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HYDRAULIC MODEL STUDY OF A FISH SCREEN STRUCTURE FOR THE McCLUSKY CANAL

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16. ABSTRACT

The development of a new concept in fish control structures is presented. The structure was designed to prevent fish, fish eggs, and fish larvae from passing through the McClusky Canal in North Dakota. Maximum discharge for the canal is 1,950 ft^3/s ($55.2\ m^3/s$). The report describes the initial problem encountered which created a need for the structure, the analysis that resulted in the structural concept used, and the hydraulic model study that resulted in refinement of the structural design.

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HYDRAULIC MODEL STUDY OF A FISH SCREEN STRUCTURE FOR THE McCLUSKY CANAL

by

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December 1975

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

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

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PURPOSE

These studies were made to refine the design of a fish control structure for the McClusky Canal, Garrison Diversion Unit, North Dakota. The structure was a new concept and, therefore, no design guidelines existed.

RESULTS

1. The structure as developed functioned satisfactorily in the model. The screen should remove all fish, fish eggs, and fish larvae from the flow. Likewise, the model data indicates that the screen surface should be self-cleaning.

2. The flatter the downward slope of the screen, the shorter the flow length of the screen required to pass a given discharge. Thus, a horizontal screen would result in a smaller structure than would be required for a downward sloping screen.

3. The steeper the downward slope of the screen, the more efficient the screen self-cleans. The tendency for debris to cling to the screen depends on the angle at which the flow impinges on the screen. If the flow direction is nearly tangent to the screen's surface, then the debris is swept clear of the surface and no clogging occurs. But if the flow impinges sharply, then the debris will accumulate in the impingement area. This accumulation resulted from the impact head of the flow, forcing and holding the debris against the screen surface. The debris did not actually tangle with the screen fiber; therefore, it could easily be dislodged and washed clear.

4. Screen mesh and wire size affect the length of screen required to pass a given discharge. Finer mesh screens tend to require more screen length as do screens made from larger diameter wire.

5. If the region under the screen is inadequately vented, reduced pressures will develop. Reduced pressures under the screen tend to suck water through the screen, which reduces the required screen length and increases clogging. The reduced pressures also place additional loading on the screen structure.

6. The quantity of debris that will be encountered in the prototype is unknown. Therefore, it is conceivable that the screens might be overwhelmed by debris, and clogging could become a problem. The screen arrangement allows the installation of several possible devices which would improve self-cleaning. For the present, none of these devices is to be incorporated in the prototype structure. If a clogging problem is found to exist when the prototype structure goes into operation, then the devices could be installed without major modifications.

7. The optimum screen configuration developed from this study has a screen length in the direction of flow of 6.5 feet (2.0 m) and a slope of 5° downward from horizontal. This structure was developed to pass a maximum unit discharge of 6 ft^3/s (0.2 m^3/s).

APPLICATION

The results of these studies may be used as generalized design guidelines. The study yields the configuration of typical screen sections. Thus, the analysis is independent of the size and shape of the overall structure. The particular structure for which this study was undertaken has a V-shaped overflow wier with a crest length of approximately 325 feet (99.0 m). The structure will pass a maximum discharge of 1,950 ft^3/s (55.2 m^3/s). Structures with smaller maximum discharges would be built proportionately smaller. However, the typical screen sections would remain the same and only the weir crest length would be reduced. In addition, the analysis is applicable to structures with many different weir shapes. The only limitations are that both the typical section and the approach flow conditions to the section be similar to those in the model. Any transverse component of velocity (parallel to the weir) in the approach flow should be small compared to the flow velocity down the screen surface.

INTRODUCTION

The Garrison Diversion Unit of the Missouri River Basin Project consists of an extensive, multibasin, irrigation system (fig. 1). About 250,000 acres (100,000 hectares) in east-central North Dakota will be served by the system. The water will be withdrawn from the Missouri River and delivered to the farmland through a series of pumping plants, reservoirs, and canals. The land to be served lies 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. The Souris River and the Red River of the North both flow into Canada. In addition, several isolated closed-basin areas (that generally contain shallow lakes and marshlands which have great importance as habitat and breeding areas for water fowl) will receive water.

The Missouri River contains species of fish that are considered undesirable. It appears, however, that the

