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CLOGGING, CLEANING, AND CORROSION STUDY OF POSSIBLE FISH SCREENS FOR THE PROPOSED PERIPHERAL CANAL

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CLOGGING, CLEANING, AND CORROSION STUDY OF POSSIBLE FISH SCREENS FOR THE PROPOSED PERIPHERAL CANAL

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FOREWORD

The State of California is investigating concepts for preventing migrating adult and juvenile anadromous fish from entering a proposed canal with a maximum diversion of 617 cubic metres (21,800 cubic feet) per second from the Sacramento River. The Department of Water Resources constructed test facilities next to the river to study clogging rates, cleaning feasibility, and corrosion rates of small-aperture fish screens in natural river water. This report documents the results of that study.

CONTENTS

	Page
FOREWORD	iii
ACKNOWLEDGEMENTS	xi
SUMMARY	xiii
Chapter 1. INTRODUCTION AND PROGRAM DEVELOPMENT	1
The Delta	1
The Fish Protective Facility	1
The Fish Facilities Program	1
Biological and Engineering Studies	2
Clogging, Cleaning, and Corrosion Study	2
Chapter 2. SCREEN CLOGGING STUDY	7
Aquatic Growth on Screens	7
Test Facility and Methods	7
Results and Discussion	8
Debris Occurrence and Distribution Survey	10
Equipment and Methods	10
Results and Discussion	11
Screen Clogging Tests	17
Test Facility and Methods	17
Results and Discussion	22
Chapter 3. SCREEN CLEANING TESTS	37
General	37
Methods	37
Results	37

CONTENTS (Continued)

	Page
Mechanical Wiper Brush	38
Equipment and Methods	38
Results and Discussion	39
Pressurized Water Spray With Screen Out of Water	45
Equipment and Methods	45
Results and Discussion	46
Pressurized Water Spray With Screen Under Water	49
Equipment and Methods	49
Results and Discussion	49
Cleaning Interval and Occurrence	51
Chapter 4. SCREEN CORROSION TESTS	55
Equipment and Methods	55
Results and Discussion	56
Chapter 5. CONCLUSIONS	61
LITERATURE CITED	63

FIGURES

		Page
1	Major Facilities of the Central Valley Project and State Water Project	3
2	Hood Fish Screen Test Facility	4
3	Water Quality in the Sacramento River near Hood During 1975	5
4	Aquatic Growth Test Canister and Screen	7
5	Debris Sampled in the Sacramento River at Hood - 1975-1979	12
6	Isogram of Debris Concentration in the River Cross Section at Hood (mg/L) - 1975-1979	13
7	Concentration of Debris at Each Sampling Station - 1975-1979	14
8	Turbidity in the Sacramento River at Hood - 1975-1979	14
9	Flow in the Sacramento River and Concentration of Debris at the Hood Test Facility	15
10	Concentration of Debris in the River and in the Hood Test Facility - 1976-1979	16
11	Organic Content of Debris in the Test Flume at Hood	16
12	General Arrangement of the Hood Fish Screen Test Facility	18
13	Approach Flume	19
14	Test Chamber	19
15	Clogged 4 mm Perforated Plate	23
16	Clogged Woven Wire Mesh	24
17	Clogged 2.4 mm Welded Wedge-Wire Slotted Screen	25
18	Clogged 2.4 mm Welded Wedge-Wire Slotted Drum Screen	26
19	Clogged 2.4 mm Welded Wedge-Wire Slotted Tee Screen	27
20	Clogging Rates of Vertical Flat Screens	28
21	Clogging Rates of Various Screen Orientations and Configurations	29
22	Clogging Rates of 4 mm Perforated Plate at Various Debris Concentrations	30

FIGURES (Continued)

		Page
23	Clogging Rates of 4 mm Perforated Plate for Each Test Velocity	31
24	Clogging Rates of 2.4 mm Welded Wedge-Wire at Various Debris Concentrations	32
25	Clogging Rates of 2.4 mm Welded Wedge-Wire at Each Test Velocity	33
26	Percent of Debris in Water Trapped by Clogging Screen	34
27	Accumulated Debris Load on Clogging Screen	34
28	Clogging Time to Reach Screen Head Loss of 0.06 Metres (0.2 Foot)	36
29	Nylon and Polypropylene Strip Brushes	38
30	Wiper Brush Assembly	40
31	Brush Cleaned with Screen Under Water	42
32	Brushing Cycles Required to Clean a Clogged 4 mm Perforated Plate Screen	43
33	Brush Size and Average Residual Head Loss	44
34	Manually Operated Water Spray Bar	45
35	Flat Spray Nozzles	46
36	Spray Cleaned with Screen Out of Water	47
37	Underwater Spray Cleaning Assembly	49
38	Spray Cleaned with Screen Under Water	51
39	Occurrence of Sacramento River Flows and Cleaning Frequencies	53
40	Corrosion Float, Rack and Samples	55
41	Stainless Steel Type 304	57
42	Stainless Steel Type 304	58
43	Stainless Steel Type 304	58
44	Aluminum Type 5052-H32	59
45	Aluminum Type 6061-T4	59

TABLES

		Page
1	Taxonomic Composition of Samples from the Aquatic Growth Test Facilities	9
2	Test Screens and Specifications	21
3	Screen Clogging Tests	22
4	Strip Brushes and Specifications	39
5	Brush Cleaning Tests	41
6	Average Head Loss on 4 mm Perforated Plate After Brush Cleaning	43
7	Flat Spray Nozzles and Specifications	46
8	Water Spray Cleaning Tests with Screen Out of Water	48
9	Summary of Results of Spray Cleaning 4 mm Perforated Plate Screen Out of Water	49
10	Water Spray Cleaning Tests with Screen Under Water	50
11	Corrosion of Possible Fish Screen Materials	57

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SUMMARY

This is the final report of a fish screen clogging, cleaning, and corrosion study, conducted by the California Department of Water Resources for the Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary.

Decomposing terrestrial and aquatic material coming down river during winter and spring high riverflows caused the most rapid clogging. Comparing screens of similar fish screening efficiency, woven wire mesh took about one-and-one-half times longer to clog than perforated plate, and welded wedge-wire slotted screen took about three times longer to clog than perforated plate. A positive and significant correlation found between riverflows and screen clogging rates can be used to predict required cleaning frequency.

Cleaning tests indicated all screens can be cleaned with water jet spray or wiper brush. The most effective was water spray with the screen out of water. When the Sacramento River is flowing at 2 100 cubic metres (75,000 cubic feet) per second, perforated plate may have to be cleaned as often as every hour and welded wedge-wire as often as every 5.3 hours to maintain screen head loss at less than 0.06 metre (0.2 foot) with a design approach velocity of 0.06 metre (0.2 foot) per second.

Perforated plate and welded wedge-wire screens made of type 304 stainless steel had no measurable corrosion after being submerged in the river for four years.

Chapter 1. INTRODUCTION AND PROGRAM DEVELOPMENT

The fish screen study is an indirect result of the need to divert water from the northern part of California to the water-deficient central valley and southern half of the State. The key to the existing Federal and State diversion route is the Sacramento-San Joaquin Delta located roughly in the center of the State upstream of San Francisco Bay (Figure 1). Water from the north works its way through natural and constructed channels in the Delta on its way south.

The Delta

At present, water released from upstream storage reservoirs of the State Water Project and Federal Central Valley Project flows down the Sacramento River and is diverted at the southern end of the Delta in what are essentially dead-end sloughs. As the demand for water has built up, the point of diversion in the southern Delta has become less and less satisfactory because:

- Water moving through the Delta picks up ocean salts and salts from agricultural, municipal, and industrial waste water.
- Flow in some of the southern Delta channels is reversed to a southeasterly direction during low flow times.
- Fish handling is required when diverting from dead-end sloughs.

The Delta is a major nursery area for striped bass as well as a migratory route for bass and other anadromous fish. Millions of outmigrants annually are being drawn to the louvered fish protective facilities at the State and Federal projects in the southern Delta rather than being allowed their natural migration route through the Delta. Numerous studies have indicated that the best way to move water across the Delta with minimum fishery impact and to maintain the necessary quality in the Delta is to move the point of diversion to the Sacramento River near Sacramento. The diverted water would be contained in an isolated channel (the proposed Peripheral Canal) and transferred around the Delta to the pumping plants to the south. The State and Federal projects presently coordinate operation of upstream reservoirs and Delta diversions, and joint construction and operation of the Peripheral Canal would be beneficial to both.

The Fish Protective Facility

The intake to the proposed canal offers several challenges to a fish screen design team. In the first place, the maximum diverted flow is quite large -- 617 m^3/s (21,800 ft^3/s). In the second place, the Sacramento River below Sacramento is a migration route for such fish as chinook salmon, striped bass, American shad, steelhead rainbow trout, and white sturgeon, plus numerous other species. During any month, eggs and larvae, juveniles, or adults are passing the proposed diversion site.

Fish must be excluded from the canal and the excluded (screened) fish must be returned to the river without direct mortality or undue fatigue, injury, or delay.

The Fish Facilities Program

The goals of the fish facilities program are to select the type of intake and fish-screening system and to develop the criteria needed to design and operate

the fish facility. Started in 1970, the program has examined the engineering and biological feasibility of several fish screen concepts, including louvers, porous dikes, vertical and horizontal traveling screens, passive screens, and miscellaneous behavioral concepts such as electricity and sound. The choice of screens has been narrowed (Skinner, 1974, and Brown and Odenweller, 1981) to a low velocity, positive barrier, passive screen located adjacent to the river, with curtailment of diversion periodically during about five weeks in the spring to protect the eggs and larvae of striped bass.

The program is to complete most of the engineering and biological studies in 1982, leading to recommended screen type and design criteria for the first stage of the proposed Peripheral Canal. A separate report (now in review) compiles a complete history of the program, describes all the studies, and summarizes results. Although the program has generally been designed to provide data for a specific intake at Hood, many of the results will be useful for screen designs in other areas of the Delta and along the Sacramento River.

Biological and Engineering Studies

The test program has involved personnel from the California Departments of Fish and Game and Water Resources, who have worked on the biological and engineering aspects of fish screen design.

The biological studies are providing information on approach velocities, fish occurrence and distribution, long- and short-term fish swimming ability, effects of trashrack bar spacings, potential impact of predators, and the ability to pump fish back into the river.

The engineering studies have been devoted to hydraulic and sedimentation impacts of the facility and to the clogging, cleaning, and corrosion of screens that may be used in the final design. Hydraulic and sedimentation studies, using both physical and mathematical models, identified the major problem areas of bed load sedimentation and undesirable velocity patterns for different intake designs. Results of these studies as well as other design, operational, and biological considerations led to selection of the off-river configuration, in which the screen is placed in a channel parallel to the river. Flows bypassing the screen will carry the fish back to the river.

Clogging, Cleaning, and Corrosion Study

The Clogging, Cleaning, and Corrosion Study was conducted at a test facility (Figure 2), constructed on the levee along the Sacramento River. The facility was in the town of Hood, which is near the site of the proposed diversion about 32 km (20 mi) downstream from Sacramento. The facility had the capability of delivering up to 1.7 m^3/s (60 ft^3/s) of unfiltered river water to test flumes in which the flows could be passed through screens of various type and configuration.

Screens with small openings placed in an aquatic environment will eventually plug because of plants and animals growing on them and suspended particles being trapped against them. The rate at which these screens plug is a complex function of several variables, including water chemistry (nutrient availability), hydraulic conditions, sediment and detritus load, screen material, orientation to flow, and size of opening.

