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Passive Intake System for a Shallow Sand-Bed River

by

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ABSTRACT: The Jeffrey Energy Center draws its cooling water makeup from the Kansas River, a shallow sand-bed river of constantly changing bottom geometry. To accommodate this withdrawal, the water intake system was designed to be capable of maintaining intake capacity at all river stages. A set of river training devices keeps the deepest part of the river near the intake. Water is withdrawn from the river through three cylindrical wedge-wire intake screens, passed to a sedimentation basin, and then pumped to the plant site. A reinforced concrete trough installed along the face of the screen structure protects the intake screens from potentially damaging debris. The trough diverts debris from the intake screen and also reduces sedimentation in this region. Water jets periodically clean the trough. Before construction of the facility, the trough and water jets systems were modeled to confirm and refine this portion of the design. The intake is environmentally acceptable and requires little maintenance.

INTRODUCTION

The Kansas Power and Light Company's Jeffrey Energy Center (JEC) currently has three 670 MW units with room for future expansion. JEC uses a closed cycle cooling system which requires makeup water to replace evaporation and drift from the cooling towers. The Kansas River near Belvue, Kansas, is the primary source of makeup water for the condenser cooling system. The river, which flows approximately 8 km (5 miles) south of the plant, is a relatively shallow sand-bed river with a constantly changing bottom geometry. The river intake system, which has been successfully operating since October 1982, is designed to satisfy the following requirements.

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- An ultimate withdrawal capacity of 3.1 m^3/s (111 cfs).
- Freedom from damage due to floating debris.
- A sediment-free area around the screens.
- Water withdrawal during low flow periods.
- Environmental acceptability.
- Low maintenance.

The intake system is composed of a screen structure, a sedimentation basin, and a pump structure. The screen structure prevents debris and fish in the river water from entering the sedimentation basin. The sedimentation basin allows adequate retention time for much of the river sediment to settle and thus be retained in the basin before the water is pumped to the plant. In addition to these three components, river training structures provide a way to maintain water depth near the screen structure.

THE KANSAS RIVER

The Kansas River follows a meandering course for much of its 274 km (170 miles). The river bed is typically 150 to 215 m (500 to 700 ft) wide and is composed primarily of sand. Occasionally, a thin silt and clay blanket covers the sand after the river has receded. The river bed is characterized by a braided condition during the low water months of the year, with sand dunes of constantly changing location and shape. The sand dunes sometimes are as high as 1.8 m (6 ft) and can move the river channel location over 30.5 m (100 ft) in a few days during high water. The river also undergoes substantial bank erosion which contributes much of the sediment that is transported.

The intake system is located on the outer bank of a meander bend at Mile 118 of the river, as shown in Fig. 1. Fig. 2, 3, and 4 show a photographic history of the river at this location. Fig. 2 was taken on April 1972, Fig. 3 on March 1977, and Fig. 4 on February 1981. The figures show that the thalweg tends to stay along the outer bank, the outer bank is eroding, and the river dunes are unstable. The mean particle size of the bed material in the vicinity of the intake is about 0.15 mm. The sediment gradation is relatively nonuniform, with a geometric standard deviation (d85/d50) of about 2.0. The mean annual discharge at Mile 118 is approximately 76.5 m^3/s (2,700 cfs). Flows have ranged from 11,325 m^3/s (400,000 cfs) to 2.0 m^3/s (73 cfs). Several upstream reservoirs built since the extreme values were recorded have had a moderating effect on the river discharges. At the mean discharge, the water depth is about 3.3 m (11 ft) immediately in front of the screen structure. The depth of water during anticipated low flows is about 2.4 m (8 ft). The mean velocity of the river varies from 0.6 m/s (2 fps) to 0.7 m/s (2.25 fps).

Controlling the sediment transport at the site required solving two main problems. The first and most critical problem was to ensure that the portion of the river bed carrying water during low flows remained next to the screen structure. The second problem involved stabilizing the river banks immediately upstream of the structure. If the bank erosion had been allowed to continue, an intake at this site would have been subject to a much larger coarse-grained sediment load, and, eventually, if the bank receded enough, the intake could possibly have been left in the middle of the river channel.

Two river training structures mitigate these problems. A jetty of dumped riprap rock adequately sized to remain stable during floods is constructed across the meander to direct low flows toward the screen structure. It is aligned to promote mild local scour of the river bed in the vicinity of the intake, thereby ensuring adequate water depth in front of the screen structure. To ensure that the deepest part of the river remains immediately in front of the screen structure, the jetty is extended across a large sandy point bar to the more stable inner bank. The jetty slopes down from the high point at the inner bank (El. 947 at station 0+00) to El. 940 at station 5+00. The jetty maintains a constant elevation of 940 until the jetty makes its first change in direction at station 11+50. From this point the jetty slopes down to El. 937 at the point where it begins to parallel the intake (station 19+50). The jetty maintains the 937 elevation as it parallels the intake. The 947 elevation corresponds to the 10-year flood elevation. The 940 elevation is 1 foot below ordinary high water. The 937 elevation is 1 foot above design low water. A 10-foot wide notch in the jetty allows water to pass to the area behind the jetty to prevent water stagnation. Buoys help prevent the minimal river traffic from striking the submerged jetty. (Although the river is classified as navigable, it is not used for commercial purposes; river traffic is limited to pleasure boaters and sportsmen.) As the height of the jetty is set to allow flood flows to pass unimpeded, most of the jetty is submerged during normal flows.

The bank erosion problem was solved by constructing a revetment along a portion of the outer bank. Most bank sloughing occurs when the river recedes after a high water condition. The sand and silt, which make up most of the bank material, absorb water rapidly during high water. The saturated silty banks have very little cohesion and little capacity to resist shallow slope failures. When the resisting force of the high water level is removed, the heavy, saturated bank material usually slides into the river and is carried downstream. The revetment is constructed of dump riprap, set at a height to correspond to the level of the 10-year flood. The level of the top of the bank approximates the 100-year flood stage. Bank sloughing occurring less frequently than once every 10 years was determined to be acceptable. The revetment extends past the point where the main river channel impinges on the bank. This impingement point is subject to much change and will need to be reevaluated often during the life of the intake. The revetment has an additional benefit of directing the river flow toward the intake in a manner that minimizes local high levels of turbulence, sediment erosion, and sediment deposition.