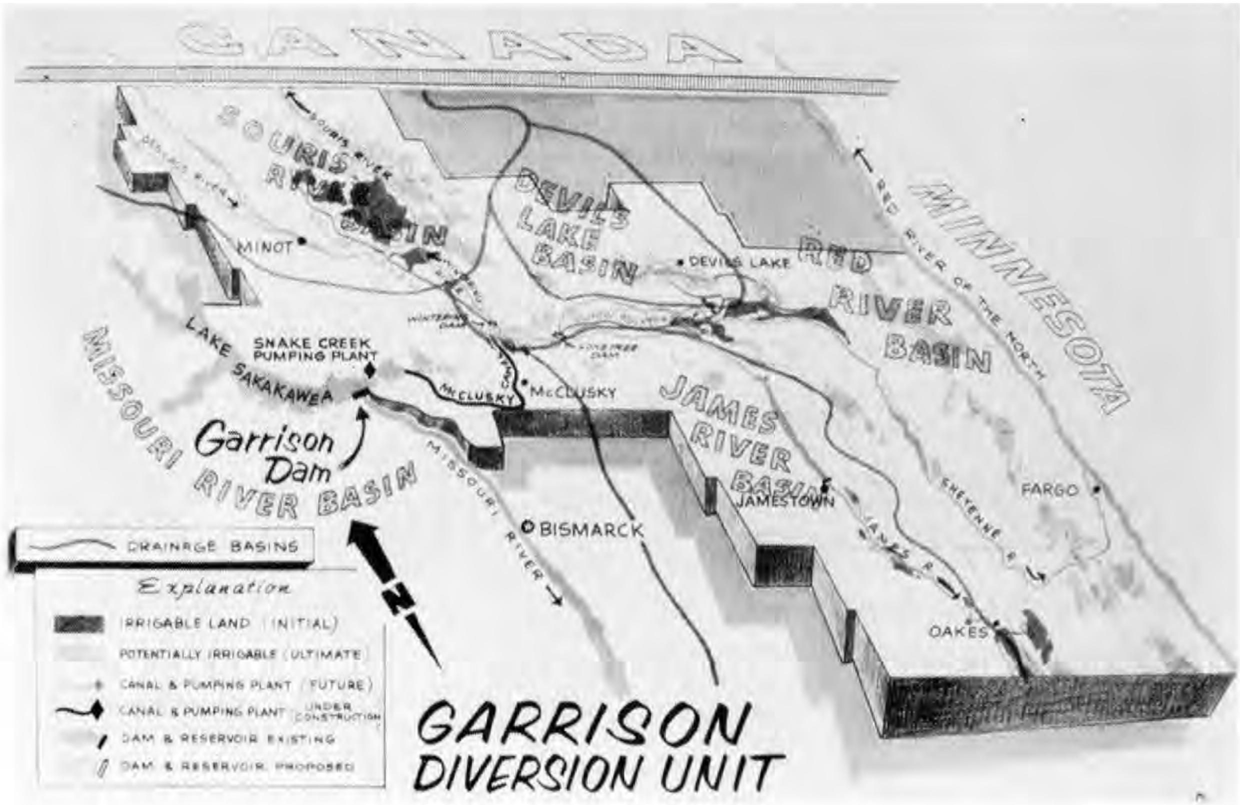

Figure 1. Map of Garrison Diversion Unit. Photo P769-D-46127

Souris and Red River of the North may not contain all of these species. It is also known that some of the tributaries of these rivers and many of the closed basins contain none of the undesirable species. Of importance is that the presence of these undesirable fish can eliminate the effectiveness of waters as breeding areas for waterfowl as well as having a negative impact on the water as a sports fishery.

A study team was organized at the E&R (Engineering and Research) Center of the Bureau of Reclamation to evaluate and develop methods for eliminating the possibility of transporting these fish. The team reviewed the literature and evaluated modern methods of fish, fish egg, and fish larvae control. In addition, the team contributed its own ideas for more effective control. A contract was awarded to the University of North Dakota to survey the fish populations in those bodies of water that may be affected. The survey would determine which waters presently contain the undesirable fish and define the extent of the problem in each. However, the survey would not be completed before canal construction was to be initiated in the locations that were most suitable for fish control structures. Therefore, designs proceeded on the assumption that no fish, fish eggs, or fish larvae migration could be tolerated.

The E&R Center team began by attempting to comprehend the biological aspects and constraints of the problem, which would give the team insight into the problem and, consequently, give significant direction to the study. A brief review indicated that the species of fish which might be of concern include carp, goldeye, burbot, green sunfish, shortnose gar, quillback, bullalo fish, saucer, and freshwater drum. The findings indicated that the minimum egg diameter was larger than 1 mm, that the larvae will be approximately the same size as their eggs, that eggs or larvae will be present in the system throughout 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 larger than 1 mm in diameter must be removed.

3. The control structure 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 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. The water will be withdrawn from the Missouri River at Lake Sakakawea and lifted by the Snake Creek Pumping Plant to Lake Audubon (fig. 1). The water then flows through most of the remainder of the system by gravity. From Lake Audubon, the water flows approximately 80 miles down the McClusky Canal to Lonetree Reservoir. Only a few small deliveries are planned from the McClusky Canal. In the initial phase, the water will flow from Lonetree Reservoir (which will store and regulate the flow) 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 approximately equal to that of the McClusky Canal. Therefore, it seemed 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 would probably cost nearly twice that of the single 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 also might allow fish to 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 controls. Operational techniques were considered initially. It was thought that the canal might be dewatered when eggs or larvae were present, thus eliminating the eggs and larvae 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 considered briefly. Poisons could control the fish, but the canal system passes through several lakes used for both recreational and wildlife purposes. Portions of the delivery system will serve as habitat and breeding areas for waterfowl. These uses not only have environmental significance, but are also economically important to the region and poisons could have detrimental effects on these functions. It was concluded therefore, that a physical method of fish control was most desirable. In this vein, several control methods were given limited consideration during the initial portion of the review. Violent hydraulic action such as turbulence in a hydraulic jump or cavitation is not 100 percent lethal to mature fish for the heads considered. No data were found on the effects of violent hydraulic action on eggs and larvae. The indications were that violent hydraulic action does not offer a solution. When electrocution was considered, it was found that voltages that would effectively control all sizes of fish, eggs, and larvae would pose danger to people. Sound wave control was also briefly considered, but was also found impracticable.

The attention of the team 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 initially did not appear to hold any promise because of the large amounts of trash (aquatic plants and algae) expected in the system. Fixed screens are generally susceptible to clogging which would pose a very serious handicap to the operation of the screen structure. More detailed consideration revealed two types of screen structures that appeared 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 and a sand filter could be expected to be 100 percent effective. Cursory designs revealed that a sand filter capable of handling the full canal discharge [1,950 ft^3/s (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 (fig. 2). With a sloping screen filter, the flow passes over a weir and through a fixed slightly downward-sloping screen. The screen mesh is sufficiently fine 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 indicated that this type of structure is nearly self cleaning. The screen weave is so fine (24 to 80 mesh) that the screen has a slick, fabric-like texture. Openings in the screen are generally small enough that debris will

