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A STRUCTURE TO PREVENT MOVEMENT OF FISH, EGGS, AND LARVAE

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ABSTRACT: The Bureau of Reclamation's McClusky Canal, being constructed as part of the Garrison Diversion Irrigation Project in North Dakota, will transfer water from the Missouri River Basin to the drainages of the Red River of the North and Souris Rivers which flow into Canada. Several species of fish occur in the Missouri which are absent from the other drainages or their headwaters including carp, goldeye, and buffalo fish. The canal will carry 1,950 ft^3/s of water. A structure designed for winter and summer operation is being installed to filter out fish, their eggs and larvae using screens with 0.40-mm openings. Laboratory tests were conducted to optimize the screen size while maintaining adequate self-cleaning. The paper details the literature survey of fish screening methods that resulted in the idea for the structure, as well as the subsequent hydraulic model study and structure design.

ACKNOWLEDGMENT

The hydraulic model study was conducted by P. L. Johnson and reviewed by D. L. King, Head, Applied Hydraulics Section, under the general supervision of W. E. Wagner, Chief, Hydraulic Branch. Messrs. J. G. Starbuck, J. J. Sartoris, and P. L. Johnson formed the planning team that conceived the initial structure. The design was carried out by the staffs of the Canal Structures and Bridges Section, Hydraulic Structures Branch, and the Gates and Valves Section, Mechanical Branch of the Bureau's Engineering and Research Center.

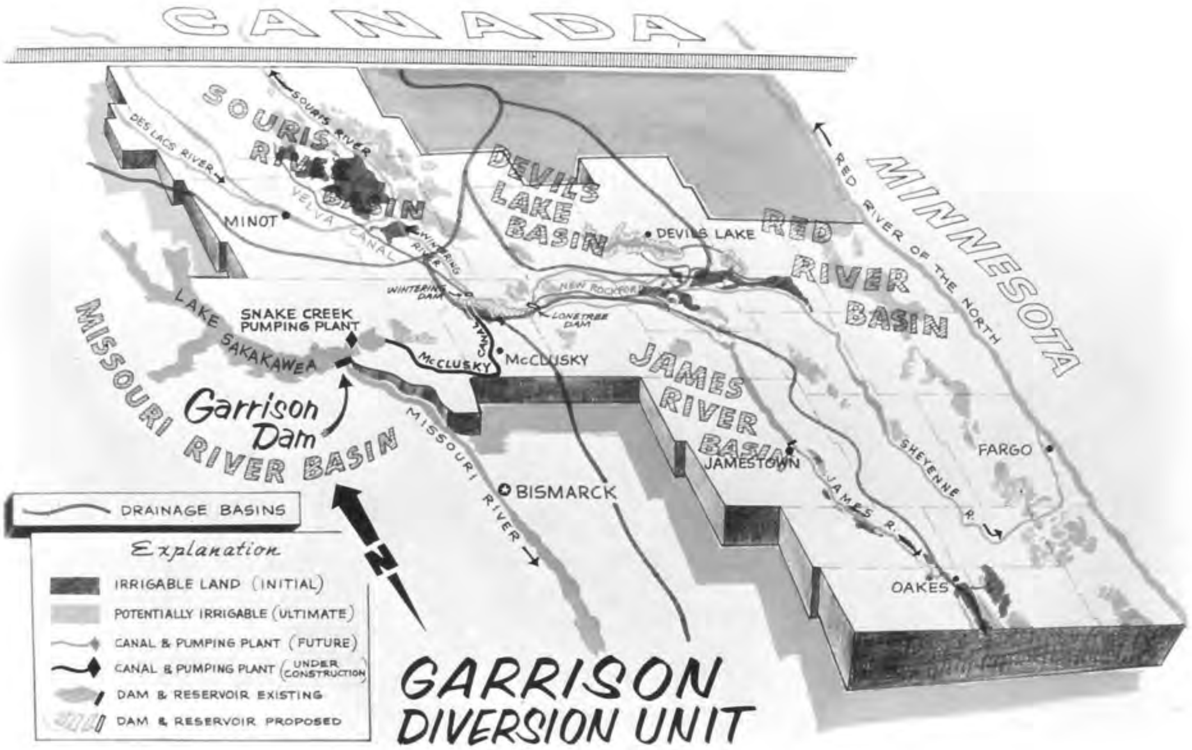


FIGURE 1 LOCATION MAP

The Garrison Diversion Unit of the Missouri River Basin Project is an extensive, multipurpose project, whose initial stage is designed to irrigate 250,000 acres of east-central North Dakota (Figure 1). Water will be pumped from Lake Sakakawea on the Missouri River through a series of canals, lakes, and reservoirs to lands in the Souris, Sheyenne, James, and Wild Rice River drainages.

The James River is a tributary of the Missouri. The Sheyenne and Wild Rice Rivers are tributaries of the Red River of the North which, with the Souris, flows into Canada. Also within the service area are closed basins such as the Devils Lake Chain that contain shallow lakes and marshes of major importance to waterfowl.

Many species of fish occur in the Missouri River and lower James which do not occur in the waters which will receive flows from the Garrison Diversion Unit. In some cases this may be the result of evolutionary isolation. Low winter flows, temperatures, lack of oxygen, or other factors which will be altered by the project, apparently control distribution in other cases.

Most fish species evolved within the major drainages where they are now found and are in good ecological balance with other organisms in their environment. Introduction of species into a new area will certainly change an established ecosystem. The effects of carp on waterfowl habitat, competition by goldeye with young of game fish for food, predation by gar, and problems of overcrowding and stunting by panfishes are well known. Uncontrolled introductions and range extensions of certain species would nullify some of the anticipated benefits of the project and could seriously damage the fish and wildlife resources of some areas.

Knowledge of the distribution of fish in the project area is out of date and incomplete. It is known that sturgeon, paddlefish, shortnose gar, goldeye, carp, many minnows, buffalo fish, and burbot which occur in Lake Sakakawea or the Lower James River are absent from some or all of the basins and drainages which would be affected. The Bureau of Reclamation contracted with the North Dakota Game and Fish Department and Dr. John Owen of the University of North Dakota to bring the available knowledge up to date. The study began in 1974 and is scheduled to be completed this year.

Although we are unable to define the exact extent of the problem, its general limits were known and work began on a solution.

To evaluate and develop methods for eliminating the possibility of fish movement, a study team was organized in the Engineering and Research Center of the Bureau of Reclamation. The team's objective was to do a brief but concise literature review. The review would consider all possible methods of fish, fish egg, and fish larva control. The team would also do some "brain storming" in an attempt to find solutions that have not been previously evaluated. Work, therefore went ahead based on the assumption that no fish, fish egg, or fish larva migration could be tolerated.