SELECTION OF THE SCREENING SYSTEM

The water screening systems investigated for these river conditions were a traveling screen system and a passive system with wedge wire screens. Both systems use differential head created by pumped water to draw water from the river.

Conventional through-flow traveling screens have traditionally been used on the Kansas River. Though these screens have operated successfully in this environment, they have required a great deal of maintenance. The screen baskets, drive chains, and lower sprocket wear rapidly because of the abrasive river environment.

The passive screen system uses T-shaped screens, shown in Fig. 5, which features two cylindrical screen baskets attached to the cross of a T-shaped manifold. The screen baskets are made by welding a continuous stainless steel wire to an open framework of thin stainless steel members. The wire is wedge shaped in sections. The narrow point of the wedge is welded to the framework, leaving the broad side facing outward. Any debris passing the outer surface is not lodged between the screen wires because the distance between screen wires increases as the water flows into the screen.

The passive system's most attractive aspect is its potential for low maintenance. The screens have no moving parts to wear out, and replacement of screen parts is not anticipated during the life of the system. The screens are environmentally acceptable because the low water velocity between the screen wires minimizes the entrainment or impingement of small fish. The T-shaped manifold is attached to the screen baskets in such a way that the maximum through-slot velocity is less than 0.15 m/s (0.5 fps). Most fish, in any stage of development, should be able to escape from the screens, since the ambient Kansas River velocity is at least four times greater than the maximum intake velocity and tends to sweep fish from the screen. The sweeping action of the river flow generally keeps the screens free of debris. Debris that does accumulate can be removed by an air backwash system.

Because of the potentially low maintenance and favorable capital costs, the passive system consisting of fixed T-shaped screens was selected. However, a major design challenge was to ensure that the screens would not be buried by sediment transported as bed load in the river.

THE RIVER INTAKE SYSTEM

The river intake system is composed of three parts: a screen structure, a sedimentation basin, and a pump structure. The plan view and elevation view of these parts are shown in Figs. 6A and 6B.

The Screen Structure

The screen structure is composed of a row of three passive wedge-wire screens located along the face of the structure, as shown in Fig. 7. Each screen is 1.2 m (4 ft) in diameter, approximately 3.4 m (11 ft) long, and has a design flow capacity of 1.0 m^3/s (37 cfs). The screens can physically pass several times this amount but are limited to the 1.0 m^3/s (37 cfs) to restrict the through-slot velocity to 0.2 m/s (0.5 fps). The slot opening between the wedge wires is 1.0 cm (3/8 in.), which is typical for traveling screen baskets along the Kansas River. Guide rails and a hoist are provided to lift the screens for periodic inspection. The guide rail system is designed so that the screens will seat firmly against a wall thimble once they reach the proper elevation (Fig. 8). A sloping bracket mounted on the top of the screen mounting plate presses against a pin attached to the rail system to guide the mounting plate to the screen structure wall. The moment generated by the screen assembly around the pin keeps the bottom of the screen mounting plate against the wall. A valve at the discharge end of each screen allows the screens to operate independently. The valves also keep unscreened water from passing to the sedimentation basin when a screen is removed and, combined with a set of stop logs, allow a screen structure bay to be dewatered if necessary.

The screens are cleaned by an air backwash system. Debris is removed from the screens by a blast of air with a volume equaling three times the screen cavity volume. This volume of air is released into the cavity in 1.0 second. The shock of the large volume of air injected into the screen cavity loosens debris that might adhere to the screen. The air bubbles tend to adhere to the material, carrying it to the surface. The ambient river current carries the debris away from the screens. The river current is critical for the proper operation of this system, for without it, the debris would eventually sink and accumulate on the screen again. A river current greater than 0.15 m/s (0.5 fps) is adequate. The air compressor and accumulator that provide the 689 to 965 kPa (100 to 140 psi) air required for this operation are located in the pump structure. The air backwash system controls are operated manually. The large volume of air creates significant agitation on the water surface. The agitation is sufficient to cause a safety hazard for small watercraft. Therefore, the air backwash initiation switch is located on the front of the screen structure where the operator can check for river traffic.

The screens require 0.6 m (2 ft) of submergence and 0.6 m (2 ft) of clearance from the side walls or floor for proper operation. The clearance provides the necessary volume of water around the screens that allows the uniform through-slot velocity. Because of the relatively shallow water depth and the active sediment dune migrations, sediment could periodically encroach on the clearance necessary for proper screen operation. To prevent this, the screens are partially enclosed by a trough with side walls extending up to the midpoint of the screens. The trough is 2.4 m (8 ft) wide, approximately 12.2 m (40 ft) long, and 1.2 m (4 ft) high. The dimensions and shape of the trough were largely determined by the screen clearance requirements. The outboard side of the trough wall forms a local obstruction to the river flow, which develops a mild localized river bed scour around the trough and screen structure. This wall and a metal railing on top of it protect the screens from floating debris. The railing, made from 0.2 m (6 in.) steel pipe, extends 1.2 m (4 ft) above the trough wall. The trough also houses a system of strategically placed water jets for sluicing sediment that, over a period of time, deposits within the trough.

The proper operation of the water jets is critical because of the very heavy sediment load and potential for deposition in the screen trough. The water jets must be functional at any river level and must clean the trough of sediment that accumulates to mid-screen elevation. The sediment sluicing operation was based on the water jets ability to agitate the sediment deposited in the trough into a cloud. The river current will then transport the cloud downstream. The design assumed that the screen isolation valves are closed to eliminate ingesting sediment through the screens during the sluicing. The sluicing operation would use 0.3 m (1.0 ft) of water from the sediment basin.

