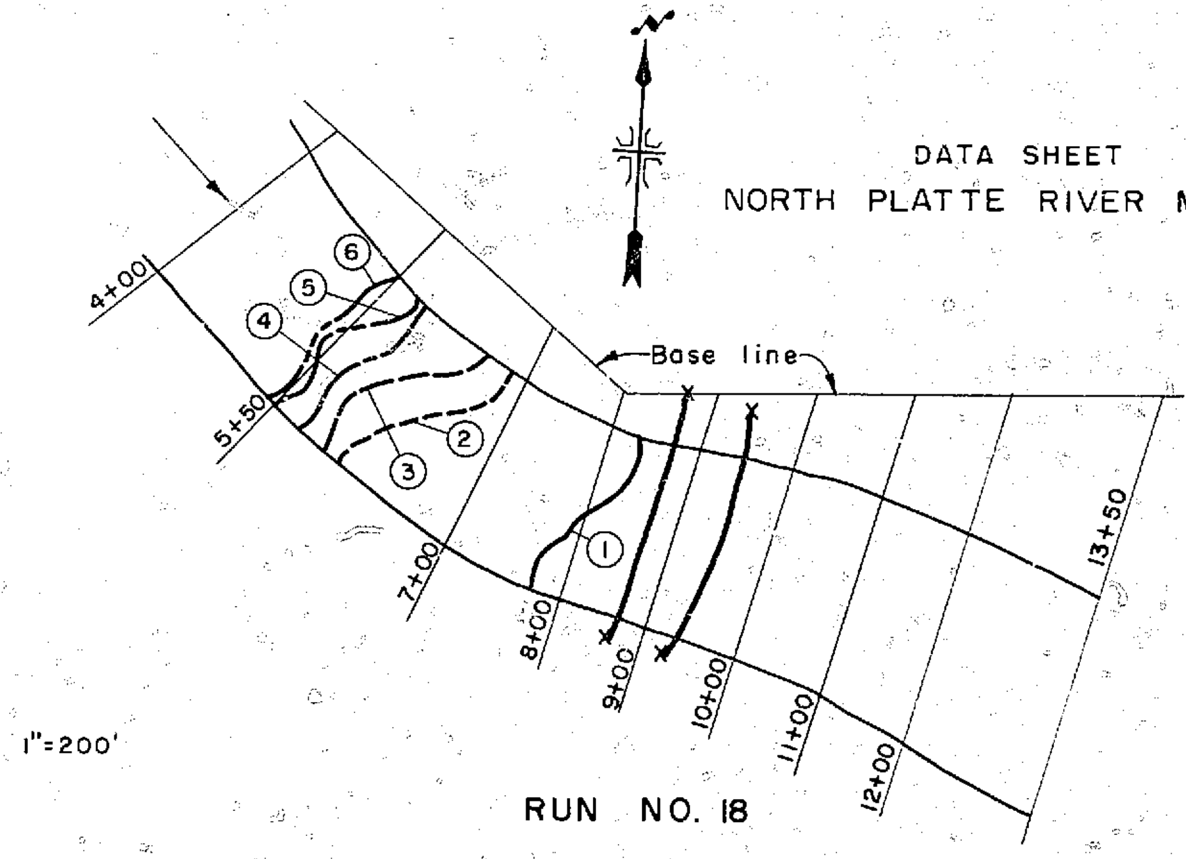
Sag 14' (4.27 m)
Timber configuration:

	No. of timbers	configuration
Upstream	15	#3
Downstream	17	#4

III. ICE COVER DATA
(Model Units)

Time -
Surface Area -
Volume -
Avg. ice thickness -
Ice Lost -

DATA SHEET
NORTH PLATTE RIVER MODEL



RUN NO. 18

Time (model) min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension oz
0		5146.27	-
16	1	5146.27	-
29	2	5146.32	-
53	3	5146.34	-
83	4	5146.36	-
173	5	5146.38	-
*218	6	5146.39	-

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs (26.60 m^3/s) Elev. Sta. 12+00 5145.18

V 1.63 ft/sec (0.50 m/sec) Fr = 0.142

D 4.1 ft (1.25 m)

II. BOOM CONFIGURATION

Sag 8' (2.44 m)

Timber configuration:

	No. of timbers	configuration
Upstream	17	#4
Downstream	17	#1

III. ICE COVER DATA
(Model Units)

Time 218 min.