The E&R Center team began by attempting to understand the biological aspects and constraints on the problem. This understanding would give the team additional insight into what the problem consists of and would, therefore, give significant direction to the study. A brief review indicated that the minimum egg diameter to be encountered is larger than 1 mm, that larvae will be approximately the same size as their eggs, that eggs or larvae will be present in the system through most of the summer and early fall (the peak operation periods for the canals), and that most of the eggs will not float but that some do. The implications of these findings are that:

1. Any filtration system used must filter every drop of water that passes the structure.

2. If filters are used, all material in the flow larger than 1 mm in diameter must be removed from the flow.

3. Any structure built must be large enough to handle the maximum discharge of the system.

4. Whatever control system is used must be able to either remove or kill all fish, eggs, and larvae in the flow under all operating conditions.

A second aspect of the problem that was considered early in the analysis was the physical layout of the project. It was realized that this layout (number, size, and location of turnouts; canal branching to various drainages; etc.) would dictate the number and size of fish control stations required. As can be seen in figure 1, the water will be taken from the Missouri River at Lake Sakakawea and lifted by the Snake Creek Pumping Plant to Lake Audubon. The water then passes through most of the remainder of the system by gravity flow. From Lake Audubon the flow passes approximately 80 miles down the McClusky Canal to Lonetree Reservoir. There are only a few small deliveries planned from the McClusky Canal. From Lonetree Reservoir (which will store and regulate the flow) the water will pass north into the Souris River drainage, and east and southeast into the Sheyenne, James, and Wild Rice River drainages. Both distribution canals leaving Lonetree Reservoir, the Velva Canal going north and the New Rockford Canal going east and southeast, have maximum discharges that are approximately equal to that of the McClusky Canal. It, therefore, seems advantageous to locate the fish control structure on the McClusky Canal. Placement of the controls on the Velva and New Rockford Canals would require facilities that could process a combined flow of nearly twice that of the McClusky Canal. This alternative, thus, would probably be nearly twice as expensive as a single McClusky Canal structure. In addition, placement of the fish controls on the Velva and New Rockford Canals would allow the undesirable fish to pass into Lonetree Reservoir. This would not only adversely affect the fishery and recreational uses of the Reservoir, but it would also create the possibility that fish could pass through the outlet works or spillways of Wintering and Lonetree Dams and into the protected drainages.

The team considered several possible means for achieving the desired fish controls. The initial consideration was that operational techniques might be used. It was thought that the canal might be dewatered when eggs or larvae were present and, thus, they would be eliminated as a concern. But, this cannot be done because eggs and larvae will be present in the flow throughout most of the peak operational season. Poisons were also briefly, but not seriously, considered. Poisons could control the fish, but the canal system passes through several lakes and is to be used for both recreational and wildlife purposes. Portions of the system will serve as habitat for waterfowl. These uses not only have environmental significance but are also economically important to the region. It was, therefore, concluded that a physical method of fish control was most desirable. In this vein, several control methods were also given limited consideration during the initial portion of the review. Violent hydraulic action such as turbulence in a hydraulic jump or cavitation were found to not be 100 percent lethal to mature fish for the heads considered. No data were found on the effects of hydraulic action on eggs and larvae. The indications are that hydraulic control does not offer a solution. When electrocution was considered, it was found that voltages that would effectively control all sizes of fish, their eggs, and their larvae would pose a danger to men. Sound wave control was also briefly considered, and as with the others it was found to be inadequate.

The attention of the team was, therefore, shifted to various screening methods and devices. The team's initial reaction was that screen systems cannot be expected to be 100 percent effective. There would be small openings at seams and seals, especially for moving screens. Eggs might cling to moving screen surfaces and be transported past the structure. Fixed screens did not initially appear to hold any more promise because of the large amounts of trash (aquatic plants and algae) expected in the system. Fixed screens are generally susceptible to clogging and clogging would pose a very serious handicap to a screen structure's operation. More detailed consideration revealed two types of screen structures that appeared to be able to meet the needs. The first was a sand filter similar to, but much larger than, those used for domestic water treatment. This type of structure would have filtration capabilities far beyond those required for this particular problem. A sand filter could, thus, be expected to be 100 percent effective. Rough designs, however, revealed that a sand filter capable of handling the full canal discharge (1,950 ft^3/s or 55.2 m^3/s) would have a surface area of from 5 to 10 acres (20,000 to 40,000 m^2). The cost of such a structure would be prohibitive. The second promising structure considered was a sloping screen filter (figure 2). The flow passes over