An undistorted loose-bed model was constructed to determine the placement, method of operation, and effectiveness of the water jets for sluicing sediment from the trough. The linear scale of five prototype units to one model unit was used. The associated discharge and time scales for the model were obtained from the criterion of Froude number similarity. The bed sediment was selected to satisfy the criterion for similarity in suspended sediment transport; the ratio of the sediment fall velocity divided by sheer velocity of the river flow should be consistent. A nearly uniform sand with an average diameter of 0.30 mm was selected as the bed material for the model.

The location of the jets was determined empirically. The necessity of an upstream set of jets in the trough head wall was considered axiomatic. The model was operated with only the upstream jets to determine the extent they could clean the trough. The downstream jets could then be determined. By testing several configurations, the spacing of the jets was selected that ensured proper operation. The jets operated consecutively with a prototype discharge of 0.8 m^3/s (28 cfs). One pair of jets was placed in the upstream wall of the trough, and the other was placed in the side of the trough beneath the downstream screen, at a distance 0.7 times the trough length. In each case, the bottom of each jet was flush with the floor of the trough. Fig. 9 shows the sluicing of sediment when the trough is filled to its mid-depth (0.6 m or 2 ft, in the prototype). The upstream pair of jets was operated for four minutes (about 10 prototype minutes) and then stopped. The downstream jets were then operated for an additional four minutes. This consecutive operation of the jets removed almost all of the sediment from the trough. Further tests showed that operating the jets for only half as long still adequately cleaned the trough. Additional testing revealed that larger discharges available from operating multiple pumps did not increase the effectiveness.

If the trough were to become brimful with sediment (an extreme condition that should not be allowed to occur), consecutive application of both pairs of jets for a period of four minutes would successfully remove about 85 percent of the sediment from the trough.

The trough supports a deicing manifold. Ground water from an existing well field maintains an ice-free condition around the intake screens. Approximately 0.2 m^3/s (5.6 cfs) of ground water is available for this operation. With a water temperature of 12 C (54 F), approximately 6850 megacalories per hour of heat above ambient conditions would be injected into the river. This heat load is expected to keep the intake area ice free even during the most severe winters. The model was again used to determine the manifold design and volume of water needed to uniformly bathe the screens.

The screen structure stability limited the differential head across the structure to 1.5 m (5 ft). A large head differential across the structure would be possible if the screens were plugged or the isolation valves were closed and (1) the pumps kept emptying water from the sedimentation basin or the river stage was increasing because of a flood, or (2) the river stage dropped rapidly after a flood. To ensure that the differential head would be within the specified limits, two equalizing pipes were placed through the structure. One pipe has a flap gate on the river side that lets water from the sedimentation basin flow back to the river. This pipe operates with only a minimal differential head. The flap gate prevents unscreened water from entering the sedimentation basin. The second pipe has a weighted flap gate on the sedimentation side and is open on the river side. The weighted flap gate opens only when the differential head limitation is reached. The river intake system controls are designed to trip the pumps if a certain differential head is reached. Plant personnel are dispatched to determine the cause of the problem. The equalizing pipe is the final level of protection for the screen structure.

The Sedimentation Basin

The sedimentation basin provides a still water body in which much of the sediment carried through the screen structure can be deposited by natural settlement. The basin is sized so that all particles larger than 0.5 mm are deposited. The sedimentation basin is 60 m (200 ft) long and 15 m (50 ft) wide with sloping sides along its length. The decreased sediment concentration that passes through the pumps reduces pump wear. A floating hydraulic dredge cleans the basin, and the dredge spoil is deposited in a settling basin and removed when the water is decanted.

The Pump Structure

The pump structure houses three 0.8 m^3/s (28 cfs) pumps which supply water to the makeup lake at Jeffrey Energy Center. A piping and valve arrangement connects the pump discharge manifold with the sediment jets. The pump structure also houses the control cabinets for the river intake system. The system is designed for local control.

INTAKE OPERATION

During the past 4½ years, the procedures for intake operation have evolved to meet the site conditions and intake performance. The intake system is controlled on location. Several key system fault indicators are transmitted to the main plant. Plant personnel visits to the intake have been reduced to twice a day for general inspections. During one of the two visits, the sediment sluicing system is operated as a preventive measure. The screen isolation valves are left open during sluicing operations. The amount of extra sediment ingested through the screens during this operation is minimal compared to the effort required to close the manually operated valves. Plant personnel have not determined the amount of sediment that accumulates in the trough before sluicing. The screen air backwash system is also used once a day. The sedimentation basin is cleaned once a year during the summer low river periods when the dredge can more readily reach the desired elevations. The material dredged is predominantly a clean sand. The dredge spoil decanting basin is cleaned every other year, and the material is sold to local interests or used by plant operations. The screen structure cells require cleaning along with the sedimentation basin. The dredge was modified to clean these areas. The screens have been removed once for inspection and cleaning, and were cleaned with only a minimum of effort. The air backwash system was apparently doing its job. A second screen inspection is not scheduled.

INTAKE PERFORMANCE

The intake has been very reliable since it was put into operation, although some operational and maintenance difficulties have occurred. The first unexpected problem involved the screen structure filling with sediment transported by the intake water. A large sand dune formed in the screen structure cells and partially blocked the flow of water from a screen. The sedimentation basin dredge head was prevented from getting into the cells to clean this area. Initially, to overcome this difficulty, the system operators opened only one screen per operating pump. The increased discharge velocity kept the screen structure cells relatively free of sediment. Later, the dredge head was modified to attach a suction hose to the dredge. This suction hose cleans the screen structure cells. A possible design improvement is to connect a short pipe to the discharge of the screens so that sediment drawn into the screen structure can be sluiced through it.