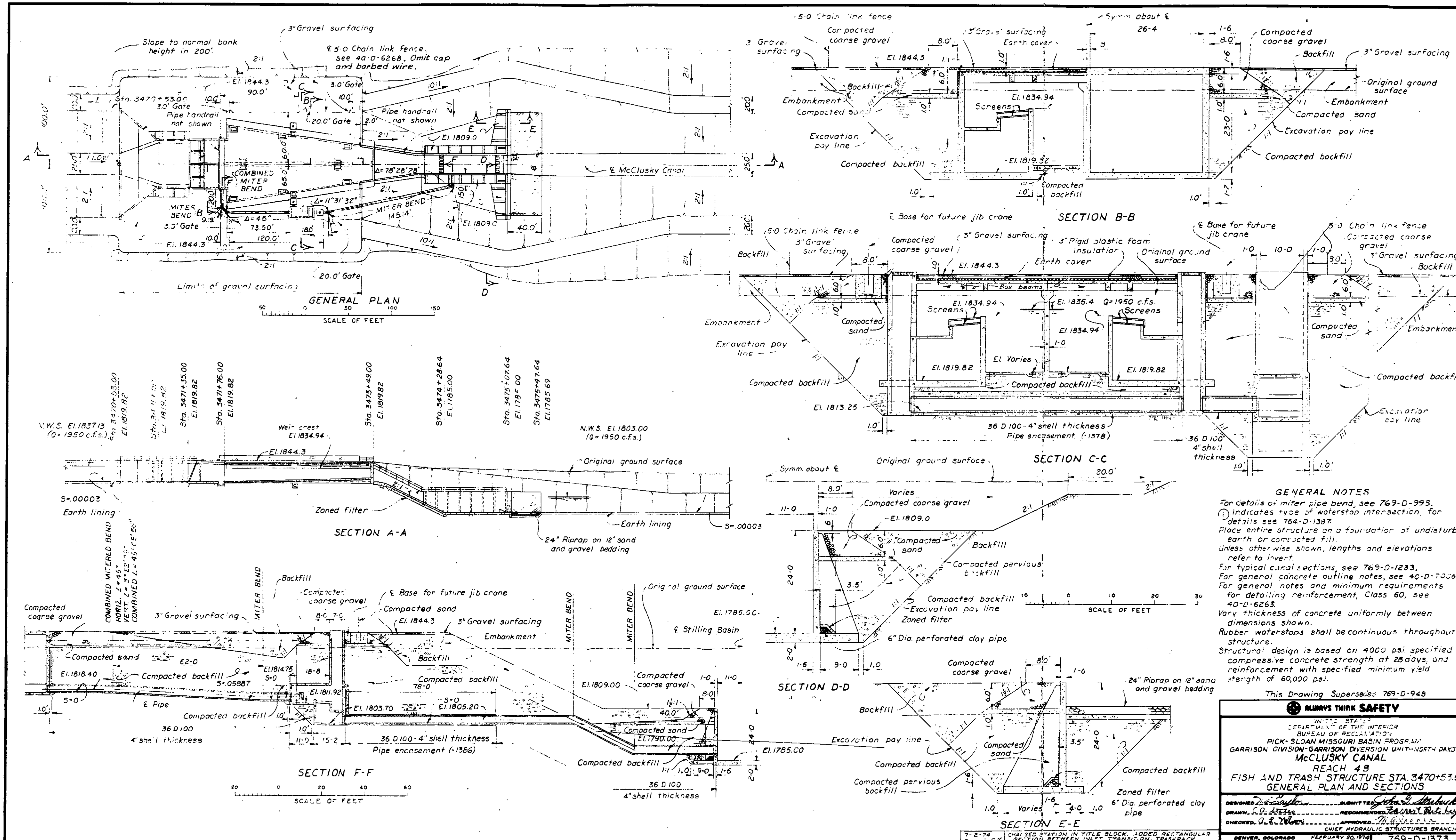

Figure 2. Final prototype structure.

not cling to the individual wires. Therefore, the debris passing onto the screen is washed down the screen surface to the point where the last of the flow drops through the screen. As the debris accumulates, the leading edge of the debris stays at the flow limit; thus the debris is pushed down the screen.

Previous installations of this type screen have been used for relatively small discharges [less than 100 ft^3/s (2.8 m^3/s)] with the objective of either filtering weed seed from irrigation water or collecting biological samples from small streams. Structures using the same principal but with coarser screens have also been used for collecting or concentrating fish.

The final canal structure (fig. 2) is a new concept because of its size and because of the fine mesh and structural configuration. It is felt that a structure of this type can be designed to function satisfactorily and meet the filtration requirements at a reasonable cost. With these factors in mind, the sloping fixed screen structure was selected and studies were initiated to develop and refine the design.

THE MODEL

To aid in developing the design, a sectional hydraulic model of the screen was constructed (fig. 3). The model was a full-scale representation of a 20-inch (51-cm) wide section of the proposed prototype structure (fig. 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. The screens were mounted on frames which fit into a support box. The screens could thus be changed easily, and the effects of screen mesh and wire size quickly evaluated. The screens placed in the model were approximately 10 feet (3.1 m) long, which is longer than any screens 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 extra long so that a wide range of flow conditions could be tested. For the different test conditions observed, the location on the model screen where the last of the flow dropped through was used to establish the screen length required. The model was constructed with the screen structure hinged to the weir wall, making 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 flow was filtered through an 80-mesh screen after it passed through the model to evaluate the filtration efficiency of the screen structure. All discharges through the model were established through the use of venturi meters.

THE INVESTIGATION

The three main objectives of the model study were to:

1. Evaluate the ability of the screen to self-clean.

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

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

Six basic factors considered to achieve these objectives 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.

Many of these factors are interrelated, which required observing several hundred specific operating conditions to obtain a complete understanding.

As an example, 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 required length of the screen increases. Conversely, 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, the greater the resistance to the flow, and a longer screen would be required. But a finer mesh might give the screen a slicker finish and, therefore, improve self-cleaning capabilities. A drop from the overflow weir crest to the screen surface might also be incorporated into the design. This would give the flow an additional velocity as it impacts on the screen, which would increase the flow rate through the screen in the impact zone and thus reduce the required screen length. Conversely, the higher velocity would result in a larger impact head on the screen, which

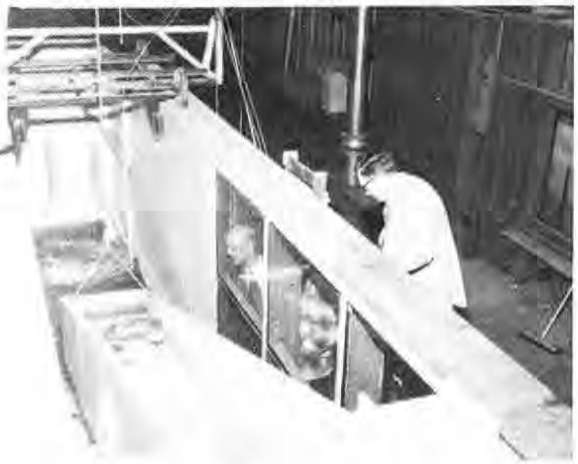

Photo P769-D-76122

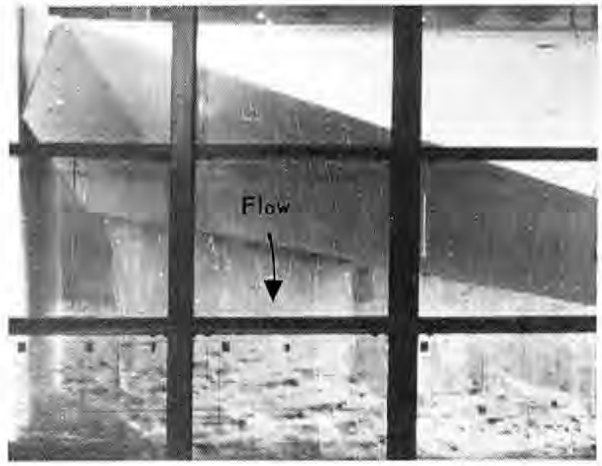

Photo P769-D-76120

Figure 3. Hydraulic model operating.