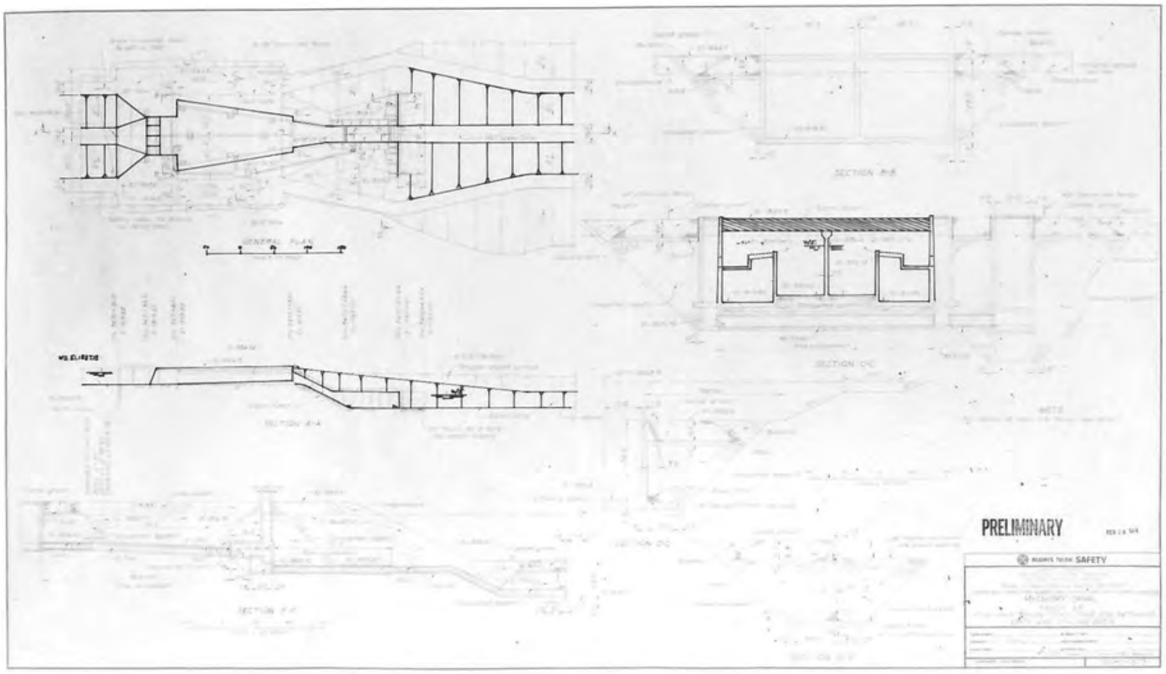


FIGURE 2 FINAL STRUCTURE DESIGN

a weir and through a fixed, slightly downward sloping, screen. The screen would be of a fine enough mesh to meet the filtration requirements. Seals around the fixed screen could be made sufficiently tight so that no flow would pass through. Previous experience with field installations of this type indicate that the structures are fairly self-cleaning. The screen weave is so fine (24 to 80 mesh) that it has a slick, fabriclike texture. Openings in the screen are generally small enough that debris will not cling to the individual wires. Therefore, debris passing onto the screen is washed down the screen surface to the point where the last of the flow drops through (figure 3). As the debris accumulates, the leading edge of the pile stays at the flow limit. The field installations to date for this particular type of screen have been for relatively small discharges (less than 100 ft^3/s) with the objective of either filtering weed seed from irrigation water or collecting biological samples from small streams. Structures using the same principle, but courser screens, have also been used for collecting or concentrating fish.

The final canal structure (figure 2) was a new concept, because of its size and because of the fine mesh and the structural configuration. It is felt that a structure of this type can be designed to function satisfactorily, meet the filtration requirements, and yet have an acceptable cost. With these points in mind the sloping fixed screen structure was decided on and work then went ahead with its design and refinement.

To assist in developing the design, a sectional hydraulic model of the screen was constructed and studied (figure 3). The model was a full-scale representation of a 20-inch- (51-cm-) wide slice of the proposed prototype structure (figures 2 and 3). Included in the model were the overflow weir (the crest of which was 6 feet [1.8 m] above the test flume floor), the screen with a backup screen 1 foot (0.305 m) below it, and a trough at the end of the screen into which the trash and overflow water would dump. Screens could be easily changed and, thus, the effects of screen mesh and wire size could be quickly evaluated. The screens placed in the model were approximately 10 feet (3.05 m) long. This is longer than any screens that were envisioned for the prototype structure. It was realized that the required screen length would vary with screen mesh, screen slope, and unit discharge. The model screen was made over length so that a wide range of flow conditions could be tested. For the various test conditions observed, the location on the model screen where the last of the flow dropped through was used to establish the length of screen required. The model was constructed with the screen structure hinged to the weir wall. This made it possible to easily vary the screen slope. A skimmer weir upstream from the overflow weir was also included in the model during a portion of the testing. The model flow was passed through an 80-mesh screen box after it passed through the model to evaluate the filtration efficiency.

The model study had three main objectives. They were:

1. Evaluate the screen's ability to self-clean.

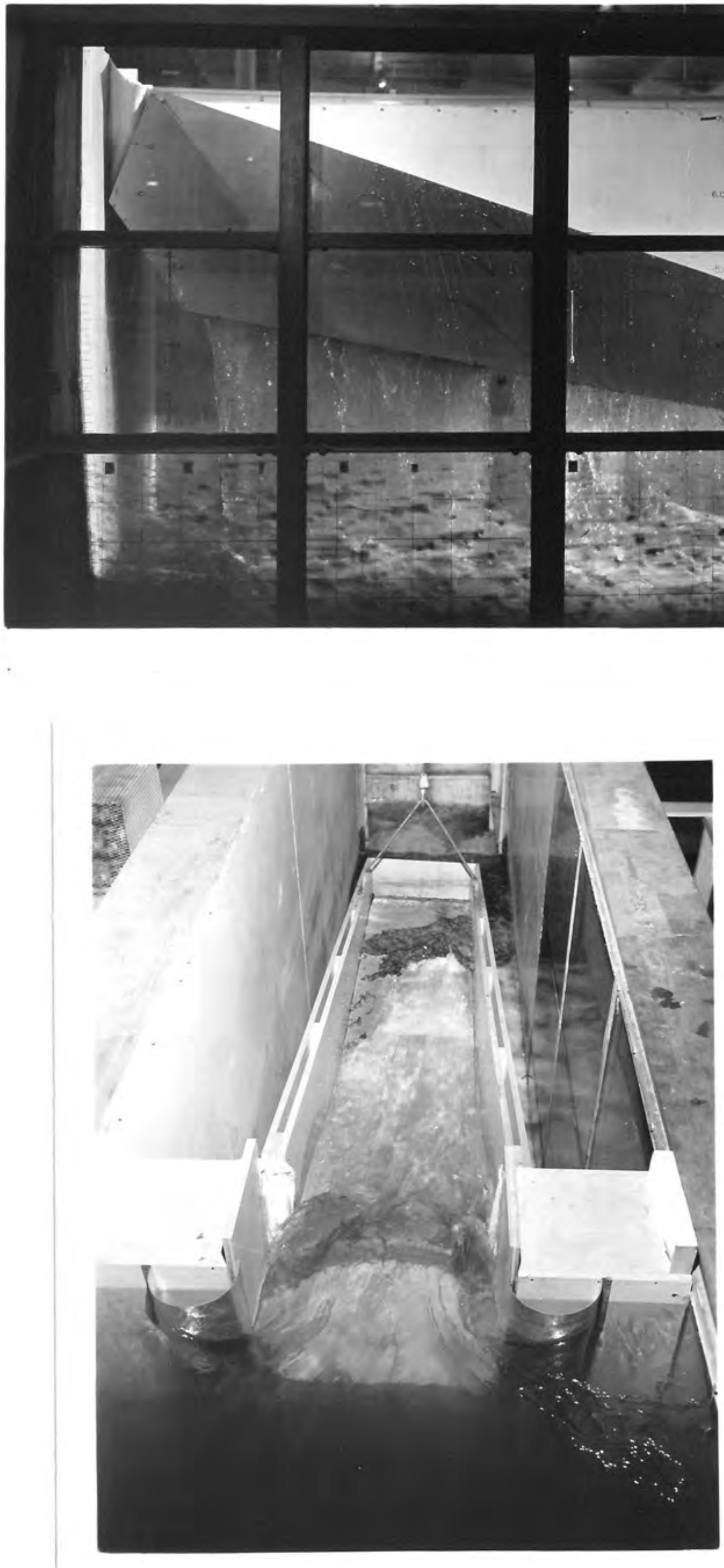


FIGURE 3 HYDRAULIC MODEL

2. Confirm that the screen will satisfactorily meet the filtration requirements

3. Minimize the screen and structure size required to filter the canal's total flow.

Six basic factors were considered to achieve these objectives. Several of these factors are interrelated which made it necessary to observe several hundred specific operating conditions to obtain a complete understanding. The six basic factors considered in the investigation were:

1. Unit discharge

2. Drop from weir crest to screen

3. Slope of screen

4. Length of screen

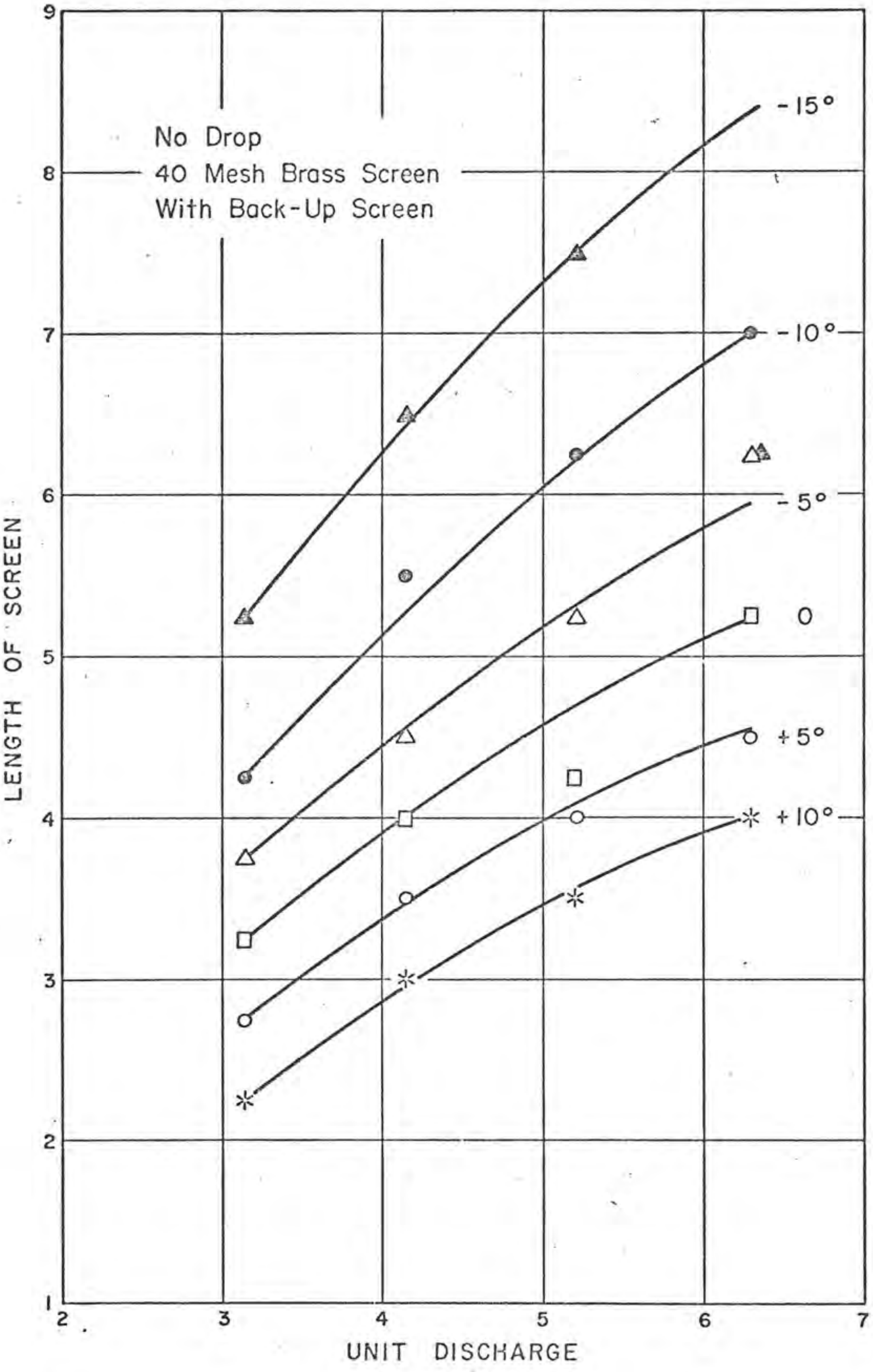
5. Screen mesh and wire size

6. Effects of various types of debris

As an example of how these factors interrelate, it might be noted that as the unit discharge (the discharge per foot width of screen) increases the length of screen required to pass that discharge also increases. Likewise, as the downward slope of the screen increases the length of the screen required increases. But on the other hand, as the unit discharge increases so does the amount of debris per unit width of screen. And as the downward slope of the screen increases, the screen more effectively self-cleans. Also, it could be reasoned that the finer the screen mesh (and, therefore, the smaller the openings in the screen) the greater the resistance to the flow will be, and therefore, a longer screen would be required. But, again, a finer mesh might give the screen a slicker finish and, therefore, improve the self-cleaning.

A drop from the overflow weir crest to the screen surface might also be incorporated into the structure's design. This would give the flow an additional velocity as it impacts on the screen, which would increase the flow rate through the impact zone of the screen and, thus, reduce the required screen length. On the other hand, the higher velocity would result in a larger impact pressure on the screen which might cause structural problems or which might tend to press and hold debris against the screen surface.

As can be seen, the overall problem is one of give and take. The model study must yield the optimum balance between these various factors which best satisfies the study's three objectives. A structure must be developed that satisfies the filtration requirements, that effectively self-cleans, and yet that has a minimum structure and screen size and, therefore, a minimum cost.