Another problem is the inability to lift the screens from the river at all river stages. Lifting the screens from the river requires attaching a wire lifting cable and harness to the bridge crane winch. The wire lifting harnesses are permanently attached to the screens. The wire cable was not securely anchored to the structure because of the fear that debris or ice would catch the cable and damage the screens by trying to pull them downstream. Debris or ice easily causes the cable to come off its access hook and fall to the bottom. Fishing the cable from the trough has not been possible. Having divers make the hookup when the river flows are high is too dangerous. Since the screens do not require frequent removal, the problem is considered minor.

When the screens were being removed, the operators attempted to close the screen isolation valves and discovered that the valves would not fully close. Sediment was the suspected cause of this problem. By simultaneously closing the valves with the pumps in operation, a high-speed scouring jet could clean out the problem sediment. This procedure for obtaining fully closed valves has not been attempted.

During the 4½ years of its operation, the intake system has performed well. The screens have remained free from blockages due to sediment inundation or debris accumulation. System maintenance on the screening system has been only the daily sediment sluicing and air backwashing and the annual sedimentation basin dredging. The pumps and bearing lubrication systems have undergone modifications but are now performing well. The jetty and revetment have performed as expected. The bank erosion along the revetment has ceased except where local overland runoff enters the river.

ACKNOWLEDGMENTS

The authors wish to thank The Kansas Power and Light Company for their permission to publish this paper.

APPENDIX 1 — REFERENCES

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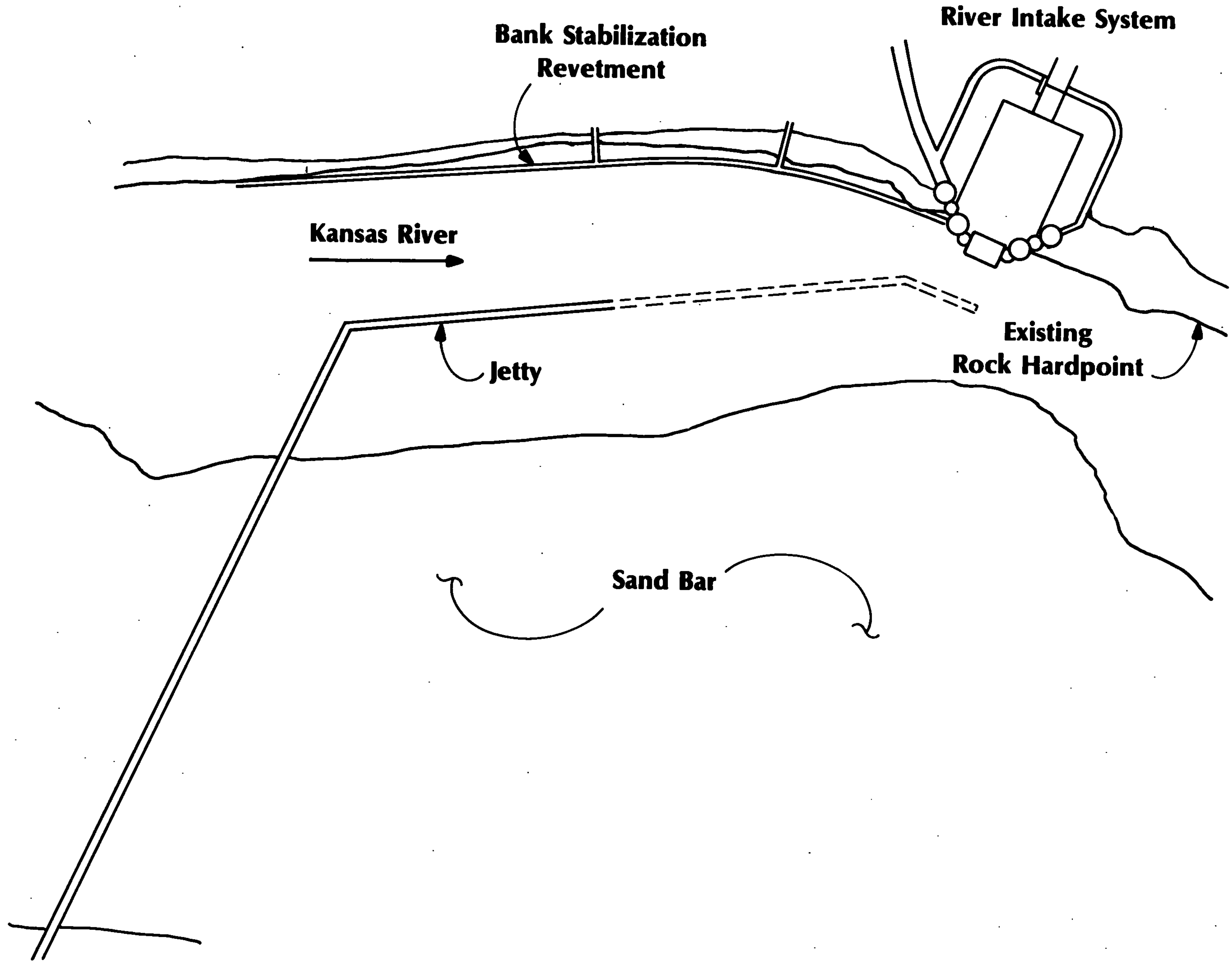
SUMMARY

Air intake is operating on a shallow sand-bed river using passive intake technology. A summary is given of the design concepts, model test results, and performance history of this intake which has been operating since October 1982.