The quality of water in the Sacramento River near Hood fluctuates with river outflow. Some high flows with high sediment and debris loads usually occur during winter and spring. During summer and fall the historical flows have been normally so low that controlled releases from upstream reservoirs were required to offset increases in salt content due

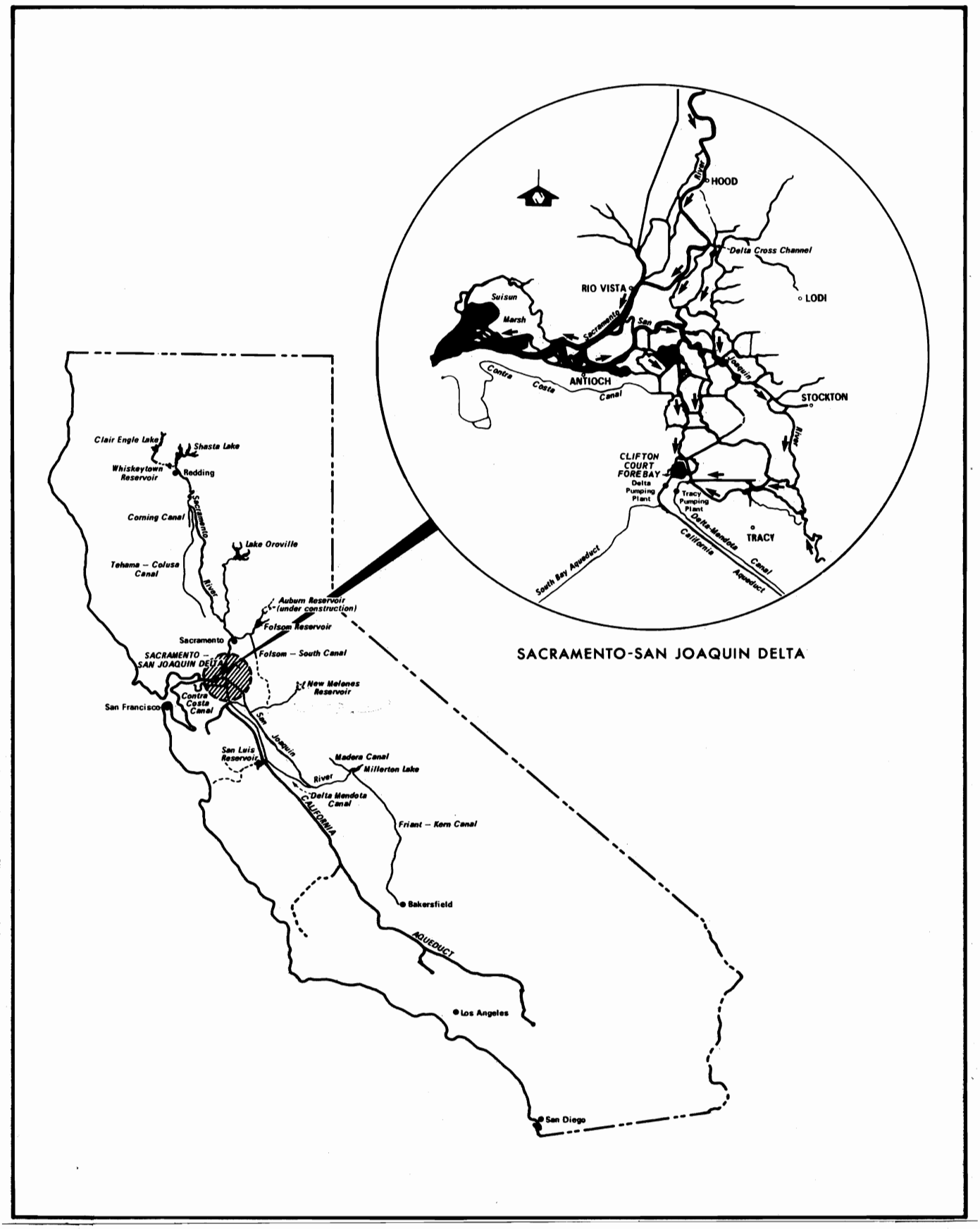
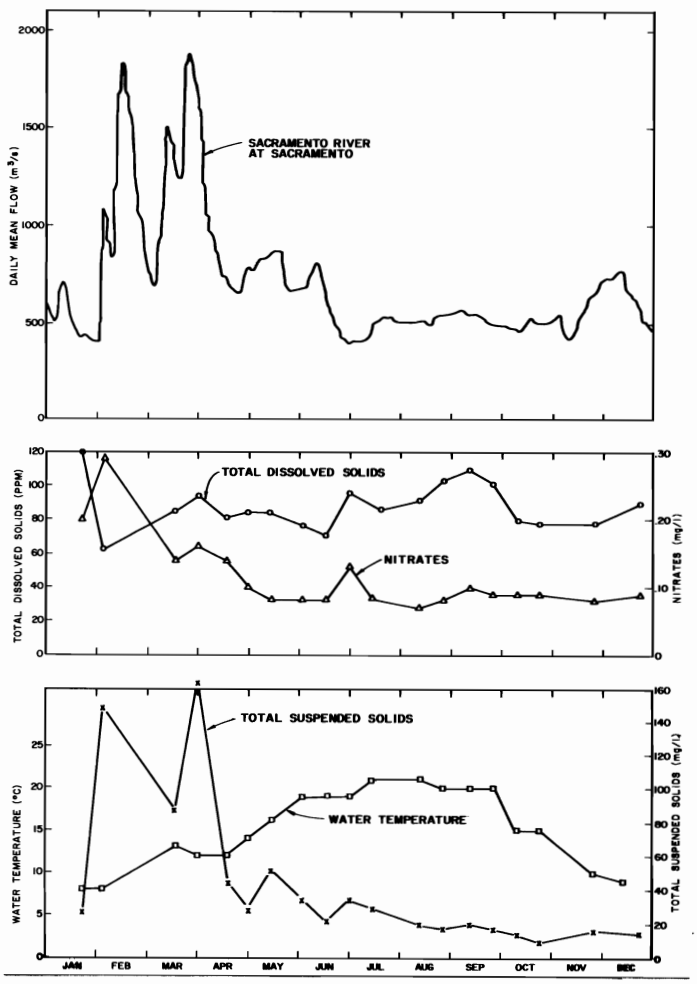


Figure 1. Major Facilities of the Central Valley Project and State Water Project

Figure 2. Hood Fish Screen Test Facility

to sea water intrusion and agricultural drainage. Nutrient levels increase in summer months with the decreased river-flows and increased agricultural use. Algal levels remain typically low, although somewhat higher in summer and fall than in the rest of the year. Dissolved oxygen content is slightly depressed during the summer due to waste discharges (normal range is 8 to 11 mg/L). Figure 3 contains total dissolved solid, total suspended solid, nitrate, and water temperature values recorded during 1975 (a typical water year) at a monitoring station 4.8 km (3 mi) downstream from Hood.

Figure 3. Water Quality in the Sacramento River near Hood during 1975



The Sacramento Regional Wastewater Treatment Plant, to be completed soon, will discharge into the river 13 km (8 mi) upstream from Hood. The effluent is expected to cause a slight decrease in water quality. Increases in temperature, dissolved solids, and nitrates and a decrease in dissolved oxygen are predicted to deviate less than 3 percent from present levels.

Perforated plate with 4 mm (5/32 in) holes on 5.6 mm (7/32 in) staggered spacing was selected as the control screen and was tested simultaneously with other screens to compare clogging rates. Tests were conducted with a water approach velocity of 0.06 to 0.24 m/s (0.2 to 0.8 ft/s) perpendicular to the screens -- a range, developed from biological tests, applicable to all screen configurations being considered. Velocities parallel to the screens (bypass velocity) ranged from 0.15 to 0.76 m/s (0.5 to 2.5 ft/s).

Tests were conducted throughout the year to determine the annual variability of clogging rates. During the tests, the suspended debris (material collected in a plankton net with a nominal mesh opening of 0.5 mm) was sampled in the river and the test flumes. Test screen clogging rates are expressed in terms of head loss and time. Aquatic growth on the test screens and on screen samples placed in the river was examined for dominant genera of fouling organisms. Test screens were cleaned periodically with strip brushes or flat spray nozzles to estimate cleaning effectiveness and required frequency. Finally, samples of various types of screen material made from different stainless steels, aluminums, and other metals were placed in the river and were periodically removed and analyzed for corrosion.

A progress report on these studies (Smith and Ferguson, 1979) included discussions of test results up to 1979. That report contained more photographs of the test facilities than contained herein.

Chapter 2. SCREEN CLOGGING STUDY

The clogging study is divided into three areas: aquatic growth on screens, occurrence and distribution of debris in the river, and clogging rates of screens installed in flumes at the Hood Test Facility.

Aquatic Growth on Screens

As used in this report, the term "aquatic growth" is restricted to the plant and animal community that colonizes objects suspended in water. The colony is often termed the periphyton, although a more correct term might be the "aufwuchs". Colonization generally goes through various stages, from bacteria, bryozoans, and algae as the dominant organisms, and if time is adequate, to a climax community composed of producers (plants), consumers (animals), and decomposers (bacteria and fungi). The aquatic growth tests described in this study are limited to observations of the kinds of organisms colonizing screens in the Sacramento River near Hood and to recording clogging rates as a measure of growth. The observations are qualitative because no attempt was made to distinguish between clogging caused by trapped particles and that caused by growth on the screens.

Test Facility and Methods

There were two aquatic growth test facilities -- one in the town of Hood and the second at the Paintersville Bridge about 6.4 km (4 mi) downstream of Hood. The Paintersville site was activated late in 1974 and was about 45 m (150 ft) from the east bank of the river, which is 180 m (600 ft) wide. The Hood facility was activated in March 1978 and was suspended from a floating platform about 9 m (30 ft) offshore. The floating platform was attached to the Hood Test Facility pump intake structure.

At both facilities two test screens (15 x 30 cm (6 x 12 in) each) were mounted on each of two solid canisters suspended from a movable support that could be raised above the water surface or lowered to test depth (Figure 4). The test depths were 0.9 and 3 m (3 and 10 ft) below the surface. Water was continuously drawn through the test screens and canisters by a small pump. The initial flow was about 150 L/min (40 gpm) with two clean test screens on a canister. The calculated approach velocity was about 0.03 m/s (0.1 ft/s). All testing was with perforated plate with 4 mm (5/32 in) diameter holes on 5.5 mm (7/32 in) staggered centers. Fischer-Porter flowmeters were used to monitor the flow through each canister. The reduction of flow with time due to the accumulation of material on the screens was the clogging rate.

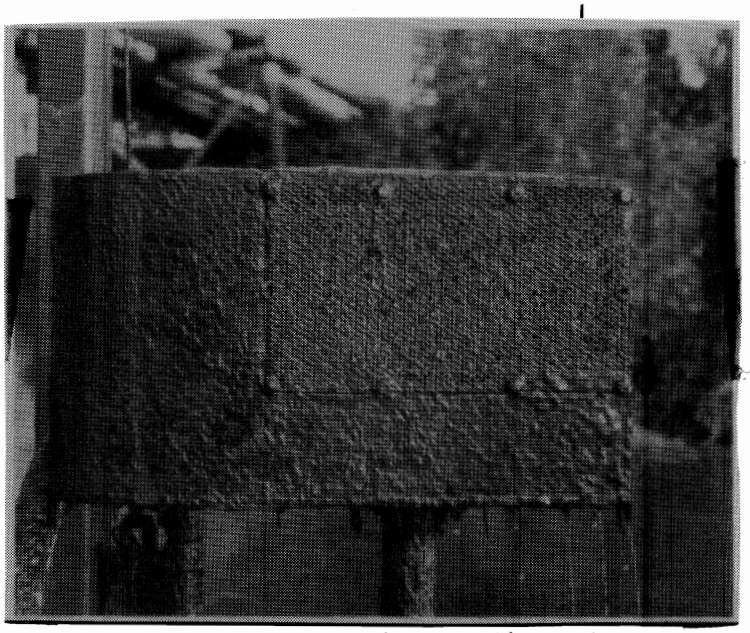


Figure 4. Aquatic growth test canister and screen

The in-river facilities at Hood and Paintersville were intended to operate 24 hours a day, 7 days a week. However, mechanical and electrical problems often caused one or the other of the test facilities to be shut down.

The operating procedure consisted of recording the flow rate through the canisters two or three times per week. Periodically the pumps were turned off and the canisters were then raised clear of the water for inspection, sample taking, and photographing. The canisters were then cleaned, lowered into position, and restarted.

Samples were collected from test screen surfaces by scraping with a spatula and depositing each sample in a collection jar with lugol's solution. The jars were marked for identification and sent to DWR's Bryte Laboratory, where the contents were qualitatively identified and organisms present were identified to lowest taxonomic group readily possible.

In addition, the large clogging test screens in the Hood facility were periodically monitored in the same manner for attached aquatic growth.

Results and Discussion

In the first half of 1975, during high winter and spring runoff, the aquatic growth test screens were allowed to run continuously. They clogged completely in two to six weeks with a fibrous, noncohesive accumulation of debris. The screens were assumed clogged when the flow was reduced from 75 to about 18 L/min (20 to 5 gpm) through each test screen. During lower river flows in the second half of 1975 and until June 1977, the screens clogged much more slowly (up to 13 weeks) with an algal gelatinous matrix of entrapped silt and debris. There was no noticeable difference in the clogging rate or the amount of material on the upper or lower test screens.