No Drop
40 Mesh Brass Screen
With Back-Up Screen
-15°
-10°
-5°
0
+5°
+10°
LENGTH OF SCREEN
UNIT DISCHARGE
1
2
3
4
5
6
7
8
9
2
3
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5
6
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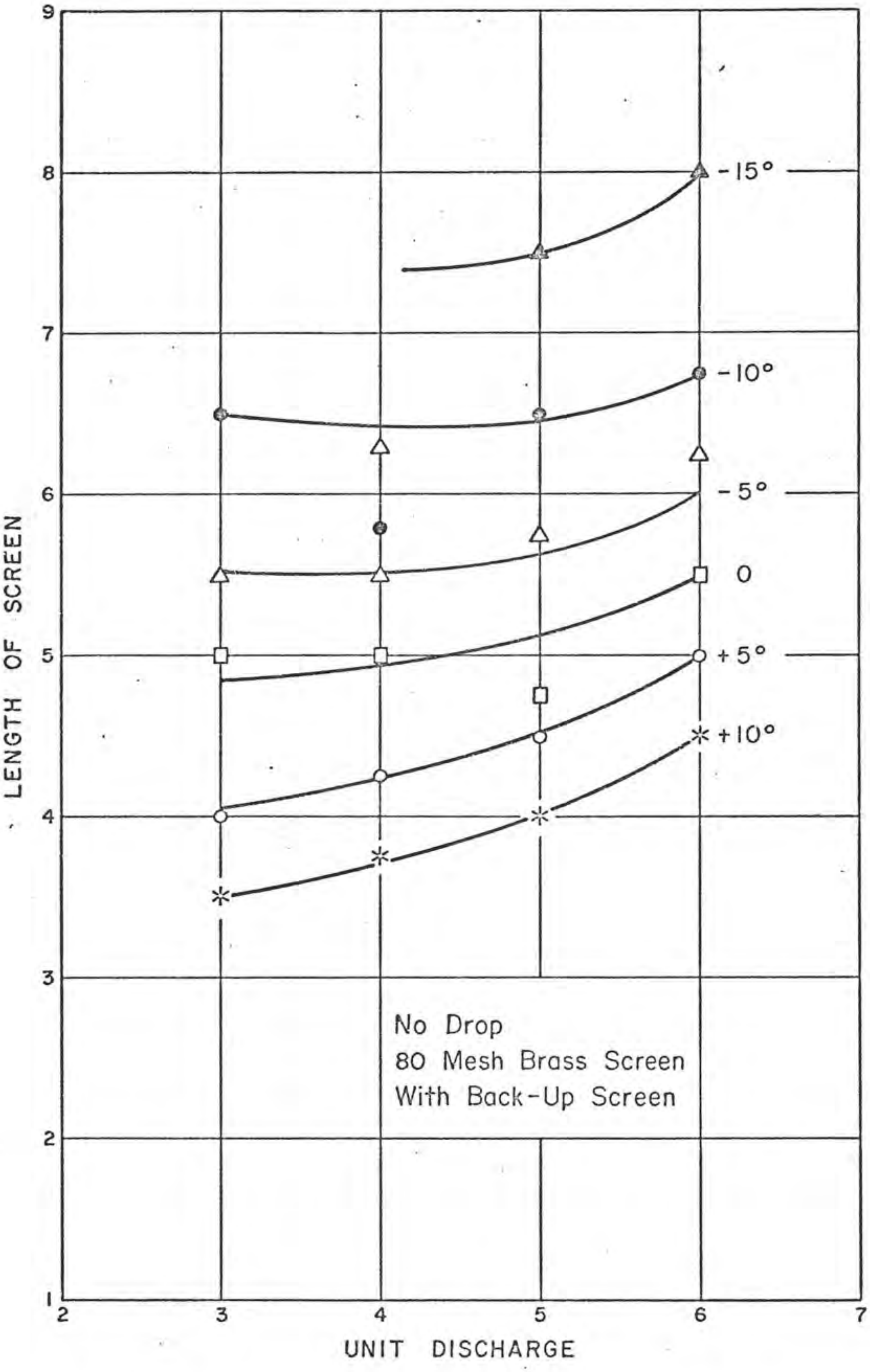
FIGURE 4



9
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1
2
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4
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6
7
LENGTH OF SCREEN
UNIT DISCHARGE
-15°
-10°
-5°
0
+5°
+10°
No Drop
80 Mesh Brass Screen
With Back-Up Screen