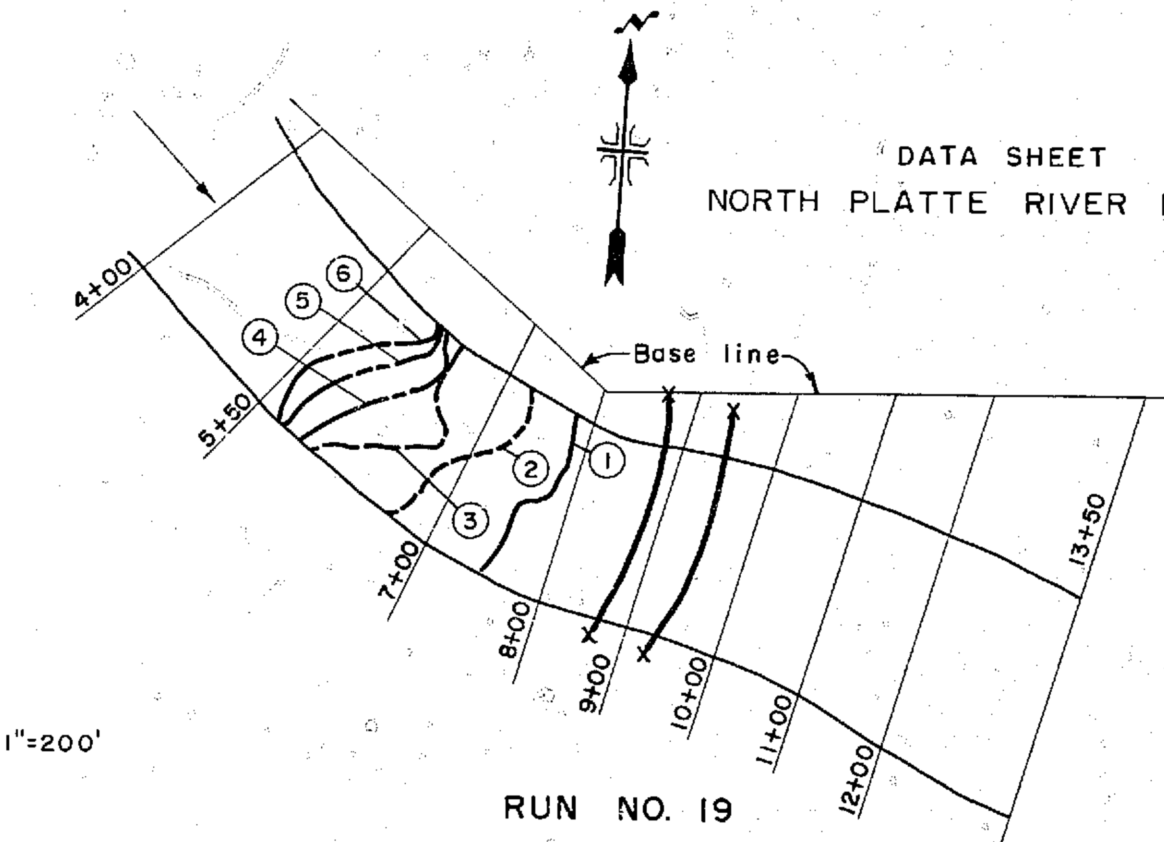
Surface Area 23,850 in.^{2} (153,833 cm^2)

Volume 6,780 in.^{3} (111,124 cm^3)

Avg. ice thickness 0.28 in. (0.71 cm)

Ice Lost 285 in.^{3} (4,671 cm^3)