KEY WORDS

Sediment Transport, Power Plants, Intakes, Passive Screens

LIST OF FIGURES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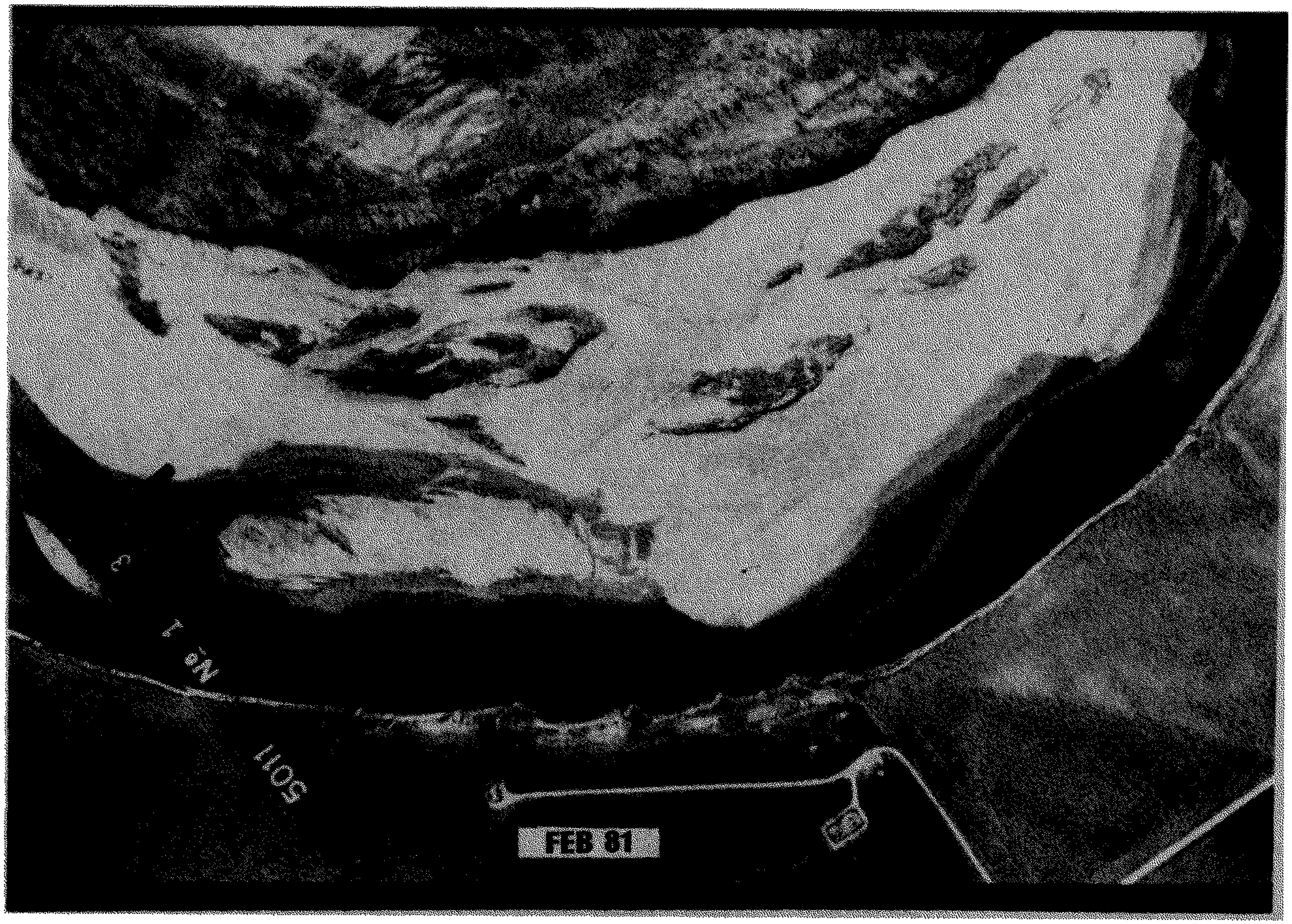
Bank Stabilization
Revetment
Kansas River
Existing
Rock Hardpoint
Jetty
Sand Bar