Starting in June 1977, visual inspection and sample taking of the screens once each month indicated a greater accumulation of material (mainly algae) on the top screens as compared to the lower ones. The difference in accumulated growth, observed but not measured, was not enough to cause flow rates of water through the upper and lower test screens to be very different. The flow decreased by less than 5 percent each month, and thus was relatively slow compared to the early 1975 tests. One would expect more growth on the upper canister because turbidity in the Sacramento River severely limits light penetration.

Since June 1976, the content of each sample was qualitatively analyzed for taxonomic composition by biologists at the Department's laboratory. The data are summarized in Table 1. The most abundant forms identified were the algae *Melosira*, *Synedra*, *Fragilaria*, and occasionally *Spirogyra*. Animal material included insect larvae (mainly chironomids), polychaetes, and stalked ciliates. Bryozoans were also commonly found. The analysis did not discriminate between material growing on the screens and that trapped on the screens.

Several months of simultaneous operation of the two aquatic growth facilities were completed during 1978. Data collected on the fouling organisms indicate that the taxonomic composition at the two sites was similar but that the observed quantity of material on the screens at Hood was generally less than that at Paintersville. The difference was most likely due to the way the facilities were suspended in the river. The Paintersville screens were attached to pilings and were therefore stationary and not subjected to up and down motion from waves and boat wakes. The Hood screens were suspended from a float. The often violent pitching of the float probably washed off some of the accumulated material. The decrease in flow for both facilities due to the combined effects of aquatic growth and

Table 1. Taxonomic composition of samples from the aquatic growth test facilities

Sample Date	7-7-76		12-21-76		4-6-77		4-28-77	7-1-77		8-2-77		9-2-77		9-30-77		10-31-77	12-1-77		6-8-78		7-5-78		8-8-78		9-26-78		11-2-78		12-13-78		1-16-79		4-4-79	
Sample Depth (m)	.9	3	.9	3	.9		3	.9	3	.9	3	.9	3	.9	3	3	.9	3	.9	3	.9	3	.9	3	.9	3	.9	3	.9	3	.9	3	.9	3
Algae:																																		
Melosira	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Synedra					X		X	X	X	X		X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Fragilaria					X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Hydrosera	X		X	X			X	X		X		X	X	X	X		X		X	X	X		X	X	X	X	X	X	X	X	X			
Bacillaria							X												X	X	X	X	X	X	X	X	X	X	X	X				
Spirogyra	X	X	X		X		X	X		X		X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X		X		
Cymbella					X		X	X	X	X	X			X	X				X		X		X	X	X			X	X					
Biddulphia	X											X					X		X				X	X	X	X	X	X	X	X		X	X	X
Hydrodictyon							X	X				X	X	X				X			X		X	X	X	X	X	X	X					
Cladophora			X		X					X		X	X	X	X	X	X	X					X	X	X	X		X	X					
Diatoma					X		X	X	X	X	X	X	X	X	X	X			X	X			X				X		X					
Navicula					X		X	X	X	X		X	X	X	X	X		X	X	X														
Cyclotella					X		X	X	X	X	X	X	X	X	X	X		X	X	X														
Gomphonema					X		X	X		X	X								X			X				X								
Oscillatoria					X			X		X	X	X	X	X		X						X	X	X						X	X			
Lyngbya								X		X													X	X										
Oedegonium																										X								
Vaucheria	X				X		X	X			X	X	X	X	X	X											X							
Cocconeis					X			X		X			X																					
Nitzchia					X			X		X		X	X		X	X														X				
Rhoicosphenia					X									X	X																			
Tabellaria																									X				X	X			X	
Silt			X		X		X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X		
Mucus			X		X		X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X		
Animal Material:																																		
Insect Material	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Oligocheate					X				X	X	X	X	X			X	X		X						X	X	X	X	X	X				
Stalked Ciliates			X	X	X		X				X	X	X			X	X						X	X	X	X	X	X	X	X	X	X		
Bryzoan Colony									X					X	X																			
Colonial Hydroids													X	X	X	X								X										
Porifera												X					X											X						
Nematoda																X																		
Amphipoda																																X		

trapped debris averaged less than 5 percent each month.

Species composition was very similar for samples from the large screens being tested in the flumes of the Hood Test Facility and from the in-river aquatic growth units. The extent of proliferation of various algal and animal species on the submerged screens depended, in part, on the length of time between cleanings and on water temperatures. The extent of the algal gelatinous matrix and, hence, of silt and debris trapped was affected by the same two variables. A quantitative assessment was not attempted of the importance of fouling organisms to the overall problem of screen clogging because suspended particles (including aquatic organisms) became trapped on the screens. Detritus, silt, and other suspended matter were the predominant clogging mechanism during winter and spring higher riverflow periods. Aquatic organisms were predominant during summer and fall, with much slower clogging rates than in winter and spring.

The impact of aquatic growth on the rate of fish screen clogging was evaluated by examining the growth on screens in the flumes of the Hood Test Facility and focusing on the ability of various cleaning mechanisms for removing any observed growth. These data, combined with up to four years of data from the in-river test units, provide adequate information on clogging of fish screens by aquatic growth in the Sacramento River near Hood.

Hanson et al. (1978) and Browne (1979) both found that biofouling was the important component in clogging wedge-wire screens in brackish water. Data collected at Hood indicate that detritus accumulation was the critical clogging component. The difference may be that the rate of aquatic growth is generally greater in estuarine environments than in freshwater environments.

An aquatic growth study similar to the Hood study was conducted by Lifton (1979) with 0.3 m (1.0 ft) diameter wedge-wire round screens, with axis horizontal, in a freshwater estuary. Flow rates through the test screens remained very close to initial rates after 2 to 4 weeks of continuous operation. Almost all biological growth was found on the upper surface of the screens. The small amounts of detritus found were on the upper surface also. Lifton concluded that detritus did not appear to be a problem.

Debris Occurrence and Distribution Survey

As defined in this study, debris is that portion of material suspended in the river that is captured by a plankton net and collection bottle with a nominal mesh opening of 0.5 mm. The debris study was designed to identify the kinds of debris occurring in the Sacramento River and the temporal and spatial distribution of the material. Samples were collected in the river and in the flumes of the Hood Test Facility to determine the concentrations in both locations and to determine if debris entering the flumes and clogging the screens was representative of that found in the river.

Equipment and Methods

Debris samples were collected from the river at 2- to 4-week intervals throughout the year starting in 1975 and about three times per week from the approach flume at the Hood Test Facility starting in 1976. Plankton nets were used at both locations to capture river debris. Mounted in the mouth of the plankton net was a current meter that gave average water velocity entering the net. The volume of water filtered was calculated for each sample.

River samples were collected from a transect across the river near the intake of the Hood Test Facility. A total of nine samples was collected on each run: near-surface, mid-depth, and

near bottom for the stations near each bank and at mid-channel. The nets were left in the river from 15 to 60 minutes, dependent on the riverflow, an interval required to accumulate several grams of debris in the nets.

The same nets were used to collect one debris sample three times a week in the test facility. The net was attached to a beam across the approach flume and left in the flume for the sampling interval needed to provide a valid sample.

Laboratory analysis of the debris sampled began with qualitative macroscopic (unaided eye) and microscopic (30x binocular microscope) examinations to identify the various components. The samples were then drained for 5 minutes with a 40-mesh strainer and weighed. The samples were then placed in an oven and held at 120°C until constant weight was obtained (up to 24 hours). The samples were weighed again to determine dry weight and then incinerated for 6 hours at 600°C. The samples were weighed again to obtain the weight of the ash. The assumption was that the loss on ignition was organic matter -- an assumption that is not entirely true because the results may not take into account loss of water at crystallization, loss of volatile organic material before incineration, incomplete oxidation of some complex organic compounds, and the decomposition of some mineral salts during combustion. However, the assumption is sufficiently valid for purposes of this study, probably within 5 percent.

A value was calculated for each sample from the river and flume for dry weight concentration in mg/L (based on sample weight and volume of water filtered) and the percent organic and inorganic weight. Riverflow was obtained daily and as used throughout this report was the 6 a.m. reported Sacramento River flow at the "I" Street Bridge in Sacramento. River stage at Hood was continuously recorded with a Fischer-Porter punch-tape recorder. Water temperature in the approach flume of the test facility was also recorded daily.

Results and Discussion

Material collected by nets in the river and flume consisted of various combinations of fresh and decomposing terrestrial and aquatic material, including algae, sand, silt, leaves, plant, and animal -- both intact and remnants. The different types of debris varied seasonally and, as observed over the last five years, can be described as follows.

December - April. With the heavy rainfall and increased riverflows normally occurring during this period, the samples contained mainly detritus (decomposing plant and animal material, sand, and silt) and fresh plant material. Algae were consistently present but never in important quantities, probably because they were limited by low light and temperature. Insect larvae were generally scarce, although there were occasions when large numbers of mayfly and caddis-fly nymphs and larvae appeared in samples. Some mites, nematodes, copepods, and cladocerans were commonly found but never in large quantities. The nets also captured young lamprey during this period. Silt and sand were major components of the samples, with their proportions apparently dependent on the magnitude and suddenness of increase in riverflows.

May - September. Samples during this period contained ever-increasing amounts of algae relative to detritus. The complete transition from samples containing predominantly detritus to predominantly algae normally occurred in June. Animal material also became more prevalent as water temperatures rose. For example, pelagic fish eggs were common in April and May, followed by an abundance of fish larvae and fry throughout May and June. Insect

material appeared regularly, often the dominant component in the sample. Asiatic clams also appeared regularly but only occasionally were they the dominant component.

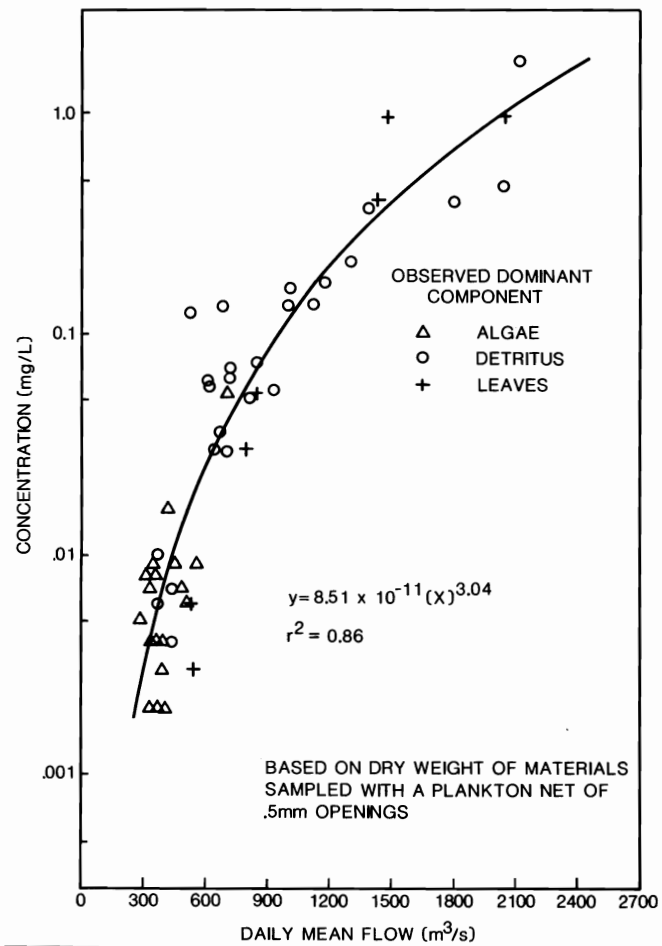
October - November. Algal amounts decreased with dropping water temperature in the fall, although the samples from this period had the greatest algal diversity. Leaf material occurred regularly and detrital material occurred irregularly, contingent on the amount of rainfall. Insect material declined rapidly with the sharp drop in water temperature usually occurring during this period. Cladocera, amphipods, nematodes, and Asiatic clams appeared irregularly but often in abundance.

Figure 5 contains, for each river debris survey taken, the dominant component (algae, detritus, or leaves), the calculated debris concentration, and the riverflow. The data indicate algae as the dominant component during low riverflows and detritus as the dominant component during high riverflows. Leaves have been dominant only occasionally; the actual occurrence probably depends on the size of storms reaching the Sacramento watershed and the resulting increase in river stage. In some years, the late fall and early winter runoff went mostly into upstream storage reservoirs and therefore did not cause higher river stages that would carry the fallen leaves and debris downstream.

Although upstream agricultural practices probably have some effect on debris load in the river, no agricultural plant waste was identified in abundance in any debris sample at Hood.