DATA SHEET
NORTH PLATTE RIVER MODEL



RUN NO. 19

Time (model) -min.	Position (avg.)	Elev Sta. 4+00	U.S. Boom Tension
0		5146.01	
55	1	5146.03	
127	2	5146.04	
187	3	5146.06	
276	4	5146.08	
332	5	5146.11	
*364	6	5146.11	

* Ice stopped

I. FLOW PARAMETERS
(Prototype Units)

Q 940 cfs (26.60 m^3/s) Elev. Sta. 12+00 5145.19

V 1.72 ft/sec (0.52 m/sec) Fr = 0.155

D 3.8 ft (1.16 m)

II. BOOM CONFIGURATION

Sag ______

Timber configuration:

	No. of timbers	configuration
Upstream	17	#4
Downstream	17	#1

III. ICE COVER DATA
(Model Units)

Time –

Surface Area –

Volume –

Avg. ice thickness –

Ice Lost –

CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg, that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
Inches	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters
Feet	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	*929.03	Square centimeters
Square feet	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	*0.40469	Hectares
Acres	*4,046.9	Square meters
Acres	*0.0040469	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
Fluid ounces (U.S.)	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
Liquid pints (U.S.)	0.473166	Liters
Quarts (U.S.)	*946.358	Cubic centimeters
Quarts (U.S.)	*0.946331	Liters
Gallons (U.S.)	*3,785.43	Cubic centimeters
Gallons (U.S.)	3.78543	Cubic decimeters
Gallons (U.S.)	3.78533	Liters
Gallons (U.S.)	*0.00378543	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
Gallons (U.K.)	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters
Acre-feet	*1,233,500	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
Short tons (2,000 lb)	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
Pounds per square inch	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
Pounds per square foot	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
Pounds per cubic foot	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
Inch-pounds	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
Foot-pounds	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
Feet per second	0.3048 (exactly)*	Meters per second
Feet per year	*0.965873×10^{-6}	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
Miles per hour	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	*0.3048	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	*0.028317	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	*0.453592	Kilograms
Pounds	*4.4482	Newtons
Pounds	*4.4482×10^5	Dynes

Table II—Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram calories
British thermal units (Btu)	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	*1.35582	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in./hr ft^2 degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft^2 degree F	*1.4880	Kg cal m/hr m^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	0.568	Milliwatts/cm^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	4.882	Kg cal/hr m^2 degree C
Degree F hr ft^2/Btu (R, thermal resistance)	1.761	Degree C cm^2/milliwatt
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	*1.000	Cal/gram degree C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
Ft^2/hr (thermal diffusivity)	*0.09290	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	*304.8	Liters per square meter per day
Pound-seconds per square foot (viscosity)	*4.8824	Kilogram second per square meter
Square feet per second (viscosity)	*0.092903	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	*35.3147	Millicuries per cubic meter
Milliamps per square foot	*10.7639	Milliamps per square meter
Gallons per square yard	*4.527219	Liters per square meter
Pounds per inch	*0.17858	Kilograms per centimeter

ABSTRACT

The investigation and results of a hydraulic river model study using polyethylene plastic to simulate river float ice is described. Modifications to an existing river ice control structure are recommended as a result of the study. The conclusions recommend: (1) channel cross-section modifications to improve the flow conditions at the control structure site, (2) two-channel constriction designs which could be used downstream of the control structure to increase the water surface elevation and decrease the flow velocity at the control structure site, and (3) several modifications to the control structure which would improve the ice retention capability.

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Bur Reclam Rep REC-ERC-71-46, Div Gen Res, Dec 1971. Bureau of Reclamation, Denver, 55 p, 25 fig, 9 ref, append

DESCRIPTORS—/ hydraulic models/ ice jams/ ice/ *floating ice/ *control structures/ Froude number/ jetties/ alluvial streams/ *model tests/ flow characteristics/ test results/ models/ ice cover
IDENTIFIERS/ North Platte River/ polyethylene/ *ice control/ *booms

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