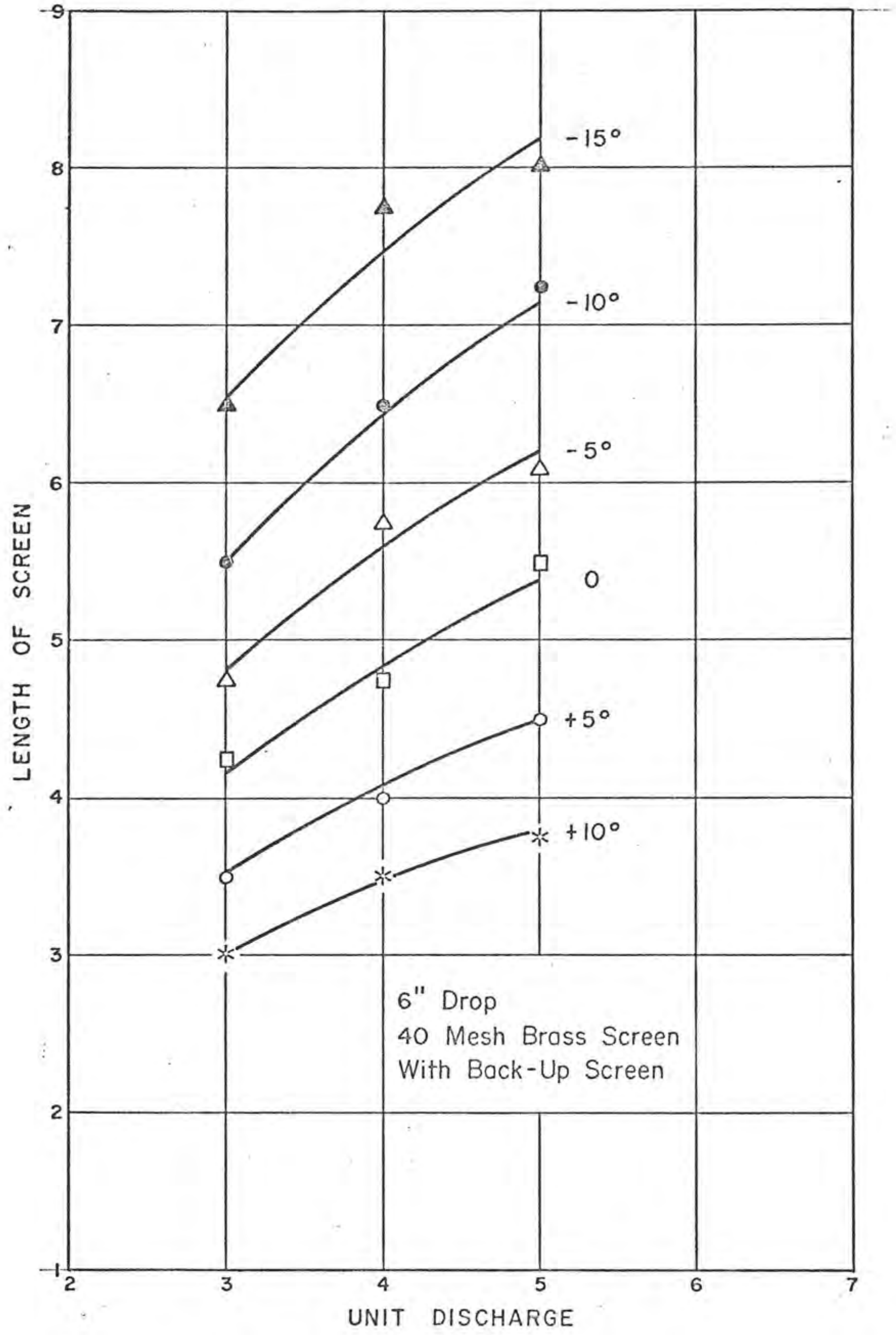
FIGURE 5

FIGURE 6 6" DROP FROM WEIR CREST

To achieve these goals the model was studied under a broad range of operating conditions. The model operating under typical conditions is shown in figure 3. Forty-mesh screens made from 0.010-inch- (0.25-mm-) and 0.006-inch- (0.15-mm-) diameter wire and 80-mesh screens made from 0.007-inch- (0.18-mm-) diameter wire were used. For each screen an initial study was made with no debris in the flow. The screens were observed operating at unit discharges of 3, 4, 5, and 6 ft^3/s (0.08, 0.11, 0.14, and 0.17 m^3/s). For each unit discharge the screen was set at slopes of 5° and 10° upward; horizontal; and 5°, 10° and 15° downward. For each setting, the length of the screen surface required to pass the flow was noted. This information yielded the optimum structure size and slope that would be required to filter the canal discharge These data are shown in figures 4 and 5 for the 40-mesh screen with 0.010-inch (0.25-mm) wire and the 80-mesh screen, respectively. It can be seen that, as previously hypothesized, for a specific unit discharge the length of screen required increases as the downward slope of the screen becomes steeper. Likewise, for a particular slope it can be observed that the length of screen required increases as the unit discharge increases. In most cases, the 40-mesh screen requires less length to pass a given discharge. In addition, for a given screen slope, the required length appears to be more variable, with respect to unit discharge, for the 40-mesh screen than for the 80-mesh screen.

At this point, interest was raised in having a drop from the crest of the weir (figure 6) to the screen surface which would result in a more direct impact by the flow on the screen surface. The flow would also have a higher velocity due to the drop. Thus, the combination of a more direct impact and a higher impact velocity would result in a higher impact pressure. It was thought that this pressure, when combined with the weight of the water, would push more flow through the screen than would pass through if there was no drop. The greater flow rate through the screen would reduce the screen surface area required and, therefore, reduce the screen length required. A second reason that the drop was considered desirable was because it would impart a free trajectory on the flow. The flow would, therefore, not come into contact with the upper edge of the screen (where the screen ties into the weir wall). This would allow great simplification of the seal design at the upper edge. It was realized that the drop would also result in additional forces on the screen structure which could either require a stronger structure, and therefore a more expensive structure, or which could shorten the life of the screen and therefore increase operation and maintenance expenses.

After consultation with the designers, it was concluded that a drop of from 3 to 6 inches (7.6 to 15.2 cm) would be most satisfactory. A drop of this size would create the flow features desired and yet would not place excessive forces on the screen structure. A drop of 6 inches (15.2 cm) was then incorporated in the model (figure 6), and a similar test to those previously described was done. The results of this test (for the 40-mesh brass screen with 0.010-inch- [0.25-mm-] diameter wire) are shown in figure 7. In comparing these results to those in figure 5,



LENGTH OF SCREEN
UNIT DISCHARGE
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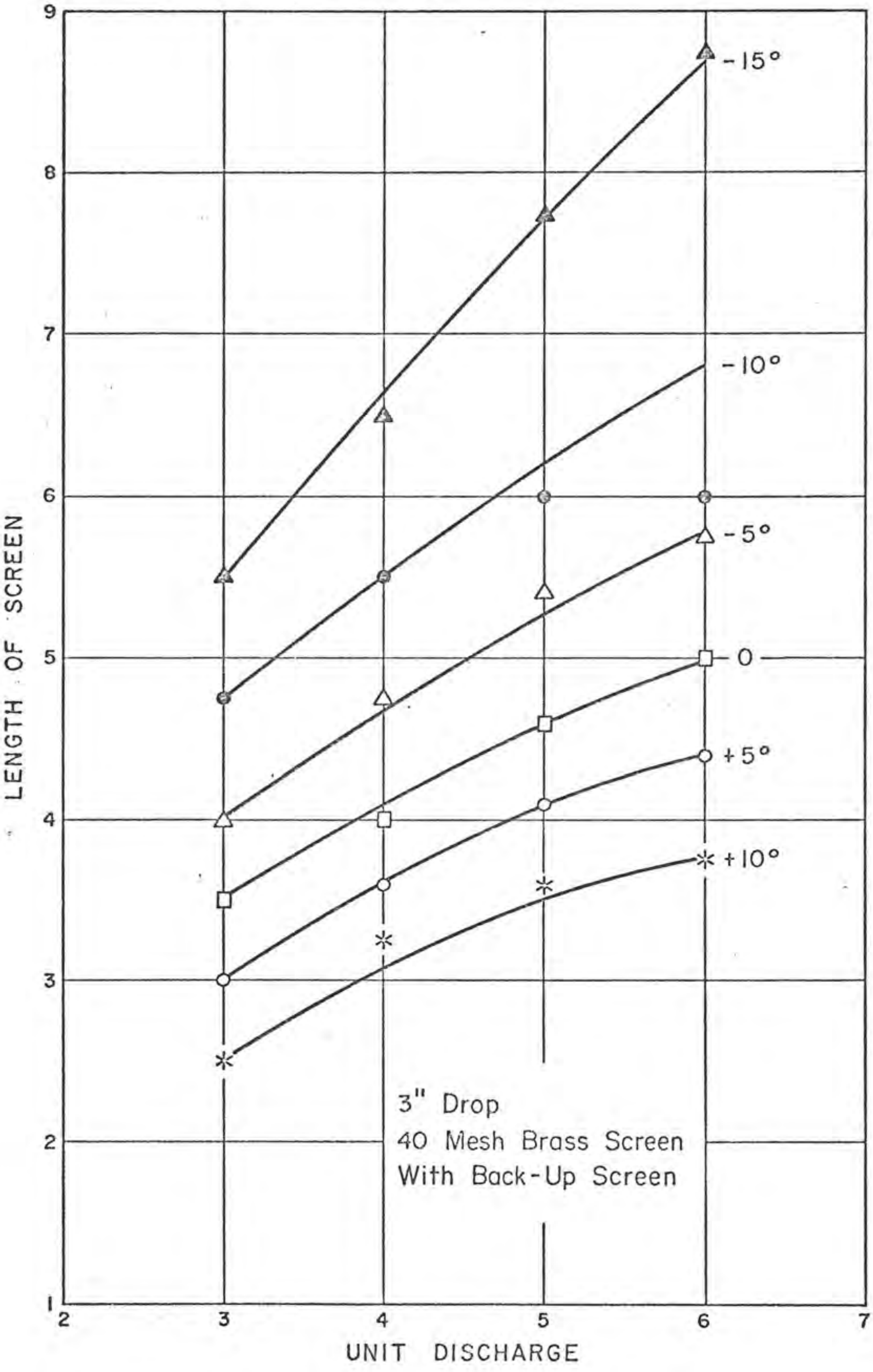
-15°
-10°
-5°
0
+5°
+10°
6" Drop
40 Mesh Brass Screen
With Back-Up Screen