The highest debris concentration measured was during the first peak flow of 2 240 m^3/s (79,000 ft^3/s) in January 1978 after two years of drought. Although the riverflows reached 1 930 m^3/s in February and 2 270 m^3/s in March, the peak debris concentrations were only about

Figure 5. Debris sampled in the Sacramento River at Hood - 1975-1979



25 percent of those in January. The logical assumption is that the first heavy flows flushed most of the accumulated debris downstream.

Collected debris was uniformly distributed across the river cross section. Content of the samples was similar throughout but concentration increased with depth. The one sample point that varied more than the others in content and concentration was in the middle of the river near the bottom. The sand content of all samples increased greatly with high riverflows. Figure 6 contains contours of debris concentration for four representative riverflows. Each figure represents an average of several data sets. Figure 7 shows the relationship between debris concentration and riverflow for the three samples in each vertical and horizontal sampling location.

Figure 6. Isogram of debris concentration in the river cross section at Hood (mg/L) - 1975-1979

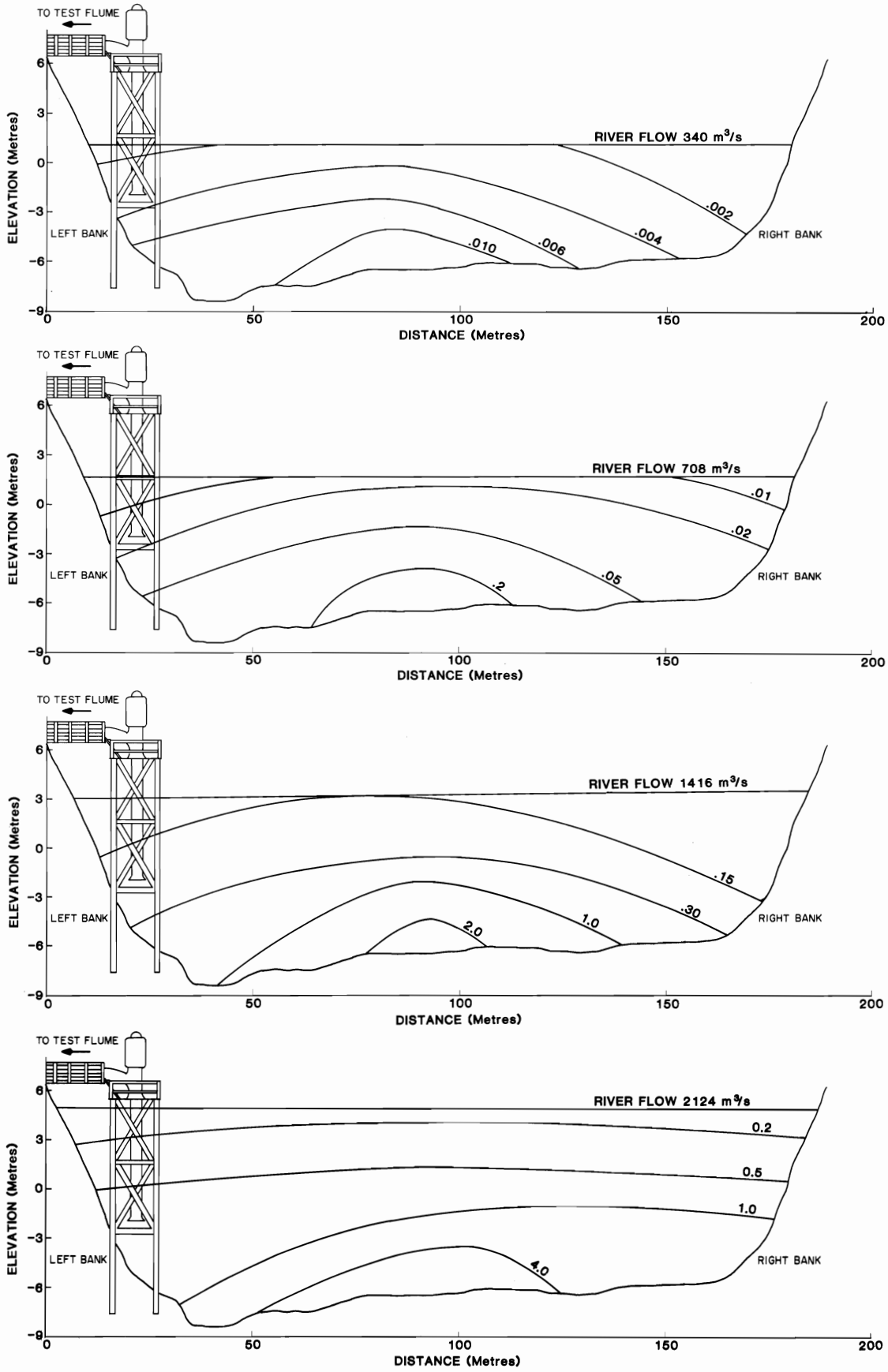
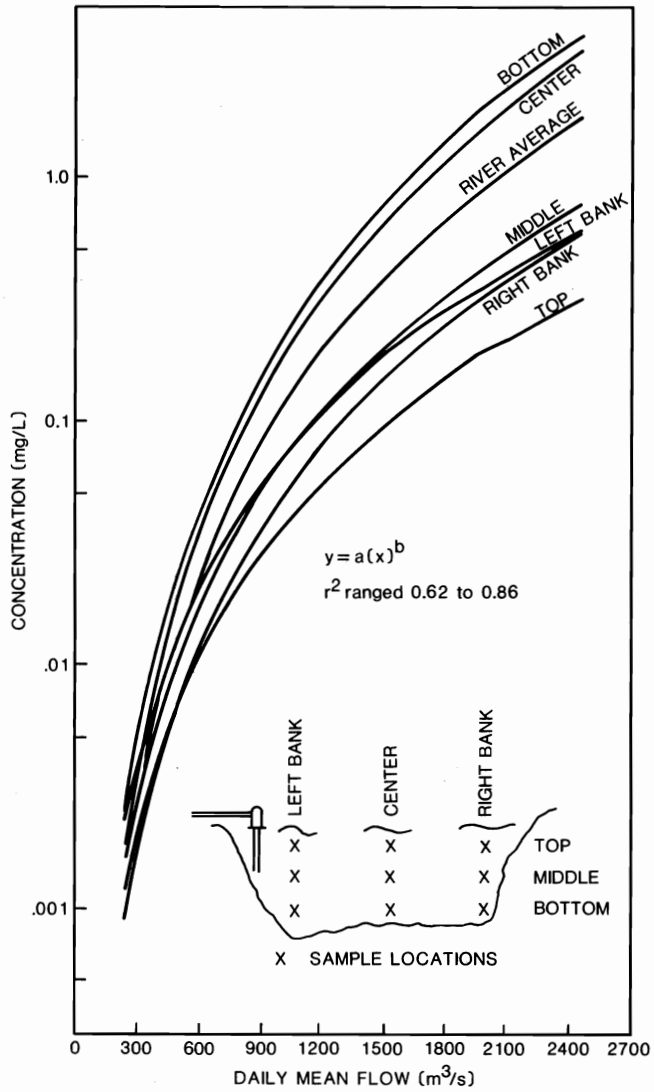


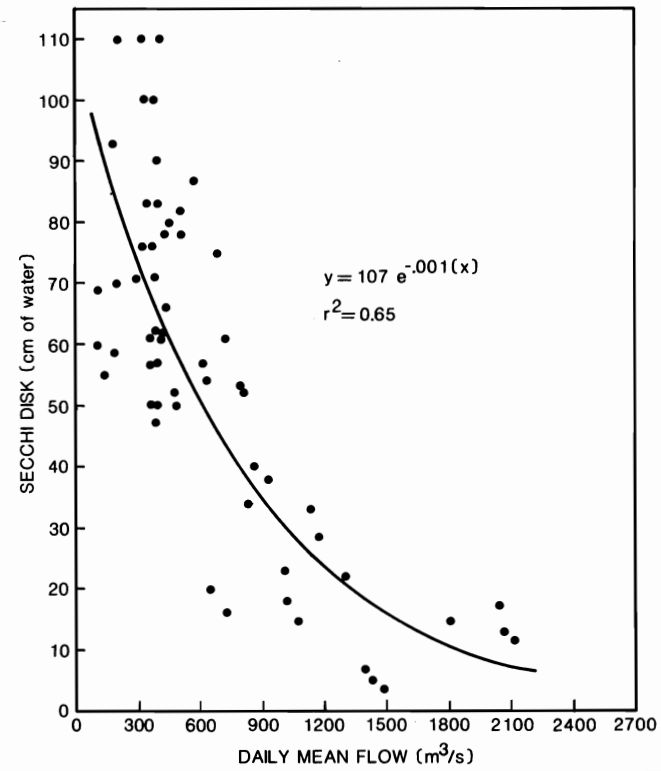
Figure 7. Concentration of debris at each sampling station - 1975-1979



Similar results of the relationship between debris load and riverflow were obtained in a study by McConnell and Monan (1964) in the Snake River. Concentration of debris greatly decreased after the first high water and fluctuated with riverflow. However, debris was more abundant near the surface in times of increasing flow and near the bottom in times of decreasing flow. This contrasts with Hood data, and may be due to higher channel velocities in the Snake River.

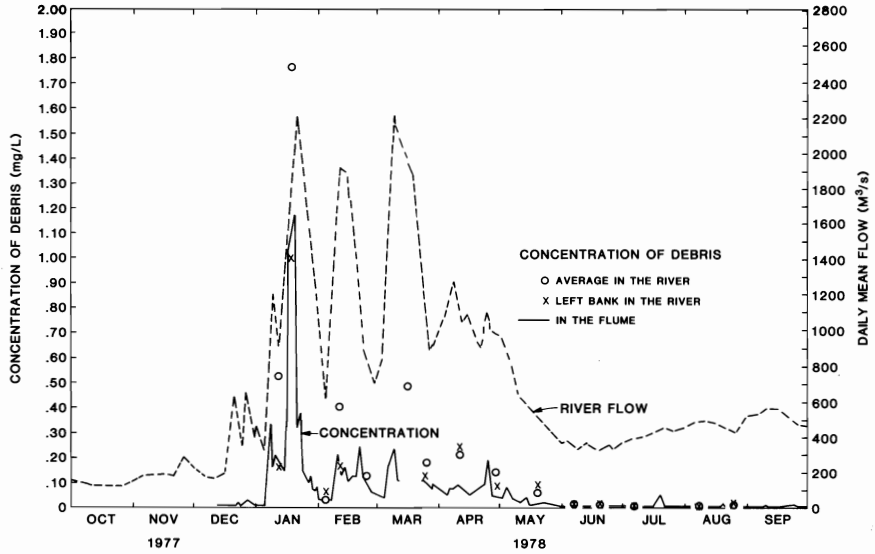
A Secchi Disk reading was taken each sample day as a measure of the turbidity in the river. Figure 8 includes the readings and riverflow and depicts the increase in turbidity with the increase in flow.

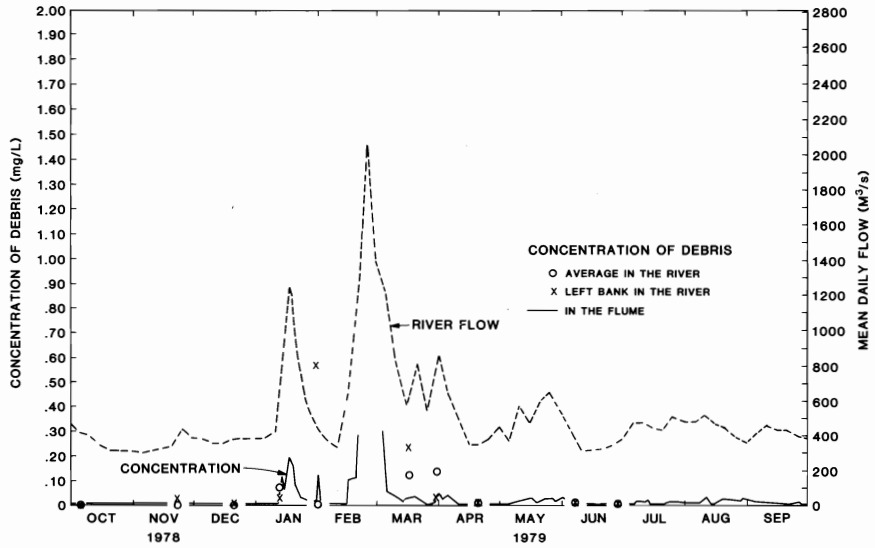
Figure 8. Turbidity in the Sacramento River at Hood - 1975-1979



As mentioned previously, samples were taken from the test flume three times a week during clogging and cleaning tests. Figure 9 contains data as collected during 1978, 1979, and 1980 in the flume, along the left bank, and for the river average. A qualitative comparison of the material collected in the flume with that in the river indicated they were similar. (Even the leaves came through the pump intake in one piece.) Figure 9 demonstrates the sharp peak and short duration of the debris load during the first high riverflows of the winter season.