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 was made to determine the optimum balance among these factors to best satisfy all three objectives. The structure had to be designed to meet filtration and self-cleaning requirements, yet be of minimum structural and screen size, and thus be built at minimum cost.

To achieve these objectives, 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 slope setting the length of the screen required to pass the flow was noted. This information yielded the various structure sizes and slopes required to filter the canal discharge. Data obtained 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. Both observations can be readily explained. First, for a given discharge, as the downward slope of the screen increases, the acceleration of the flow along the screen surface caused by gravity also increases. Additional velocity causes the flow to carry farther down the screen and increases the length of screen required. When the screen is horizontal or sloping upward, the flow moving along the screen surface decelerates. In addition, for upward sloping screens a component of the flow velocity is normal to the screen surface. Both the normal velocity component (which indicates flow impact on the screen surface) and the flow deceleration would reduce the required screen length. It can also be noted that if the screen slope is held constant and the discharge is allowed to increase, a longer screen surface is required to pass a larger flow. One other point might be noted when observing these two initial sets of data: The performance of the two types of screen is quite different. In most cases the 40-mesh screen requires less length than the 80-mesh screen to pass a given discharge. Also, the length of screen required at a given screen slope appears more variable with respect to unit discharge for the 40-mesh screen.

At this point, consideration was given to having the flow drop from the crest of the weir to the screen surface. This arrangement was considered desirable for two reasons. First, this drop would increase the velocity of the flow as it impinged on the screen surface. The drop would also result in a more direct impact on the screen. The combination of a more direct impact and a higher impact velocity would result in a significant increase in impact head. It was thought that this head, when combined with the weight of the water, would increase the flow rate through the screen.

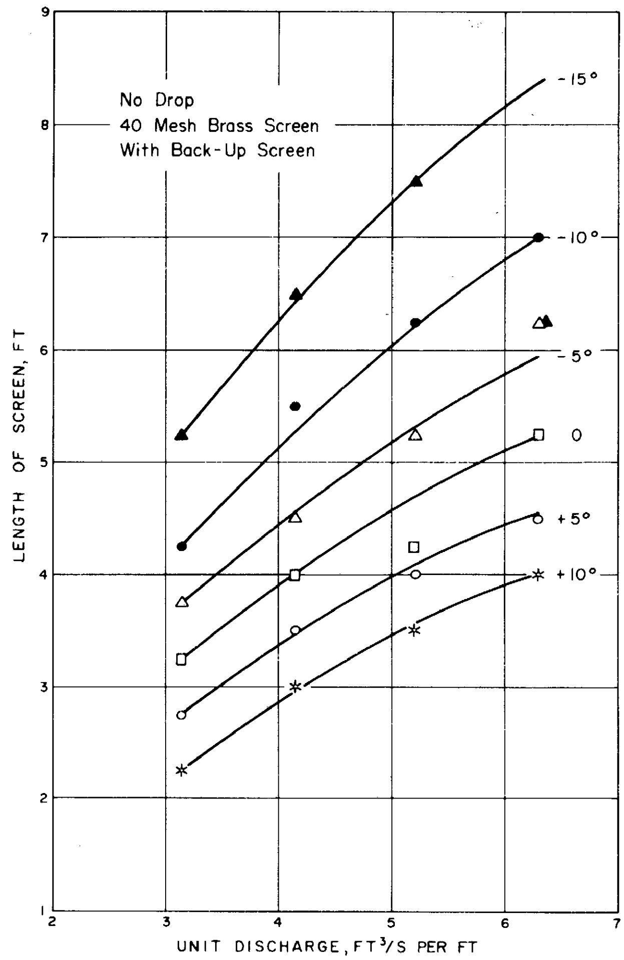

Figure 4. Design curves.

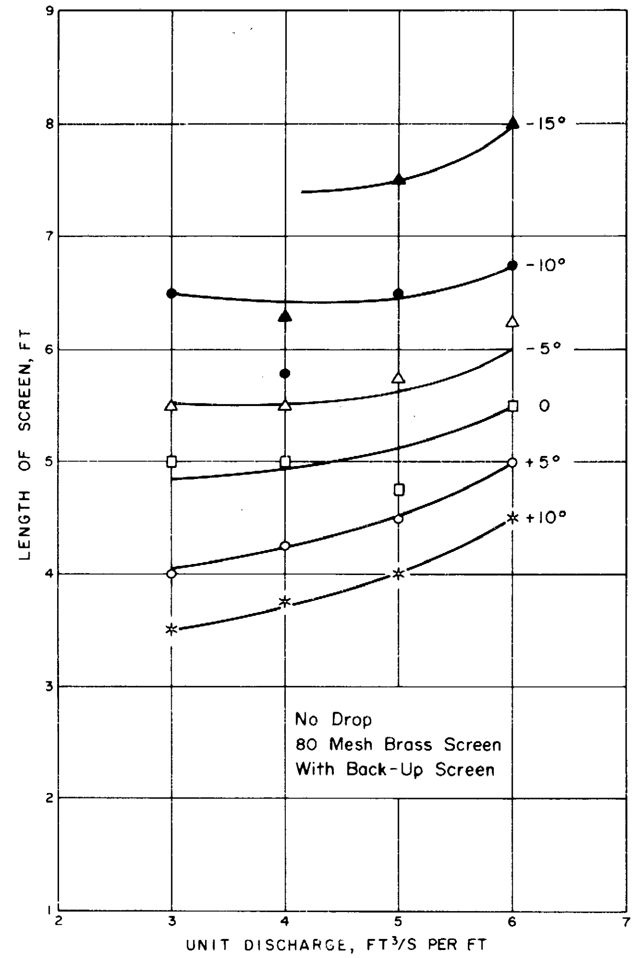

Figure 5. Design curves.