FIGURE 7



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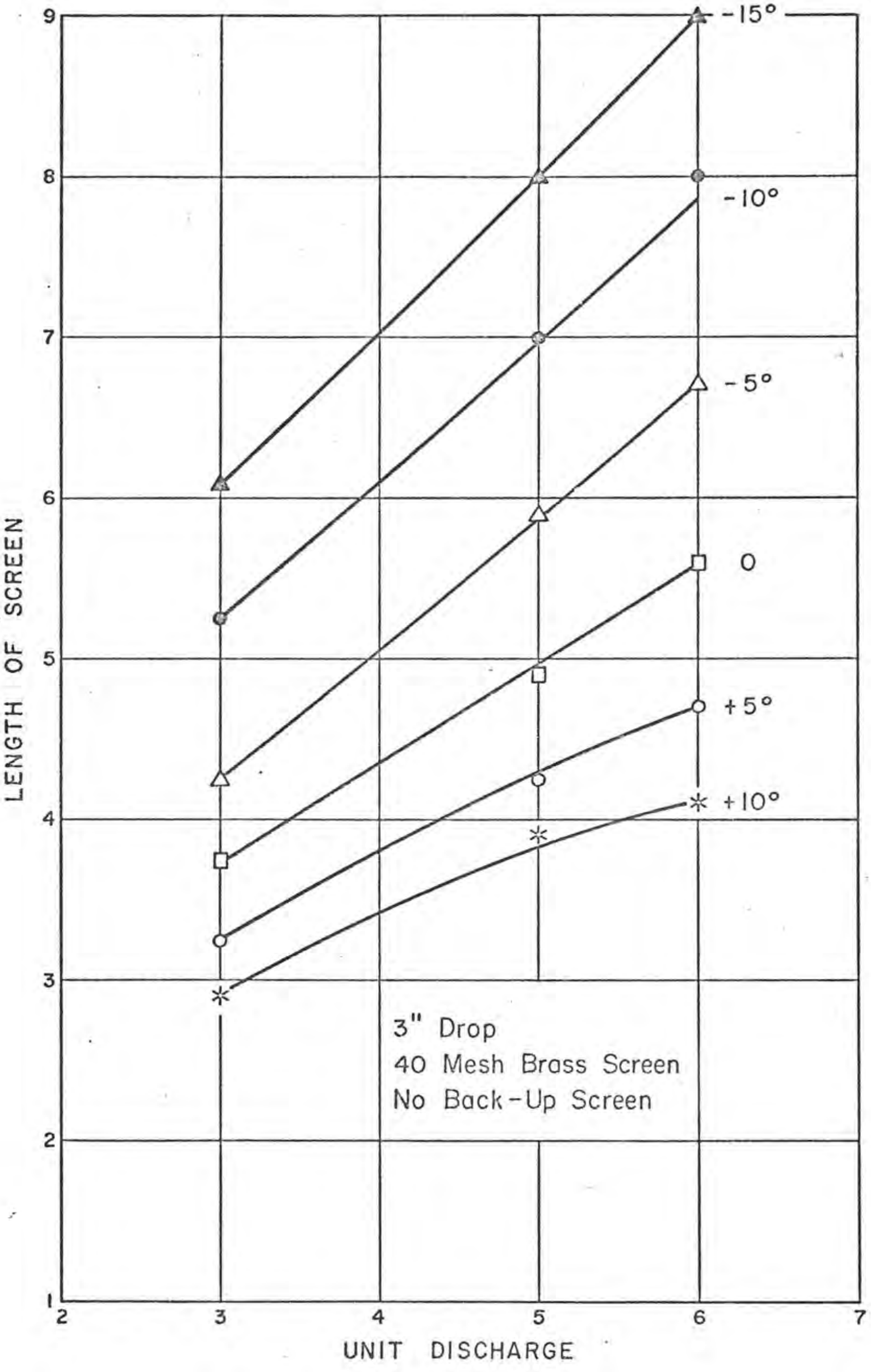
LENGTH OF SCREEN
UNIT DISCHARGE
-15°
-10°
-5°
0
+5°
+10°
3" Drop
40 Mesh Brass Screen
With Back-Up Screen

FIGURE 8

it can be observed that the 6-inch (15.2-cm) drop in all cases actually caused the required screen length to be longer. Observation of the model operating indicated that the flow would strike the screen and a portion of the flow would then be deflected and would pass down the screen surface. This was observed for all operating conditions of the model but with the 6-inch (15.2-cm) drop the deflected flow had a higher velocity and, therefore, traveled farther down the screen before it dropped through. It was thus concluded that the drop did not improve the structure's performance. However, because of the upper seal design, a drop from the weir crest to the screen was still considered desirable. Therefore, a 3-inch (7.6-cm) drop, the minimum considered feasible, was placed in the model. Again hydraulic tests were run and the results shown in figure 8 were obtained. If figure 8 (the 40-mesh brass screen with 0.010-inch [0.25-mm] wire) is compared with figure 4, it can be observed that the 3-inch (7.6-cm) drop does, to some extent, cause the required screen length to be longer. It should, however, also be noted that in general this additional length was small.

Two other hydraulic factors were considered during the model studies. First, because of the way that the model was constructed, there was concern that the region between the two screens was not satisfactorily vented. The disorganized flow passing between the two screens would entrain large quantities of air. This being the case, if the region was not properly vented, a negative pressure could develop. Such a negative pressure would not only put an additional load on the screens but would also increase the flow rate through the screens and, therefore, reduce the observed required screen lengths. To evaluate the significance of the venting and to determine the upper limit on the required screen length (screen length required when venting is complete) tests were run with the lower screen removed and with holes drilled in the wall of the screen box that faces the weir wall. This should be a vented condition that is as good as, or better than, what will be in the prototype. Observations did indicate that these conditions resulted in full venting of the flow. The results of these tests are shown in figure 9. When these results are compared to those in figure 8 (same top screen and flow conditions but without the additional venting), it can be seen that the well-vented condition requies significantly more screen length. The actual required prototype screen length is probably somewhere between the length given by figure 8 and the length given by figure 9. The screen length from figure 9 should be used in the prototype design. It may be slightly longer than what is actually required but it is best to be sure that there is enough screen surface to pass the maximum flow.