Figure 9. Flow in the Sacramento River and concentration of debris at the Hood Test Facility





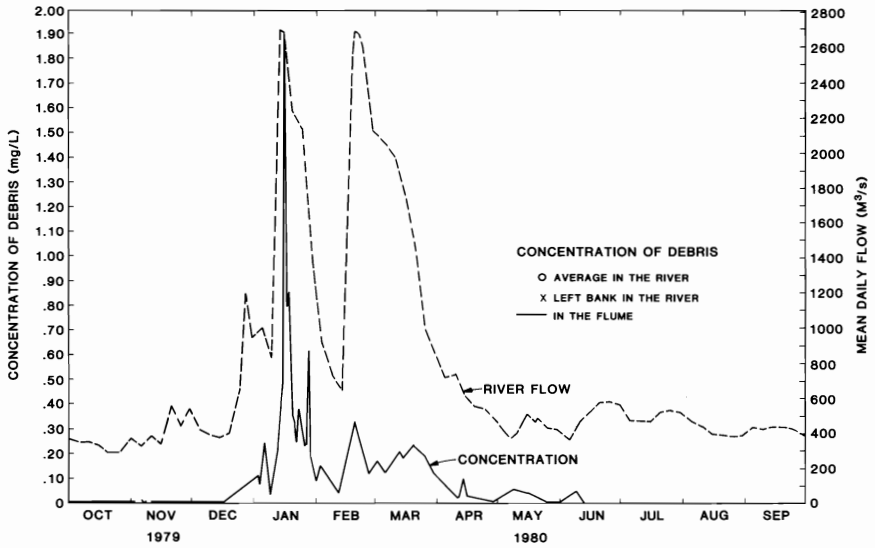
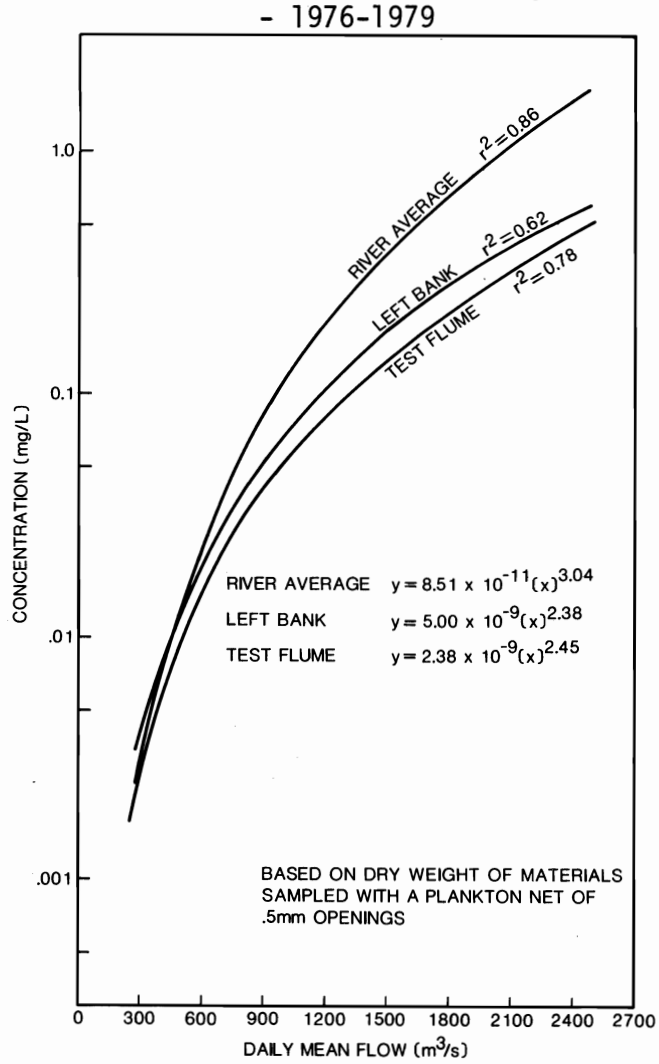


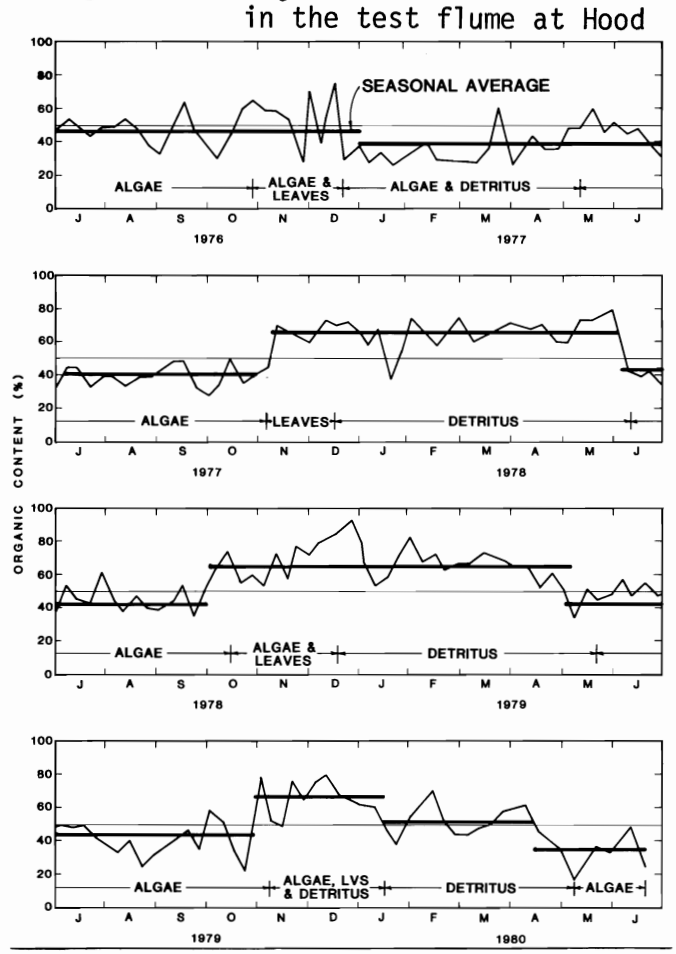
Figure 10 shows the correlation with riverflow for these three sets of data since start of operation of the test facility in 1976. Flow in the Sacramento River at Sacramento would be less than 680 m^3/s (24,000 ft^3/s) about 75 percent of the time with operation of the Peripheral Canal. In this range, test flume debris closely resembled river debris in content and concentration. The density of sampled debris was estimated by weighing wet and dry samples and measuring the volume in a graduated cylinder, loose and lightly tamped. The average density was 1 800 kg/m^3 (112 lb/ft^3) wet and 260 kg/m^3 (16 lb/ft^3) dry.

Figure 10. Concentration of debris in the River and in the Hood Test Facility - 1976-1979



Average weekly organic-inorganic ratios calculated from debris sampled in the flume are shown in Figure 11. The variation in samples from day to day was at times extreme; weekly averages gave a smoother trend. Debris samples were about 40 percent organic material during summer and fall low flow periods when sample content was principally algae. The samples were about 60 percent organic material during normal winter, spring, and fall periods when sample content was principally detritus with sand, silt, and leaves. Because ash content of plant and animal material is generally on the order of 10 to 15 percent, the high percentage of inorganic material shown by the debris sampling data indicates that the nets were capturing suspended sediment, probably because the net openings were plugged and finer particles became trapped in the debris.

Figure 11. Organic content of debris in the test flume at Hood



The concentration of debris in the river, sampled with the 0.5-mm opening plankton net, ranged up to 7.6 mg/L (point sample), and the estimated total daily load ranged up to 0.16 x 10^6 kg, based on dry weights. For comparison, Graves (1977) reported historical suspended sediment concentrations in the Sacramento River ranged to 2 000 mg/L and daily load to 500 x 10^6 kg. Although sediment was observed in the debris samples, these data indicate that most of the suspended sediment passed through the plankton nets.

Results of the debris survey can be summarized as follows.

- Three distinct seasonal periods of debris were observed:
  - Large quantities of fibrous decomposing plant material with sand and silt during winter and spring high flows.
  - Relatively small quantities of algae and animal material during summer, fall, and winter low flows.
  - Abundant leaves with algae for about 4 to 6 weeks during October, November, and December.
- Debris concentration and abundance fluctuated with riverflow.
- Highest debris load occurred with first high flow.
- Debris content was uniform across the river.
- Debris concentration increased with depth and toward the middle of the river.
- Waste from upstream agricultural practices did not appear to influence the debris load.

Screen Clogging Tests

Screens with small apertures (<1 cm) placed in flowing water will eventually plug. The plugging rate will depend on hole size, debris in the water, flow rate, aquatic growth on the screens, and possibly corrosion. In this portion of the clogging study, the objectives were to determine how fast screens clog and to determine how environmental and experimental variables affect the clogging rates. As defined earlier, the clogging rate is the increase in head loss with time due to accumulating debris and aquatic growth. Head loss is a measure of the energy loss of the water flowing through the screen.

Test Facility and Methods

Screen clogging tests were conducted in the Hood Fish Screen Test Facility (Figure 2, page 4). Figure 12 is a diagram of the general arrangement of the facility. Water was pumped from the river into the approach flume by two 149 kW (200 hp), 0.85 m^3/s (30 ft^3/s) unscreened pumps. A bypass valve on the discharge line from one of the pumps allowed the total flow to be adjusted to the amount needed for each test. The flow was maintained throughout each test and was the sum of that flow required to provide a specified normal velocity (approach velocity) to each test screen and that flow required for a specified bypass velocity. The approach flume had side overflow weirs to carry off excess water resulting from tidal fluctuations at the pump intake. The approach flume thus was a constant head source of water 1.2 m (4 ft) deep, 1.8 m (6 ft) wide, and 12 m (40 ft) long (Figure 13).