The greater flow rate would reduce the screen length required. The drop was also considered desirable because it would impart a trajectory on the flow so the flow would not come into contact with the upper edge of the screen (where the screen ties into the weir wall). This would allow greater simplification of the seal design at the upper edge. The drop would also result in additional forces on the screen structure, which could either require a stronger and more expensive structure, or shorten the life of the screen and, therefore, increase operation and maintenance costs. 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 incorporated in the model (fig. 6). A test similar to those previously described was made, the results of which [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 4, it can be observed that the 6-inch (15.2-cm) drop in all cases caused the required screen length to be longer. Observations of the model operating indicated that the flow would strike the screen and a portion of the flow would then be deflected down the screen surface. This had been observed for all previous 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 may be that the higher impact pressure resulting from the drop caused a larger portion of the flow to pass through the impact zone of the screen, but the deflected flow definitely carried farther down the screen surface. It was concluded that the drop did not improve performance of the structure. 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, the results of which are shown in figure 8. By comparing figure 8 [the 40-mesh

Figure 6. Drop from weir crest to screen. Photo P769-D-76123

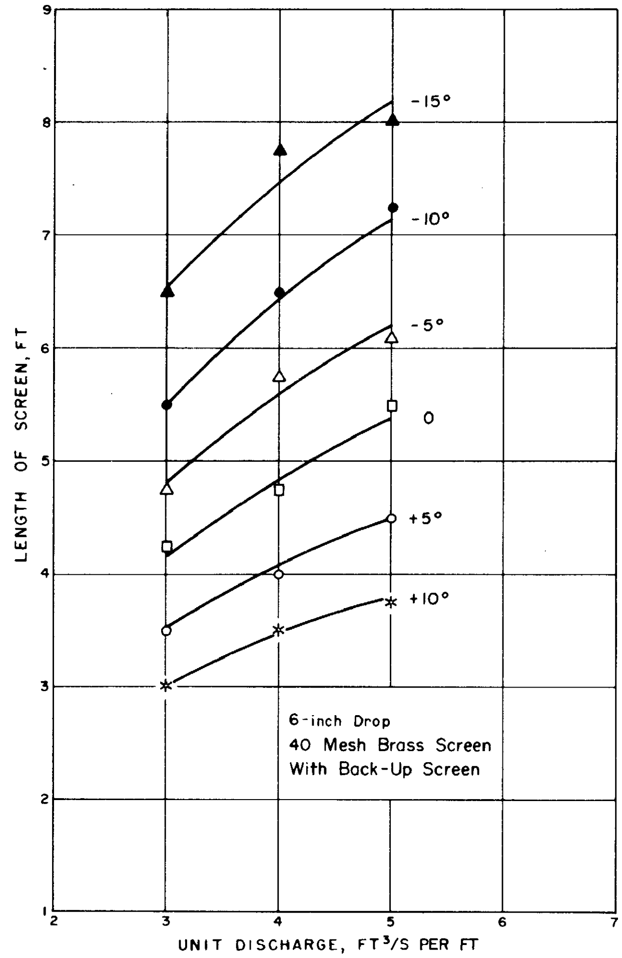

Figure 7. Design curves.

brass screen with 0.010-inch (0.25-mm) wire] with figure 4, it can be observed that the 3-inch (7.6-cm) drop required the screen length to be longer, although the additional length was small. The 3-inch (7.6-cm) drop was, therefore, considered satisfactory.

To evaluate the effect of the wire size, 40-mesh screens with 0.006-inch (0.15-mm) diameter wire were placed in the model with a 3-inch (7.6-cm) drop from the weir crest to the screen surface. The resulting design curves are shown in figure 9. By comparing figure 9 with figure 8, it can be seen that the smaller wire size reduced the required screen length by at least 20 percent for all cases and in some cases the reduction was as high as 30 percent. The change in wire size resulted in approximately a 60 percent increase in the opening area of the screen.

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 adequately vented. The turbulent flow passing between the two screens would entrain large quantities of air. If the region was not properly vented, a negative pressure could develop which would put an additional structural load on the screens as well as increase the flow rate through the screens and, therefore, reduce the observed required screen lengths and increase clogging. In the model the two screens (top screen and backup screen) were mounted in a box with solid walls. The box wall facing the weir wall was set at a 45° angle with respect to the screen surfaces to allow changing the slope of the screen (fig. 3). This wall restricted the airflow to the underside of the jet; thus, any venting of the flow between the two screens was by air passing through the screens themselves. However, large portions of these screen surfaces were often sealed by water passing over them. The model arrangement probably allowed less venting than would exist in the prototype. To evaluate the significance of the venting and to determine the upper limit on the required screen length (the 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 provided a vented condition equal to or better than that of the prototype. Observations

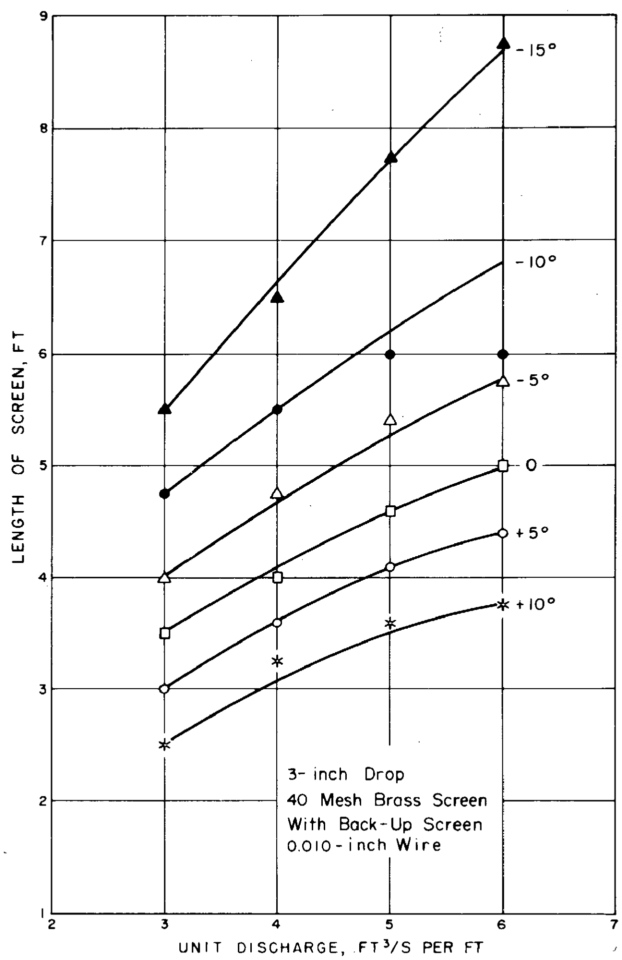

Figure 8. Design curves.