Under many of the test conditions observed, the flow on the screen was found to make a whistling noise. The noise varied in pitch and intensity with change in the screen slope and unit discharge. The whistling occurred in both the vented and unvented models. The cause of the whistle was never completely understood even though a considerable amount of time was spent in trying to understand it. Because of the high frequency of the whistle, it seemed unlikely to be caused by physical vibration of



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LENGTH OF SCREEN
UNIT DISCHARGE
-15°
-10°
-5°
0
+5°
+10°
3" Drop
40 Mesh Brass Screen
No Back-Up Screen

FIGURE 9

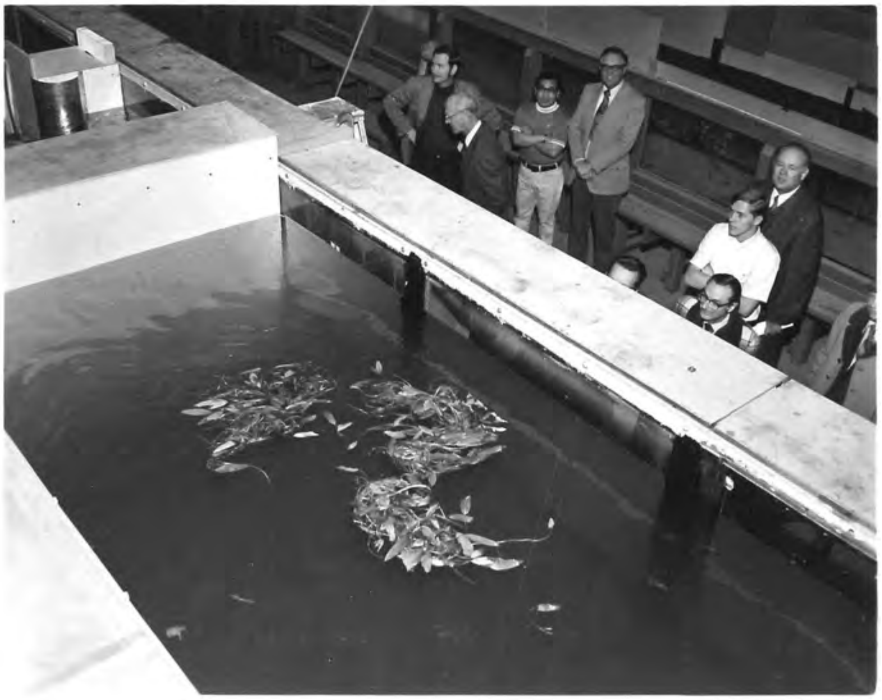

FIGURE 10 SKIMMER WEIR

the screen. It sounded more like air being drawn into a negative pressure region to aerate a flow. An unverified but possible cause is that the whistle may result from aeration of the flow passing through the individual orifices or openings in the screen. It was concluded that the prototype structure may also whistle but that the whistling does not represent a force that could damage the structure or hinder its operation.

A final hydraulic factor that was studied is the effect of a skimmer weir, placed upstream from the overflow weir, on the screen's performance. The skimmer weir studied extended 2.25 feet (0.69 m) below the crest of the overflow weir and was located 4 feet (1.2 m) upstream from the weir wall (figure 10). It was thought that the skimmer weir could intercept large quantities of floating debris and then guide the debris to a point where it could be removed by mechanical means. The skimmer weir could remove a large portion of the debris to be encountered and significantly reduce the self-cleaning problem. With the skimmer weir in place, tests were again run that related to the screen slope, the screen length, and the unit discharge. The skimmer weir had no effect on the hydraulic performance of the structure and was only partially effective in retaining floating debris. It effectively intercepted high floating material such as wood and woody aqueous plants, but materials that had densities near that of water (algae, waterlogged materials, etc.) were drawn under the skimmer weir. A weir that extended to a deeper level below the overflow weir crest might be more effective in retaining this type of debris, but it is unlikely that any such structure would be 100 percent effective.

After each of the above hydraulic tests, tests were run to determine how effectively the various structures (operating under the various conditions) would self-clean. In these tests soaked dry leaves, soaked paper, and soaked sawdust along with wood, algae, and other aquatic plants were allowed to flow onto the screen. The various materials were chosen to represent the many types of debris that could possibly clog the screen. The high floating materials (wood and woody plants) were found to pose no problem at all for they would always be washed free by the flow. Those materials with densities near that of water were found to be the most likely to clog. In general, the findings indicated that the screen most effectively self-cleaned when the direction of the flow was near parallel to the screen surface. The worst clogging seemed to be in areas where the jet impinged on the screen surface.

The reason for this is quite straightforward. No debris was ever observed actually entangled in the screen's fabric. All the clogging that was noted consisted of debris being held to the screen's surface by the weight and force of the water. In the areas where the flow impinges on the screen surface, both the weight of the water and the stagnation pressure resulting from the impingement hold the debris to the screen. In the areas where the flow is passing nearly parallel to the screen the flow can get under any debris that might come in

FIGURE 11 IMPACT CLOGGING

contact with the screen and push it clear. The result is that the screens observed tended to clog in the immediate area where the jet first impinges. The rest of the screen's surface remained quite clear (figure 11).

Upward sloping screens clog worse than downward sloping screens. In a few instances, 10° and 15° upward sloping screens were found to completely clog over their entire length. It was concluded that this was because the flow on the upward sloping screen passed more directly through the screen. It, therefore, did not flow as fast or as far down the screen surface as did the flow on the downward sloping screen. The flow on the downward sloping screen generally had a higher velocity and was more parallel to the screen surface. Thus, the upward sloping screens had much shorter required flow lengths, but they also clogged much faster than the downward sloping screens.

The next step in the study was the selection of a final screen configuration and unit discharge. The designers chose the screen size and configuration shown in figure 2 as being the most desirable. This screen structure is capable of passing a unit discharge of 6 ft^3/s (0.17 cms). This unit discharge results in a required weir crest length of 325 feet (99.1 m). The 6.5-foot (1.98-m) screen length was considered small enough to allow simplified support. The 5° downward slope was found in the model study to create good self-cleaning flow conditions on the screen surface. In all aspects, the structure was considered operationally satisfactory. Likewise, the overall prototype structure's size and cost were considered minimized.

The screen being considered for the prototype would be made from a high-copper content material. Copper is an algaecide and, therefore, should prevent algae growth on the screen. Screen made of high-copper alloy was not, however, immediately available, and so the stainless steel and brass were used in the model.

With the completion of these tests the screen was again set at the 5° downward slope, and a large amount of algae was allowed to wash onto it. Figure 3 shows the resulting clogging. As can be seen, some algae clogged the screen at its upper end where the flow first impinges, but most of the algae was washed to the point where the last of the flow dropped through. The self-cleaning properties of this final screen were, therefore, considered satisfactory. It was hoped that actual fish eggs of the size expected could be used to test the screen. There was no doubt that the screen would satisfactorily filter out the eggs (the smallest eggs expected are larger than 1 mm in diameter while the openings in the screen are approximately 0.48 mm square), but the test would show in general how the screen would handle the eggs. However, no eggs could be obtained at the times when the tests could be done. Thus, testing of the final screen configuration was completed and the screen as shown in figure 2 was considered to be satisfactory.

With the testing complete, the structure was designed in the design offices of the Bureau of Reclamation's Engineering and Research Center. The final design included a trashrack structure, upstream from the screen, that would remove all large debris from the flow. The screens were covered so that they were protected from vandalism and weather. With the addition of small amounts of heat, the screen can be made to operate satisfactorily in the winter. The skimmer weir was not included in the final design.

Construction was initiated on the structure in the spring of 1974. Completion is expected in the near future.