Figure 12. General arrangement of the Hood Fish Screen Test Facility

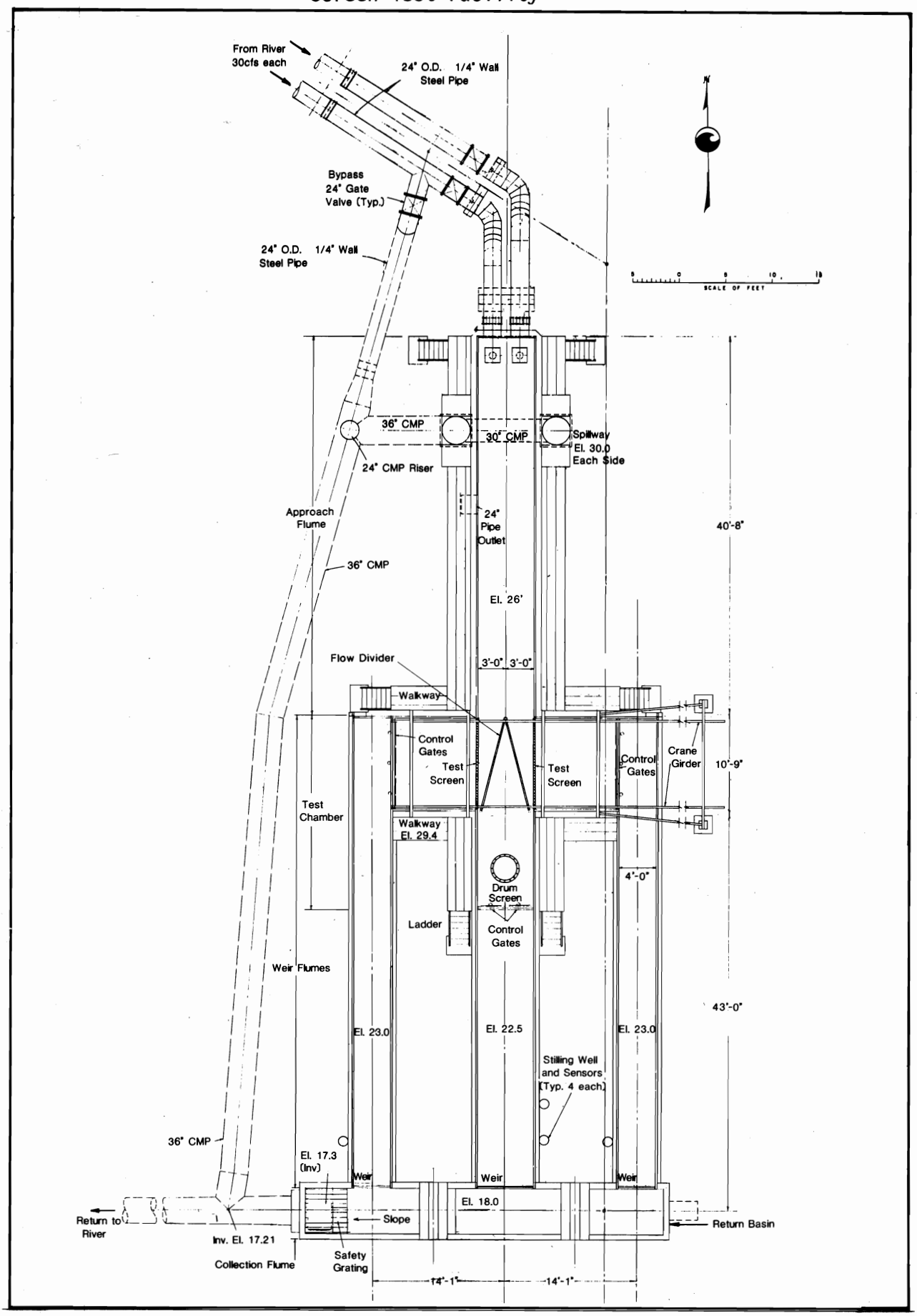
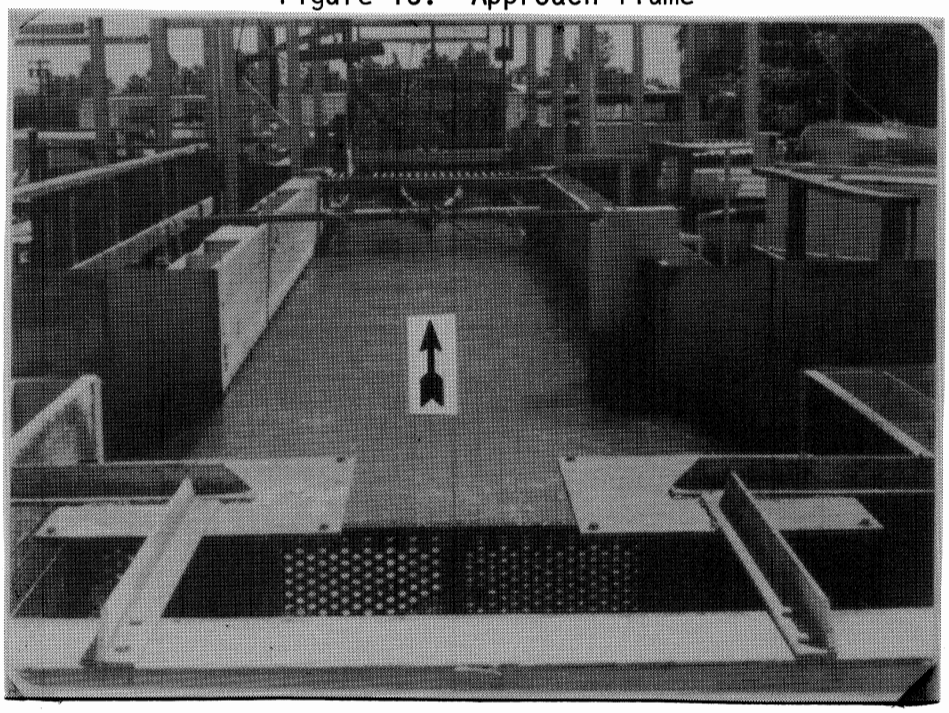


Figure 13. Approach flume



Water then flowed by gravity into the test chamber, where flows were diverted through each 3 m (10 ft) long test screen or bypassed down the center (Figure 14). Two screens were tested simultaneously, one on each side of the test chamber. To maintain a constant velocity through the test chamber, a "V" shape, solid sheet metal, hinged flow diverter was installed midway between the two screens. The downstream ends were adjusted toward or away from each screen to allow the proper flows to bypass each screen.

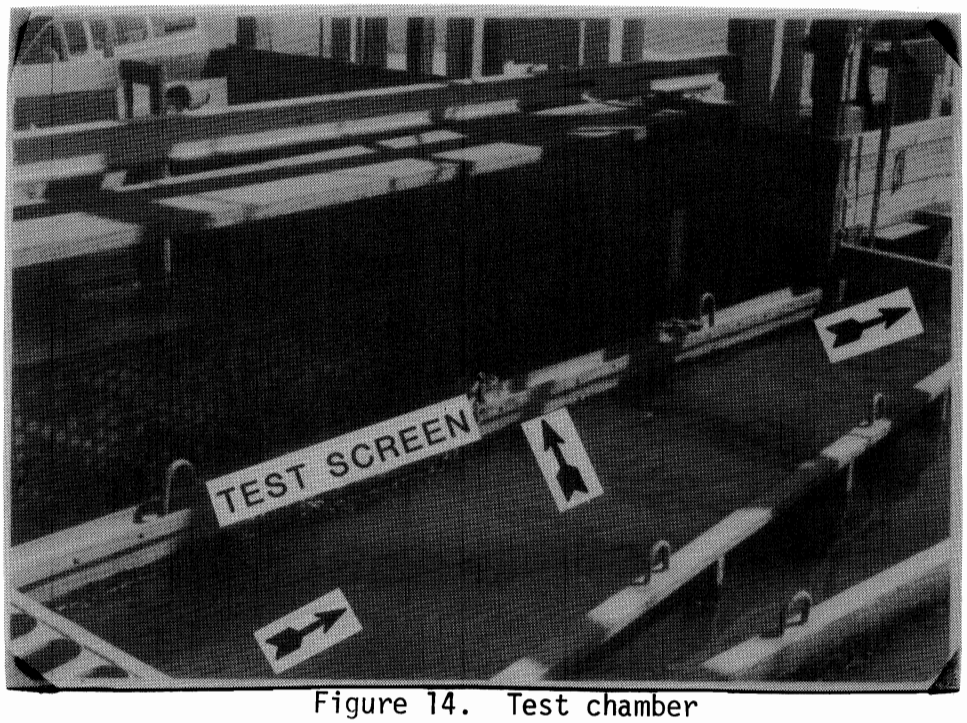


Figure 14. Test chamber

Beyond the test chamber, the flows passed through slide gates and dropped into separate flumes, 15 m (50 ft) long, each with a calibrated weir. Water level sensors at each weir activated a hydraulic control system to the slide gates when the water level rose or fell beyond the sensor. Thus, the system adjusted automatically to maintain constant flows (and therefore approach velocities) through and past each test screen. Downstream of the weirs, all water spilled into a collection flume and discharged back into the river.

The top portion of Table 2 lists all materials and specifications for flat screens tested in a vertical orientation. Experimental test variables included water velocities normal to the screen (V_n = 0.06 to 0.24 m/s (0.2 to 0.8 ft/s)) and parallel to the screen (V_p = 0.15 to 0.76 m/s (0.5 to 2.5 ft/s)). The velocity component V_n is in front of the screen, not through the screen. The flat screens had 2.7 m^2 (29 ft^2) of test area, 0.9 m (3 ft) high by 3 m (9.7 ft) long. Uncontrollable variables were seasonal changes in debris content and concentration in the Sacramento River.

Screen 1, the 4 mm (5/32 in) perforated plate (4 mm PP), was selected as the control screen and was tested continuously to provide estimates of annual variability of clogging rates. The control screen size was selected because biological tests conducted earlier by the Department of Fish and Game (Fisher, 1978) determined this screen size to be 100 percent efficient for screening the post-larval fish species and size occurring at Hood. All other screens were tested less often but simultaneously with the 4 mm PP in order to correlate results throughout the year.

The usual procedure for clogging tests was:

1. Install test screens and set water level sensors to maintain desired test velocities.

2. Start pumps.

3. Adjust bypass valve to maintain a minimum flow over bypass weirs.

4. Record hourly all water levels in approach flume, in test chamber (four at each test screen), and at weirs.

5. Continue testing around the clock until 0.3 m (1.0 ft) of head loss was accumulated across the screen, or until 3 weeks had elapsed. (These were arbitrary limits. The assumption was that cleaning would be done at more frequent intervals to conserve energy for pumping and to maintain uniform velocities for better fish survival.)

6. Raise test screens out of the water and inspect. Take pictures of both sides and take samples of accumulated debris for laboratory analysis.

Screens of different orientation or configuration that were tested are also described on Table 2. The procedure for clogging tests was similar to that for the flat screens except for measuring the clogging rate of the round screens. The decrease in discharge was monitored rather than head loss because the center bottom discharge from the round screens into a lower flume did not allow a proper downstream water surface elevation measurement.

Table 2. Test Screens and Specifications.

VERTICAL FLAT SCREENS

Perforated Plate (PP)

Screen No.	Material	Hole Diameter (mm)	Plate Thickness (mm)	Staggered Spacing (mm)	Holes Per cm^2	Percent Open Area	Weight Per m^2 (kg)
1	SS-304	4.0	1.5	5.6	3.7	46.2	5.7
2	SS-304	4.8	1.5	6.4	2.8	51.0	6.3
3	SS-304	6.4	1.5	7.9	1.7	58.0	7.1
4	AL-6061-T4	4.0	1.5	5.6	3.7	46.2	2.0
5	(Same as No. 1 with the 63.5 mm standard corrugations)						

Woven Wire Square Mesh (SM)

Screen No.	Material	Mesh Per cm	Wire Diameter (mm)	Opening Width (mm)	Opening Diagonal (mm)	Percent Open Area	Weight Per m^2 (kg)
6	SS-304	2.7	.89	2.7	3.9	57.2	2.8
7	SS-304	2.4	.89	3.4	4.7	62.7	2.3
8	SS-304	1.6	1.60	4.7	6.7	56.0	5.1
9	Polyester	2.4	.99	3.4	4.7	59.0	0.5

Woven Wire Slotted Mesh (Sl M)

Screen No.	Material	Slot Opening (mm)	Wire Diameter (mm)	Percent Open Area	Weight Per m^2 (kg)
10 1/	High Carbon Steel	2.0x13	1.6	50.1	5.8
11 2/	High Carbon Steel	2.5x9.4	1.1	61.2	3.4

Welded Wedge-Wire Slotted Screen (WWW)

Screen No.	Material	Slot Opening (mm)	Wire Thickness (mm)	Percent Open Area	Weight Per m^2 (kg)
12	SS-304	2.4x continuous	2.0	54.0	27.1

SCREENS OF OTHER ORIENTATION OR CONFIGURATION

Perforated Plate (PP)

13 (Same as No. 1 parallel to approaching flow but slanted 45 degrees)

Welded Wedge-Wire Slotted Screen (WWW)

14 (Same as No. 13, fabricated into a 0.9 m diameter drum with vertical axis, stationary)
15 (Same as No. 14, continuously rotating)
16 (Same as No. 12, two fabricated round screens, each 0.6 m in length and diameter, joined together in a "T")

1/ Had a variable thickness coating of an algaecide -- Tributyltin Oxide.

2/ Had a thin coating of a fused epoxy.

Results and Discussion

Table 3 contains the number of tests and the range of debris concentration for each screen at each test velocity.