APR 72


MAR 77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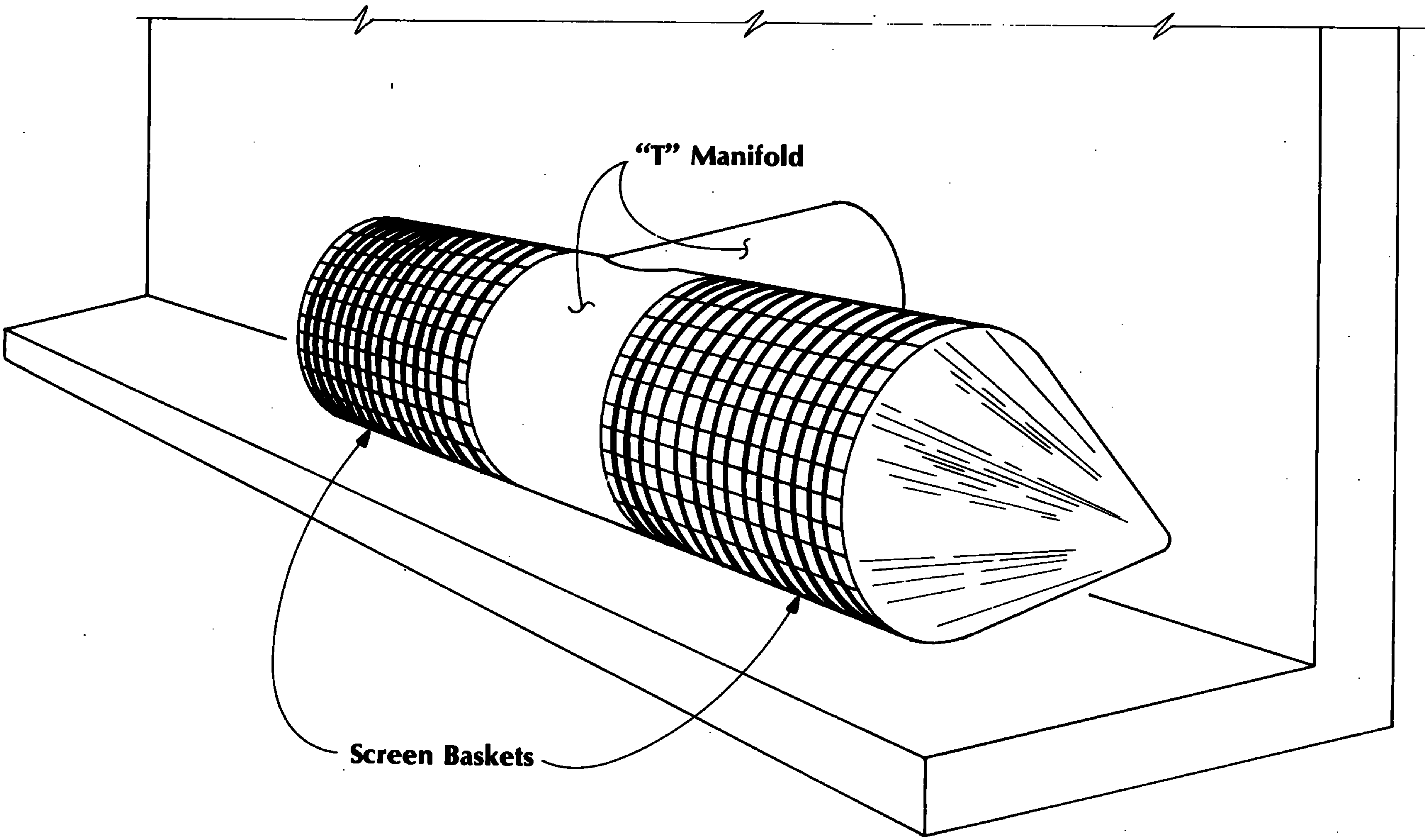
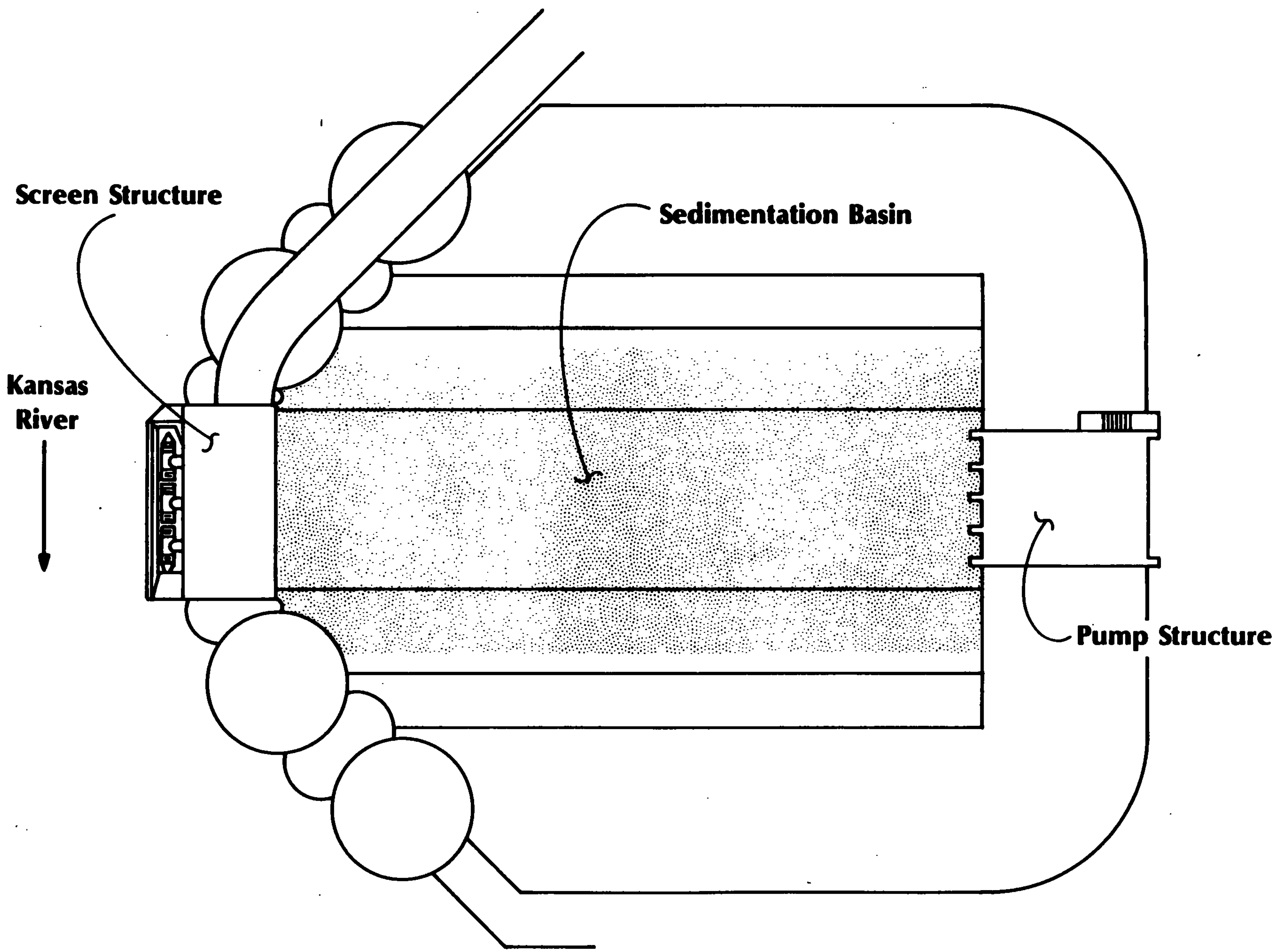