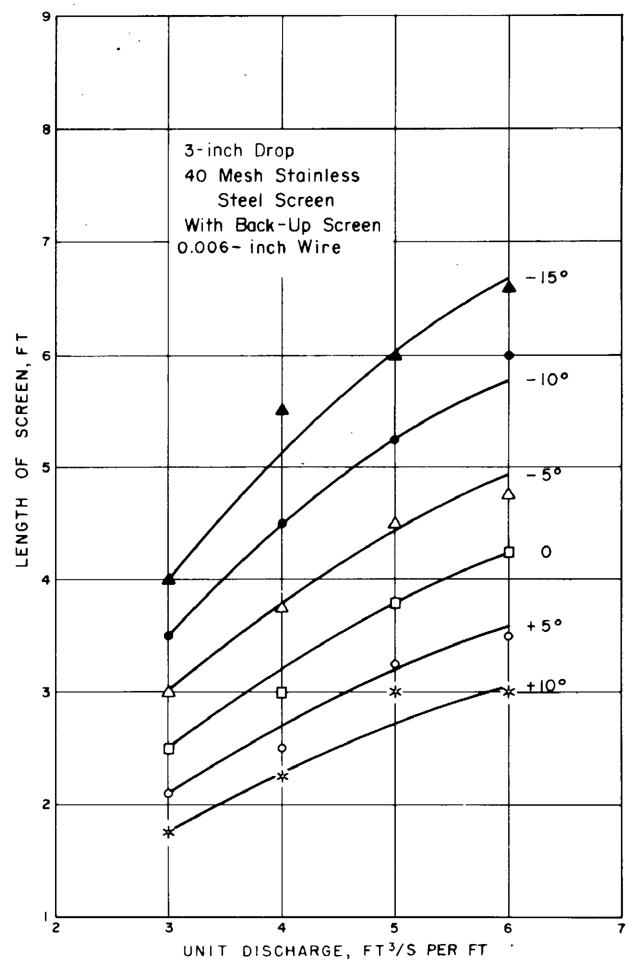

Figure 9. Design curves.

indicated that these conditions resulted in full venting of the flow. Hydraulic tests were run, the results of which are shown in figure 10. By comparing these results with those in figure 8 (same top screen and flow conditions but without the additional venting), it can be seen that the well-vented condition requires significantly more screen length. The actual prototype screen length required is probably somewhere between the length shown in figure 8 and the length shown in figure 10. The screen length in figure 10 may be slightly longer than is actually required, but it is best to allow enough screen surface to pass the maximum flow. Attempts to evaluate the negative pressure between the screens in the unvented model were inconclusive, but did indicate that the negative pressure was small.

One other observation should be noted. Under many of the test conditions observed, the flow on or through the screen made a whistling noise. The noise varied in pitch and intensity with changes in the screen slope and unit discharge and occurred in both the vented and unvented models. The cause of the whistle was never completely determined even though a considerable amount of time was spent in trying to resolve it. Because of the high frequency of the whistle, it seemed unlikely that physical vibration of the screen was the cause. The sound was more like air being drawn into a negative pressure region to aerate a flow, but, as previously stated, even the highly vented model whistled. The whistle may have resulted from aeration of the flow passing through the individual orifices or openings in the screen. The prototype structure may also whistle, but the whistling, although distracting, does not represent a force that could damage the structure or hinder its operation.

A final hydraulic factor studied was the effect that a skimmer weir, placed upstream from the overflow weir, would have 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

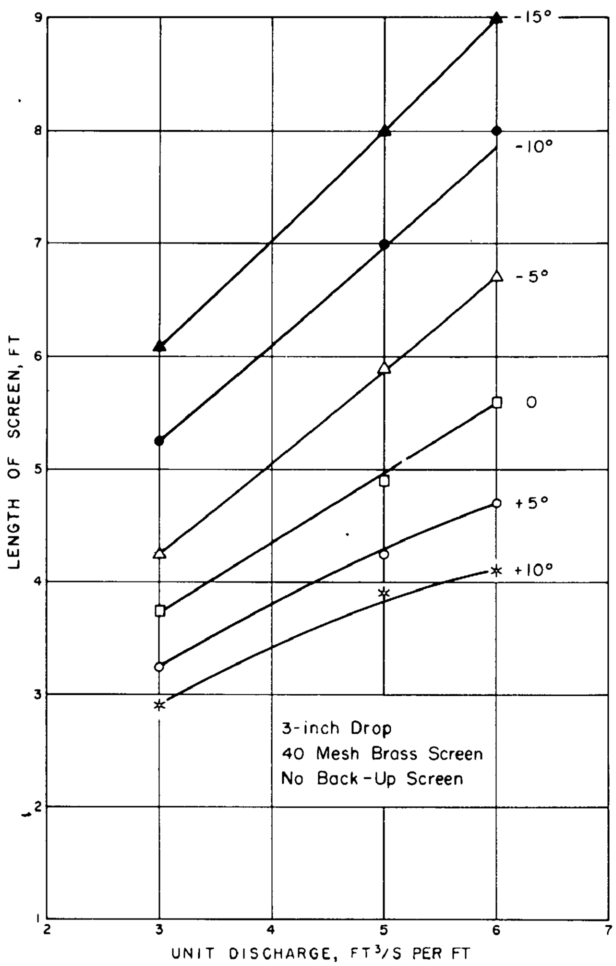

Figure 10. Design curves.

m) upstream from the weir wall. It was thought that the skimmer weir would intercept large quantities of floating debris and guide it to a point where it could be removed mechanically which would reduce the need for self-cleaning. With the skimmer weir in place, tests were again run to relate the screen slope, screen length, and unit discharge. The skimmer weir had no effect on the hydraulic characteristics of the structure and was only partially effective in retaining debris. It effectively intercepted high floating material such as wood and woody aquatic plants (fig. 11). However, materials having densities near that of water (algae, water-logged 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. Therefore, the skimmer weir was not included in the final design.