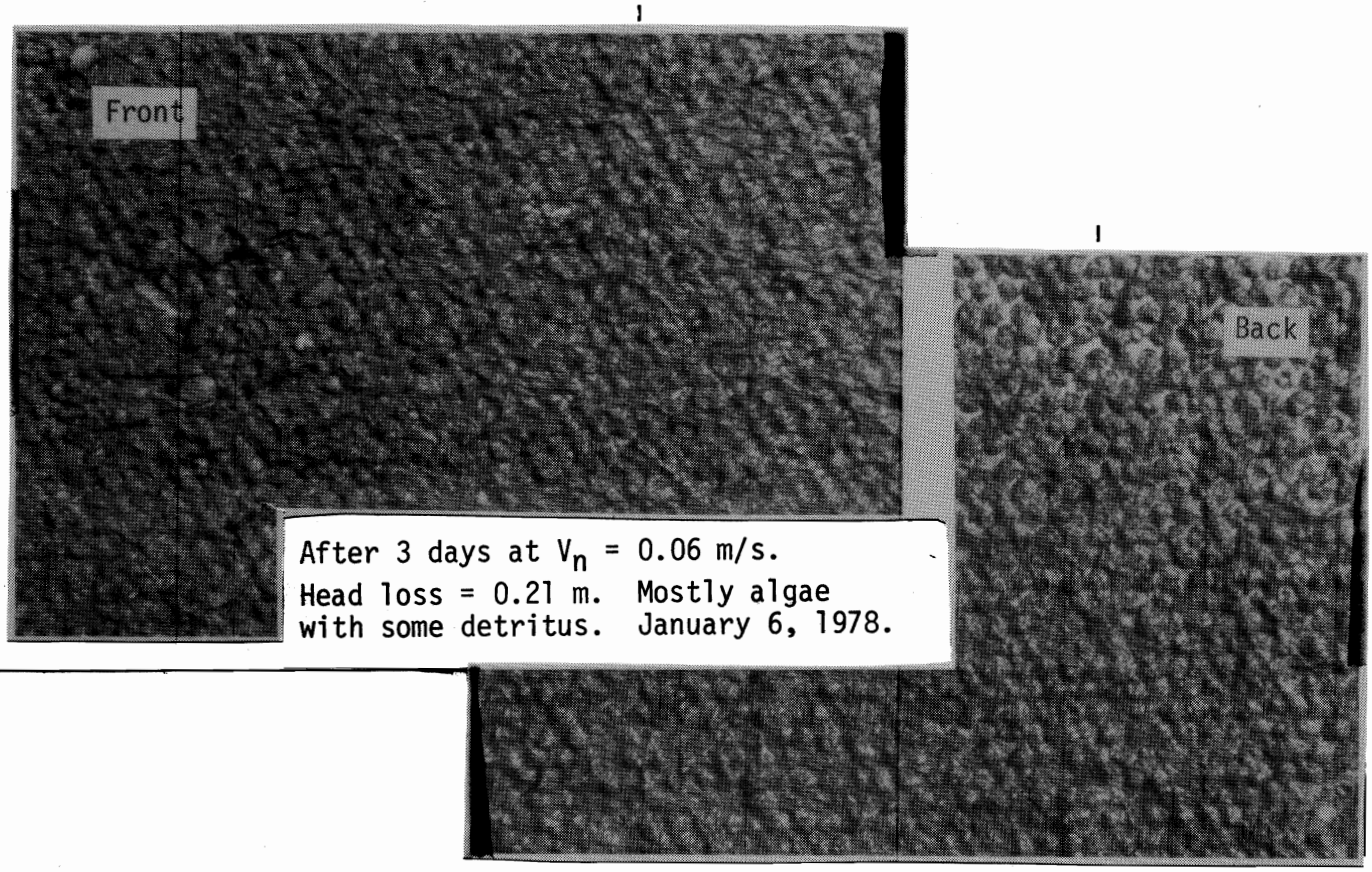
All screens accumulated detritus and algae during testing. The clogging material was the same as that collected in flume and river sampling described previously. Clogging was usually uniform across the screen surface due to the velocity controls in the facility. The one exception was the drum screen with axis vertical and no rotation. Larger particles of debris collected on a downstream lower portion of the drum.

When the drum was rotated during a clogging test, the screen was completely free of any larger debris particles. Evidently the larger particles were washed off the screen with the bypassing flow across the side of the drum. Figures 15 through 19 are photographs of screens clogged with different types of clogging material.

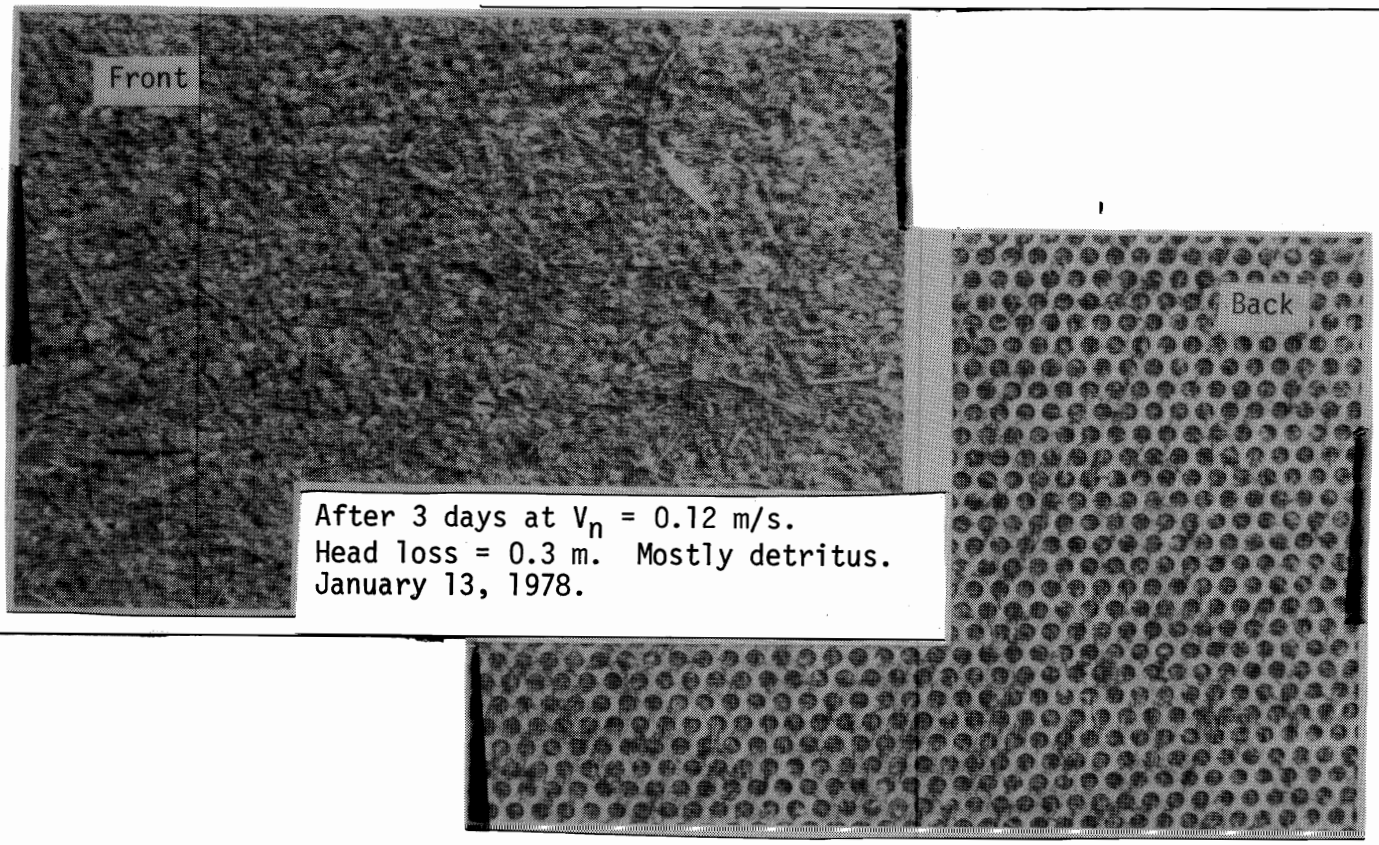
Table 3. Screen Clogging Tests

	Number of Tests				Range of Debris Concentration (mg/L)			
	Velocity Vn (m/s)				Velocity Vn (m/s)			
Screen	0.06	0.12	0.18	0.24	0.06	0.12	0.18	0.24
1. 4mm PP	54	77	84	101	.001-.400	.001-.319	.004-.412	.004-.403
2. 4.8 mm PP	4	8	10	12	.001-.224	.001-.282	.009-.360	.006-.352
3. 6.4 mm PP	2	2			.241-.287	.036-.263		
4. 4 mm PP - Aluminum		1	2			.003	.003	
5. 4 mm PP - Corrugated		1	1			.048	.112	
6. 2.7 mm SM	2	4	1		.001	.001-.005	.015	
7. 3.4 mm SM	6	16	11	11	.001-.096	.001-.244	.013-.360	.007-.309
8. 4.7 mm SM		1				.002		
9. 3.4 mm SM - Polyester		16	1			.028-.124	.042	
10. 2.0 mm SLM	1	2	2	2	.026	.033-.036	.021-.035	.011-.021
11. 2.5 mm SLM		4		2		.003-.007		.005-.006
12. 2.4 mm WWW	10	11	15	7	.017-.189	.008-.234	.012-.234	.010-.223
13. 4 mm PP - Slanted	3	5		3	.022-.106	.002-.019		.007-.012
14. 2.4 mm WWW - Drum	1	4	4	4	.002	.009-.331	.006-.530	.008-.393
15. 2.4 mm WWW - Rotating	1	2	2		.037	.448	.530-.622	
16. 2.4 mm WWW - Tee	3	4			.015-.076	.212-.335		

Figure 15. Clogged 4 mm perforated plate

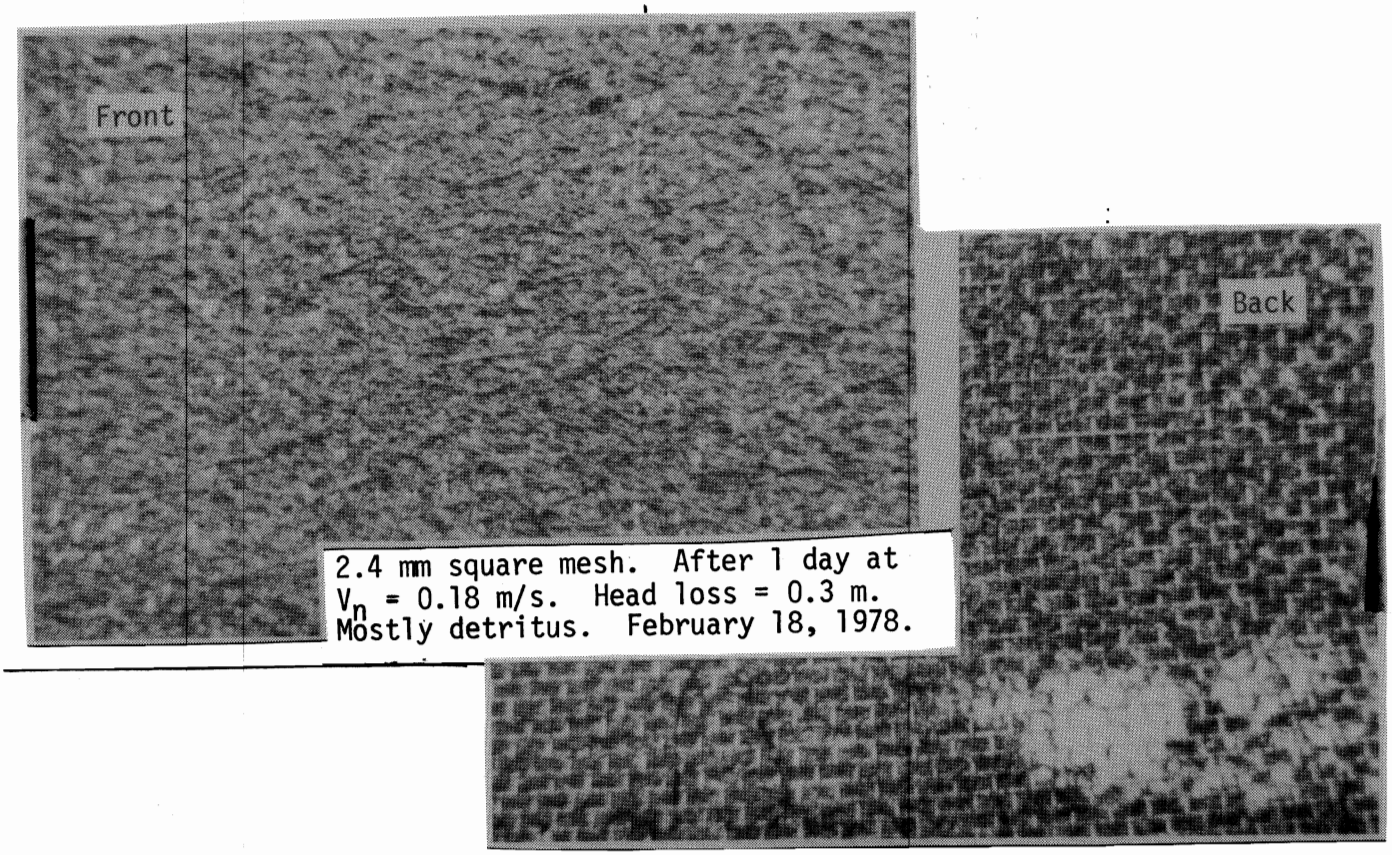


After 3 days at V_n = 0.06 m/s.
Head loss = 0.21 m. Mostly algae with some detritus. January 6, 1978.