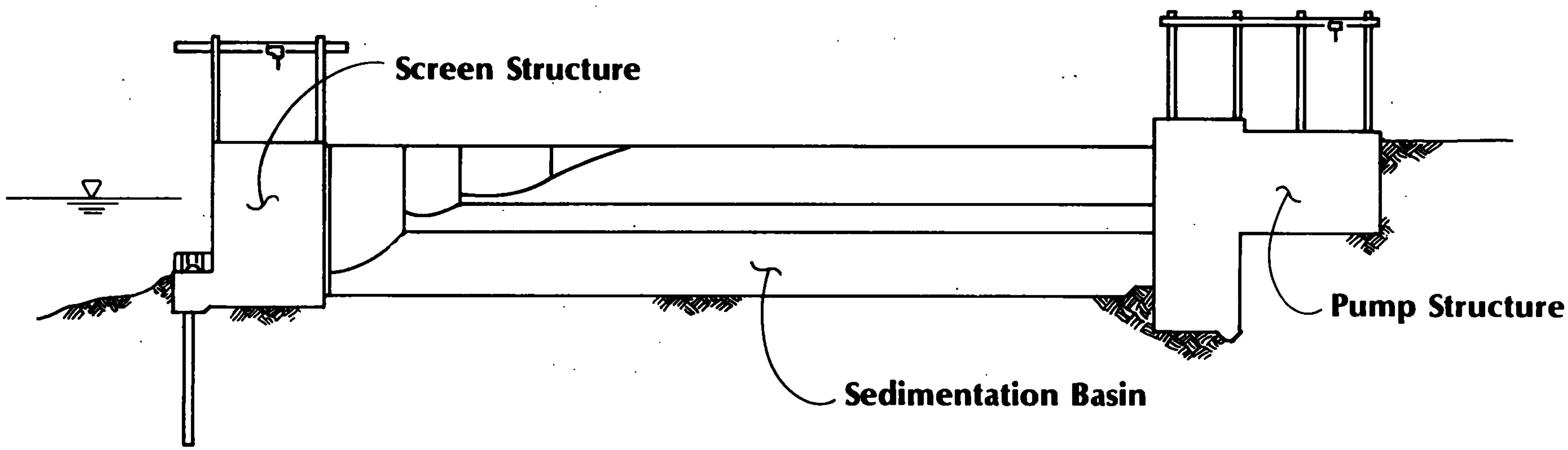
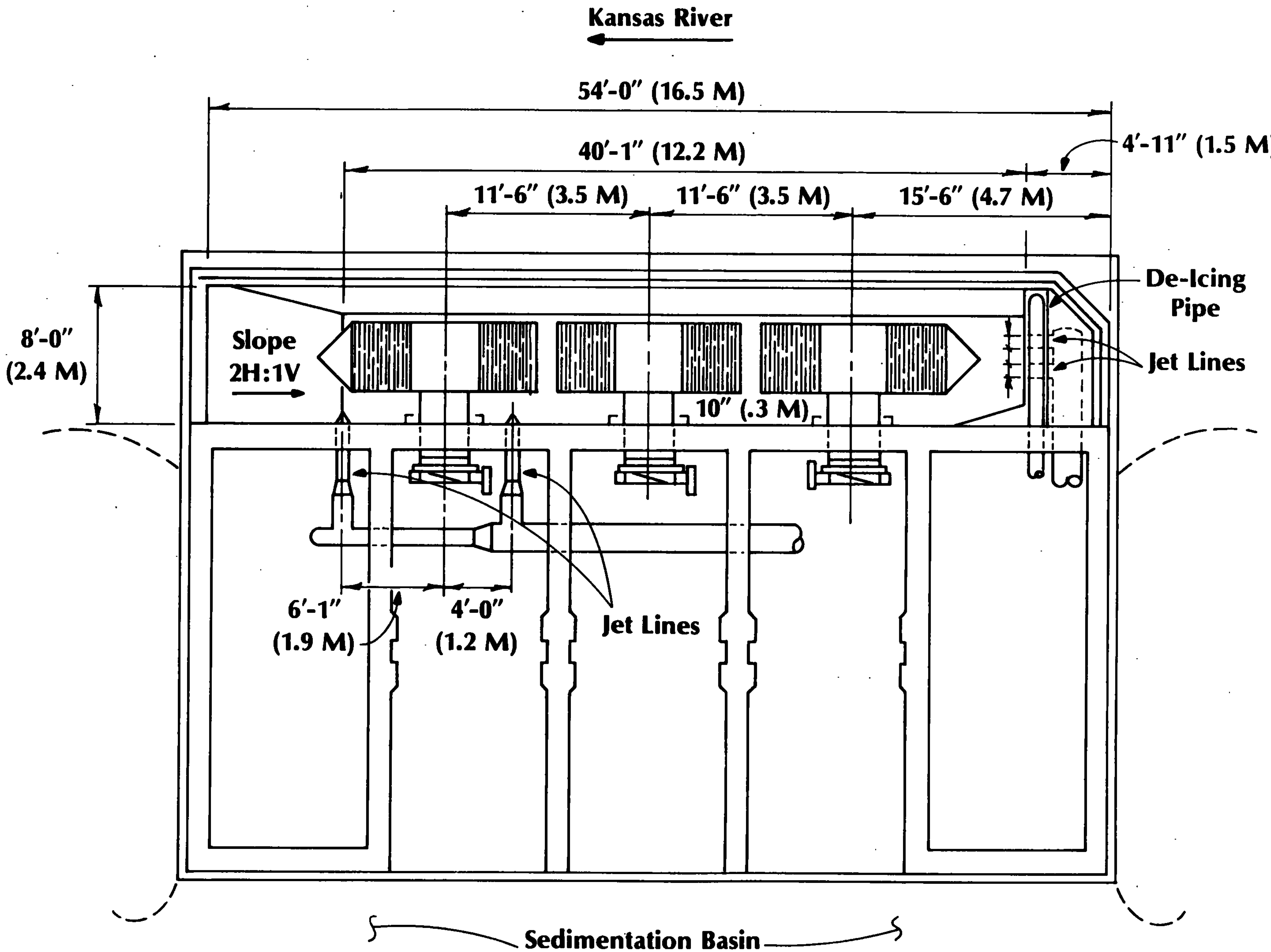
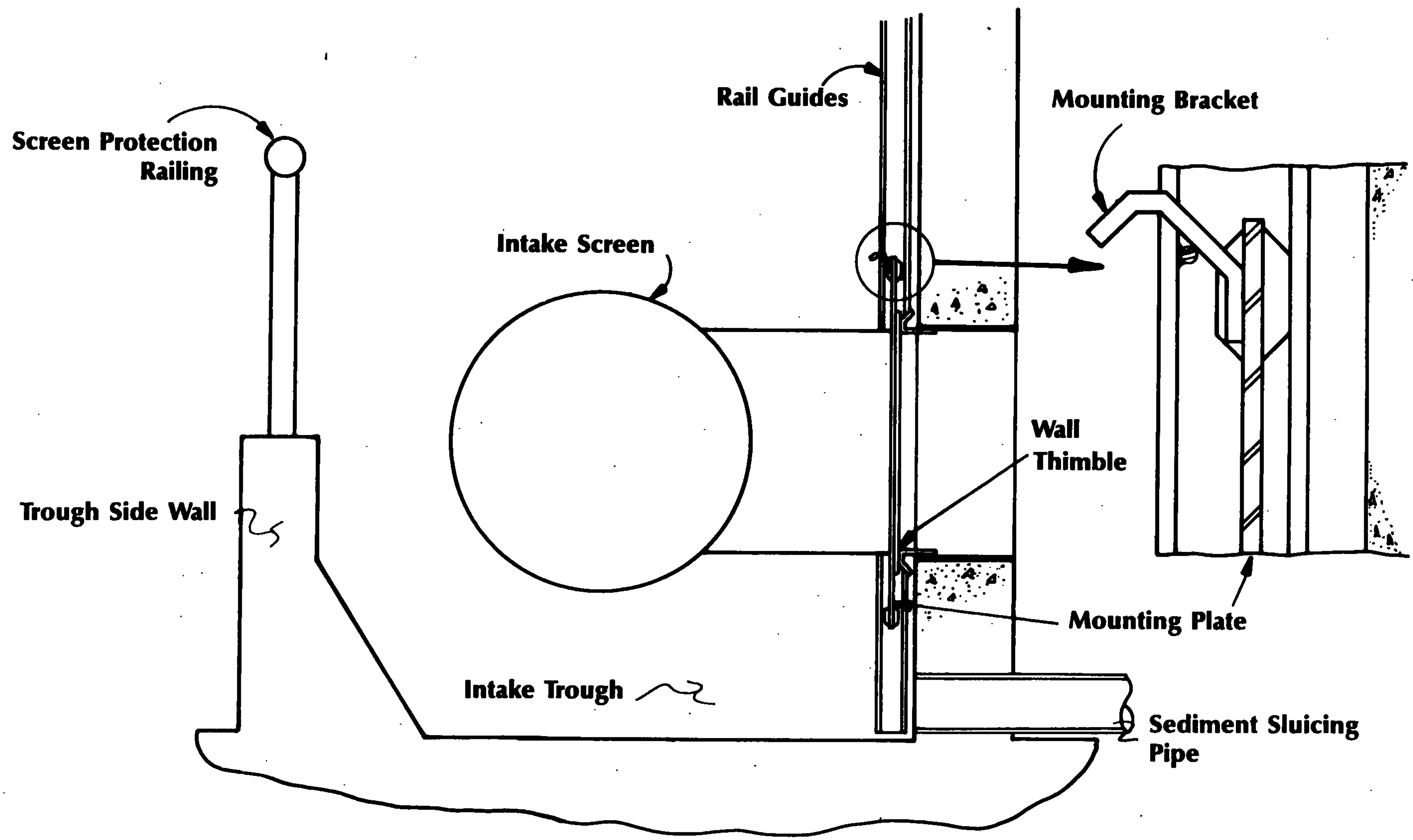