Following each hydraulic test, studies were made to determine how effectively the different structures

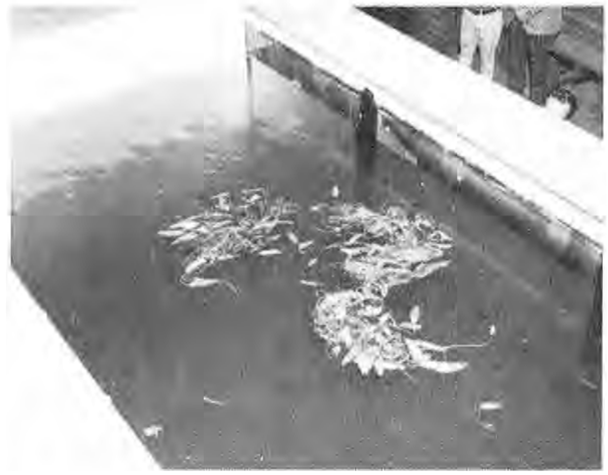

Figure 11. Skimmer weir in operation. Photo P769-D-76121

(operating under various conditions) would self-clean. In these studies, soaked dry leaves, soaked paper, and soaked sawdust, along with wood, algae, and other aquatic plants, were allowed to flow onto the screen. These materials represented the many types of debris that might possibly clog the screen. The high-floating materials (wood and woody plants) posed no problem because they were always washed clear by the flow. Materials with densities near that of water were most likely to clog. In general, the findings indicated that the screen most effectively self-cleaned when the direction of the flow was nearly parallel to the screen surface. The worst clogging occurred in areas where the jet impinged on the screen surface. The reason for this is quite clear. No debris was ever observed entangled in the screen's fabric. All the clogging that was noted consisted of debris held to the screen 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 impact head resulting from the impingment hold the debris to the screen (fig. 12). In the areas where the flow is passing nearly parallel to the screen, the flow can get under any debris that might come in contact with the screen and push it clear. The result was that the screens tended to clog in the immediate area where the jet first impinged. The remainder of the screen surface remained quite clear (fig. 12).

Upward sloping screens clog more than downward sloping screens. In a few instances, 5° and 10° upward sloping screens were completely clogged. The conclusion was that this occurred because the flow on the upward sloping screen passed more directly through the screen. It did not flow as fast or as far down the screen surface as did the flow on the

Photo P769-D-76124

Photo P769-D-76125

Photo P769-D-76126

Figure 12. Final screen with algae.

downward sloping screen and, thus, the flow was more inclined to hold debris on the screen surface and not wash it clear. The flows on the downward sloping screens generally had higher velocities and were more nearly parallel to the screen surface. Thus, the upward sloping screens required much shorter 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 structure 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 m^3/s). A unit discharge of 6 ft^3/s results in a required weir crest length of 325 feet (99.1 m). The screen length (in the direction of flow) of 6.5 feet (1.98 m) was considered small enough to allow simplified support. In the model study, the 5° downward slope created good self-cleaning flow conditions on the screen surface. In all aspects, the structure was considered operationally satisfactory. Likewise, the overall size and cost of the prototype structure were considered minimal.

To verify this final design, another series of hydraulic tests was run with the backup screen removed. During these tests, full venting of the flow occurred. The resulting observed screen lengths should be conservative. A 40-mesh, stainless steel screen with 0.006-inch (0.15-m) diameter wire was used. This corresponds closely to the wire size and mesh of the screen being considered for the prototype. The screen being considered for the prototype would, however, be constructed of a material having a high copper content. Copper, being an algaecide, should prevent algae growth on the screen. Screen made of high copper alloy was not immediately available, so the stainless steel was used in the model. The results of the test are shown in figure 13. The screen operating at a 5° downward slope and at a unit discharge of 6 ft^3/s (0.17 m^3/s) required a screen length of 5.2 feet (1.6 m).

With the completion of the hydraulic tests, a large amount of algae was allowed to wash onto the screen. Figure 12 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

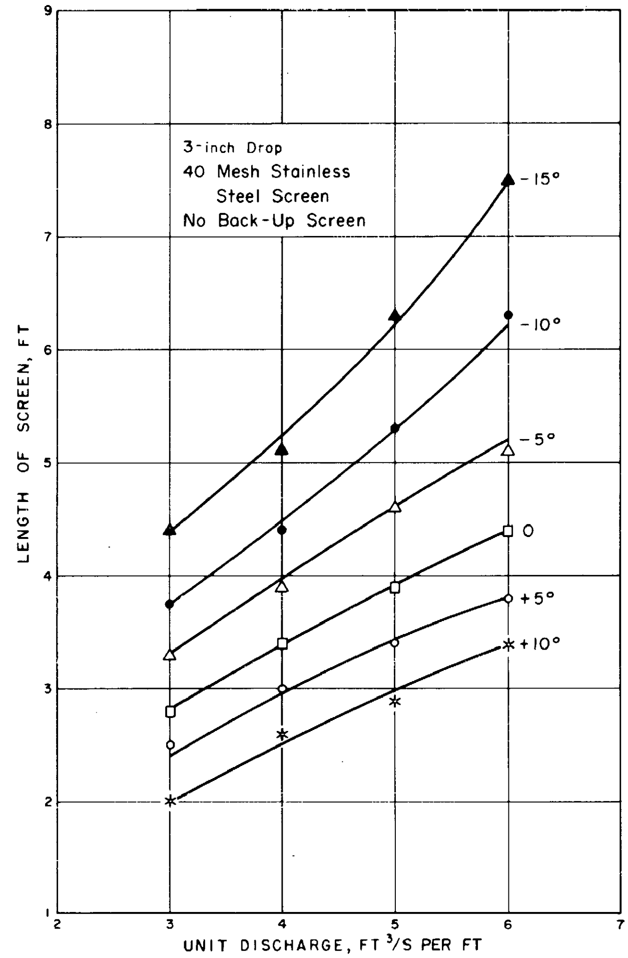

Figure 13. Design curves.

through. The self-cleaning properties of this final screen were, therefore, considered satisfactory. It was hoped that real 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 them. However, no eggs could be obtained when the tests were scheduled. Thus, testing of the final screen configuration was considered complete and the screen as shown in figure 12 was determined to be satisfactory.