"T" Manifold
Screen Baskets



Screen Structure
Sedimentation Basin
Kansas
River
Pump Structure


Screen Structure
Pump Structure
Sedimentation Basin

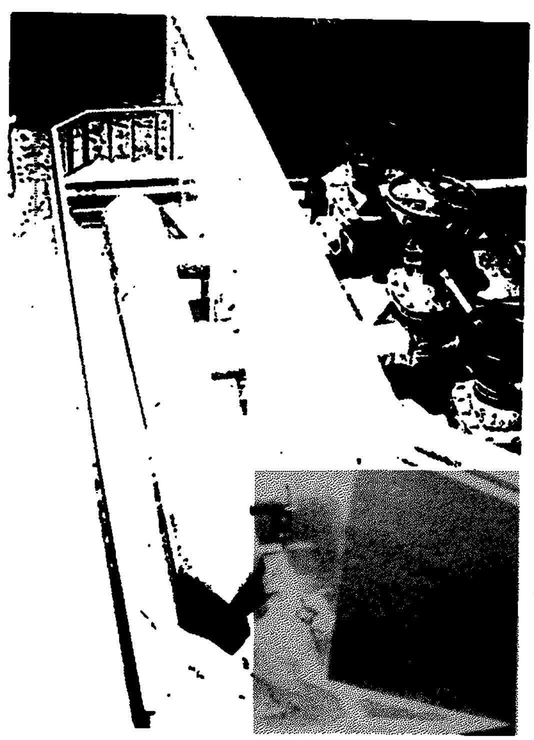

Kansas River
54'-0" (16.5 M)
40'-1" (12.2 M)
4'-11" (1.5 M)
11'-6" (3.5 M)
11'-6" (3.5 M)
15'-6" (4.7 M)
De-Icing Pipe
Jet Lines
8'-0" (2.4 M)
Slope 2H:1V
10" (.3 M)
6'-1" (1.9 M)
4'-0" (1.2 M)
Jet Lines
Sedimentation Basin


Screen Protection Railing
Rail Guides
Mounting Bracket
Intake Screen
Wall Thimble
Trough Side Wall
Mounting Plate
Intake Trough
Sediment Sluicing Pipe

A. Prior to Sluicing

B. Upstream Jets (120 Seconds)

C. Downstream Jets (120 Seconds)



D. After Sluicing