7-1750 (12-74)
Bureau of Reclamation

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 380-72) 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, it 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 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron (μ)
Inches (in)	25.4 (exactly)	Millimeters (mm)
Inches	2.54 (exactly)*	Centimeters (cm)
Feet (ft)	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters (m)
Feet	0.0003048 (exactly)*	Kilometers (km)
Yards (yd)	0.9144 (exactly)	Meters (m)
Miles (statute) (mi)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers (km)
	AREA	
Square inches (in^2)	6.4516 (exactly)	Square centimeters (cm^2)
Square feet (ft^2)	*929.03	Square centimeters
Square feet	0.092903	Square meters (m^2)
Square yards (yd^2)	0.836127	Square meters
Acres	*0.40469	Hectares (ha)
Acres	*4,046.9	Square meters (m^2)
Acres	*0.0040469	Square kilometers (km^2)
Square miles (mi^2)	2.58999	Square kilometers
	VOLUME	
Cubic inches (in^3)	16.3871	Cubic centimeters (cm^3)
Cubic feet (ft^3)	0.0283168	Cubic meters (m^3)
Cubic yards (yd^3)	0.764555	Cubic meters (m^3)
	CAPACITY	
Fluid ounces (U.S.) (oz)	29.5737	Cubic centimeters (cm^3)
Fluid ounces (U.S.)	29.5729	Milliliters (ml)
Liquid pints (U.S.) (pt)	0.473179	Cubic decimeters (dm^3)
Liquid pints (U.S.)	0.473166	Liters (l)
Quarts (U.S.) (qt)	*946.358	Cubic centimeters (cm^3)
Quarts (U.S.)	*0.946331	Liters (l)
Gallons (U.S.) (gal)	*3,785.43	Cubic centimeters (cm^3)
Gallons (U.S.)	3.78543	Cubic decimeters (dm^3)
Gallons (U.S.)	3.78533	Liters (l)
Gallons (U.S.)	*0.00378543	Cubic meters (m^3)
Gallons (U.K.)	4.54609	Cubic decimeters (dm^3)
Gallons (U.K.)	4.54596	Liters (l)
Cubic feet (ft^3)	28.3160	Liters
Cubic yards (yd^3)	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters (m^3)
Acre-feet	*1,233,500	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb) (gr)	64.79891 (exactly)	Milligrams (mg)
Troy ounces (480 grains)	31.1035	Grams (g)
Ounces (avdp) (oz)	28.3495	Grams
Pounds (avdp) (lb)	0.45359237 (exactly)	Kilograms (kg)
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 (kg)
FORCE/AREA		
Pounds per square inch (lb/in^2)	0.070307	Kilograms per square centimeter (kg/cm^2)
Pounds per square inch	6894.76	Pascals (Pa), or Newtons per square meter (N/m^2)
Pounds per square foot (lb/ft^2)	4.88243	Kilograms per square meter (kg/m^2)
Pounds per square foot	47.8803	Pascals (Pa), or Newtons per square meter (N/m^2)
MASS/VOLUME (DENSITY)		
Ounces per cubic inch (oz/in^3)	1.72999	Grams per cubic centimeter (g/cm^3)
Pounds per cubic foot (lb/ft^3)	16.0185	Kilograms per cubic meter (kg/m^3)
Pounds per cubic foot	0.0160185	Grams per cubic centimeter (g/cm^3)
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.) (oz/gal)	7.4893	Grams per liter (g/l)
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.) (lb/gal)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds (in-lb)	0.011521	Meter-kilograms (m-kg)
Inch-pounds	1.12985 x 10^6	Centimeter-dynes (cm-dyn)
Foot-pounds (ft-lb)	0.138255	Meter-kilograms (m-kg)
Foot-pounds	1.35582 x 10^7	Centimeter-dynes
Foot-pounds per inch (ft-lb/in)	5.4431	Centimeter-kilograms per centimeter (cm-kg/cm)
Ounce-inches (oz-in)	72.008	Gram-centimeters (g-cm)
VELOCITY		
Feet per second (ft/s)	30.48 (exactly)	Centimeters per second (cm/s)
Feet per second	0.3048 (exactly)*	Meters per second (m/s)
Feet per year (ft/yr)	*0.965873 x 10^{-6}	Centimeters per second
Miles per hour (mi/h)	1.609344 (exactly)	Kilometers per hour (km/hr)
Miles per hour	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2 (ft/s^2)	*0.3048	Meters per second^2 (m/s^2)
FLOW		
Cubic feet per second (second-feet) (ft^3/s)	*0.028317	Cubic meters per second (m^3/s)
Cubic feet per minute (ft^3/m)	0.4719	Liters per second (l/s)
Gallons (U.S.) per minute (gal/min)	0.06309	Liters per second
FORCE*		
Pounds (lb)	*0.453592	Kilograms (kg)
Pounds	*4.4482	Newtons (N)
Pounds	*4.4482 x 10^5	Dynes (dyn)

Table II—Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram calories (kg-cal)
British thermal units (Btu)	1,055.06	Joules (J)
Btu per pound	2.326 (exactly)	Joules per gram (J/g)
Foot-pounds (ft-lb)	*1.35582	Joules (J)
POWER		
Horsepower (hp)	745.700	Watts (w)
Btu per hour (Btu/hr)	0.293071	Watts
Foot-pounds per second (ft-lb/sec)	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, then subtract 17.78	Celsius or Kelvin degrees
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

GPO 832-463

ABSTRACT

The development of a new concept in fish control structures is presented. The structure was designed to prevent fish, fish eggs, and fish larvae from passing through the McClusky Canal in North Dakota. Maximum discharge for the canal is 1,950 ft^3/s (55.2 m^3/s). The report describes the initial problem encountered which created a need for the structure, the analysis that resulted in the structural concept used, and the hydraulic model study that resulted in refinement of the structural design.

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REC-ERC-75-6
Johnson, P L
HYDRAULIC MODEL STUDY OF A FISH SCREEN STRUCTURE FOR THE McCLUSKY CANAL
Bur Reclam Rep REC-ERC-75-6, Div Gen Res, Dec 1975, Bureau of Reclamation, Denver, 14 p, 13 fig

DESCRIPTORS—/ canal design/ *fish screen/ applied research/ *hydraulic models/ *design criteria/ fish barrier/ fish eggs/ hydraulic properties/ irrigation operation and maintenance
IDENTIFIERS—/ McClusky Canal, ND

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