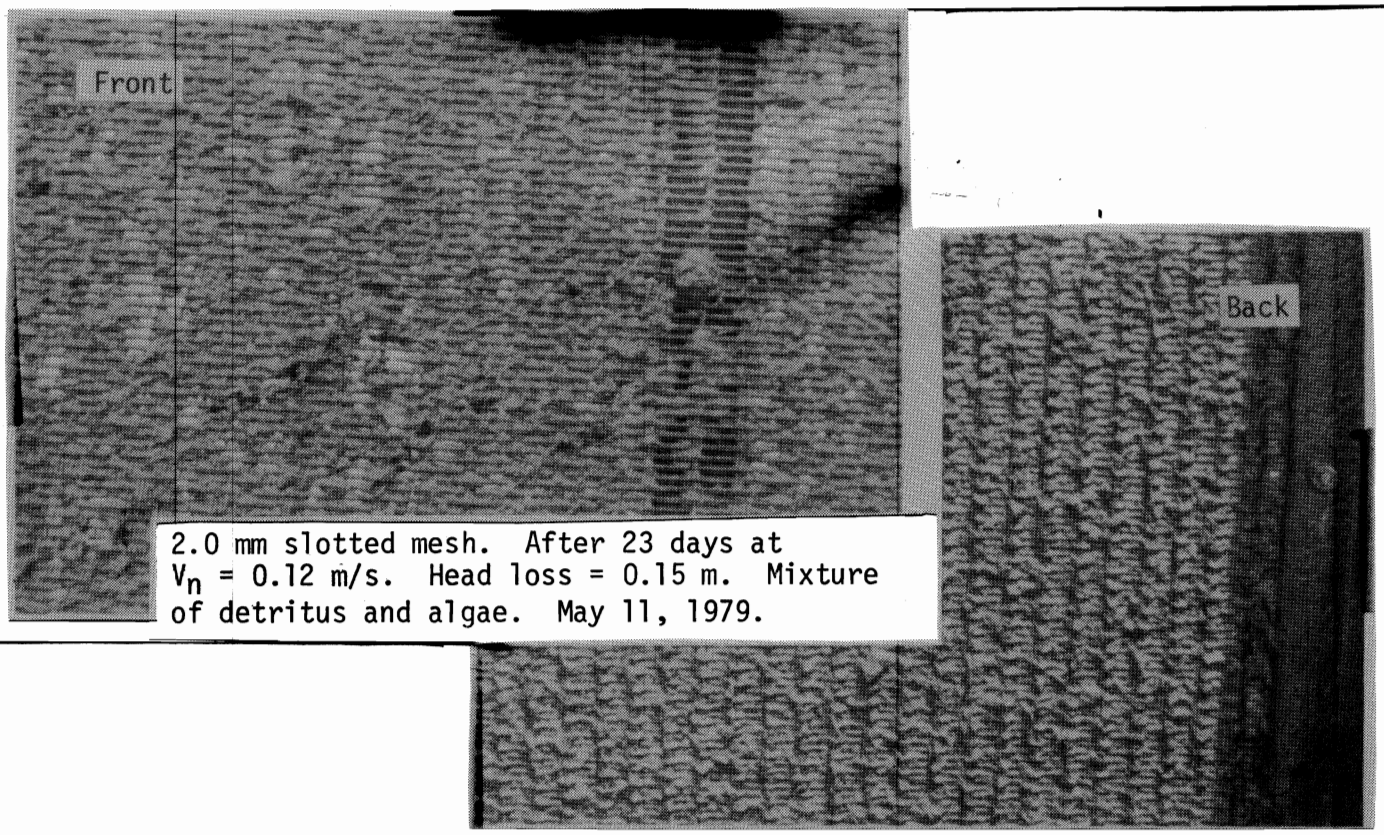


After 3 days at V_n = 0.12 m/s.
Head loss = 0.3 m. Mostly detritus.
January 13, 1978.

Figure 16. Clogged woven wire mesh



2.4 mm square mesh. After 1 day at V_n = 0.18 m/s. Head loss = 0.3 m. Mostly detritus. February 18, 1978.



2.0 mm slotted mesh. After 23 days at V_n = 0.12 m/s. Head loss = 0.15 m. Mixture of detritus and algae. May 11, 1979.

Brief and unusual conditions dramatically affected clogging rate. The worst condition tested was during January 1978 -- the first high riverflow after two years of drought. In less than one hour, 0.3 m (1.0 ft) of head loss was accumulated. A debris condition that did not occur during the test program (and may well be the worst possible) would be high riverflow during November or December when leaves are abundant in the water.

Figure 20 shows the operating time for clogging to cause a head loss of 0.3 m (1.0 ft) on the vertical flat screens.

Figure 21 shows the relationship between the 4 mm perforated plate (PP) and 2.4 mm welded wedge-wire (WWW) vertical flat screens and the screens of different orientation and configuration. Test results for both figures were adjusted to assumed conditions of V_n = 0.06 m/s (0.2 ft/s) and debris concentration of 0.03 mg/L. This adjustment is described later. The assumed V_n is the most probable design velocity at this time based on biological testing. River debris concentration would be less than 0.03 mg/L 75 percent of the time at Hood with operation of the Peripheral Canal, based on projected operation studies.

Figure 17. Clogged 2.4 mm welded wedge-wire slotted screen

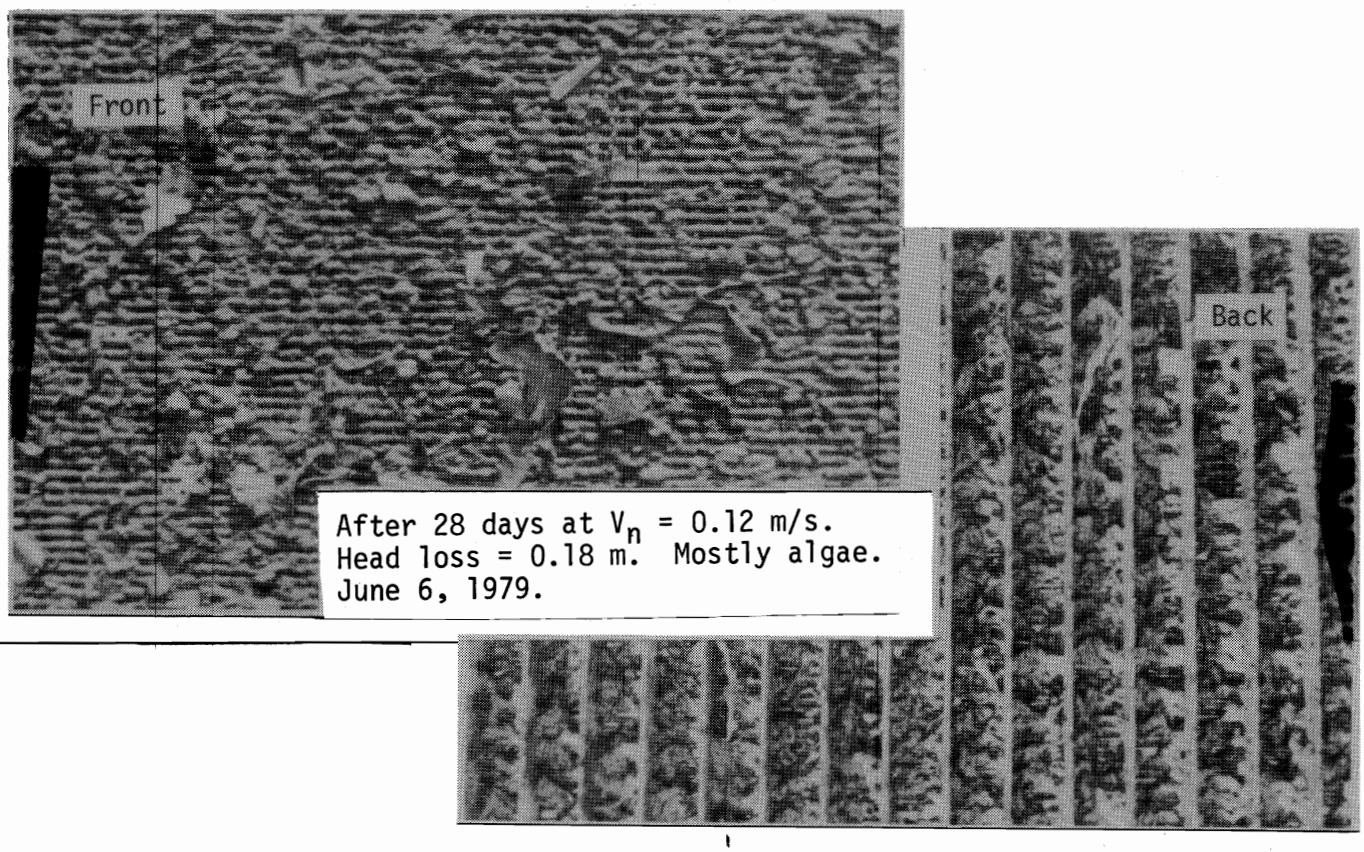
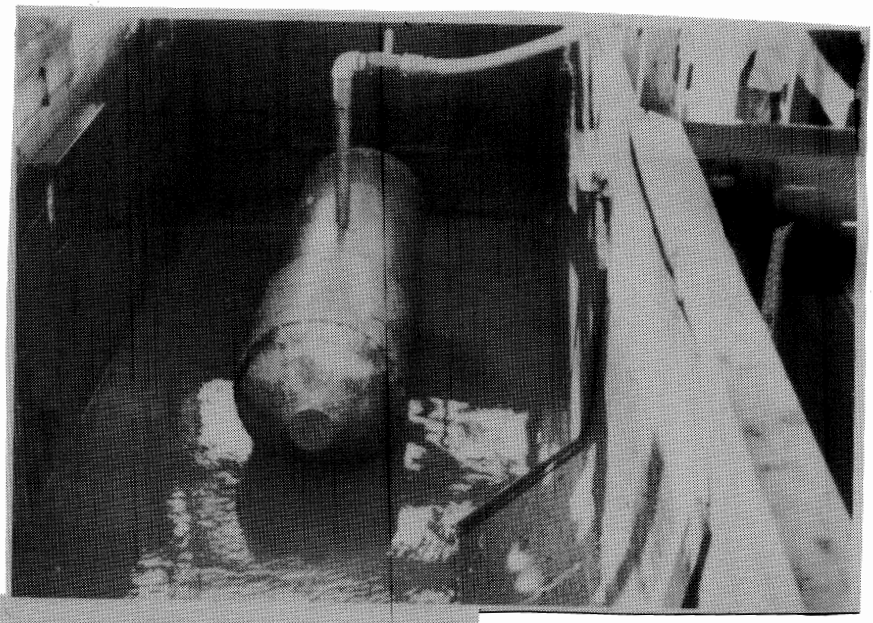
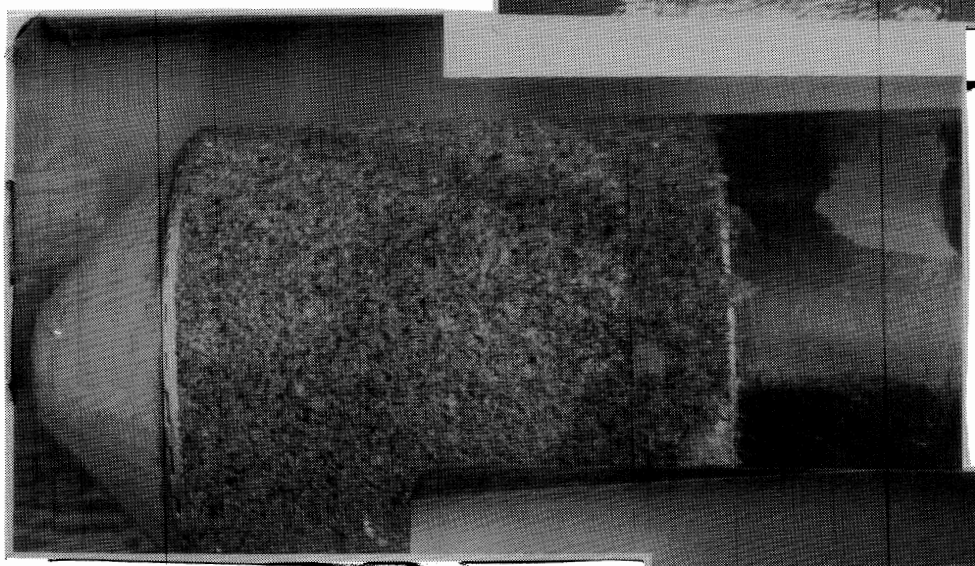
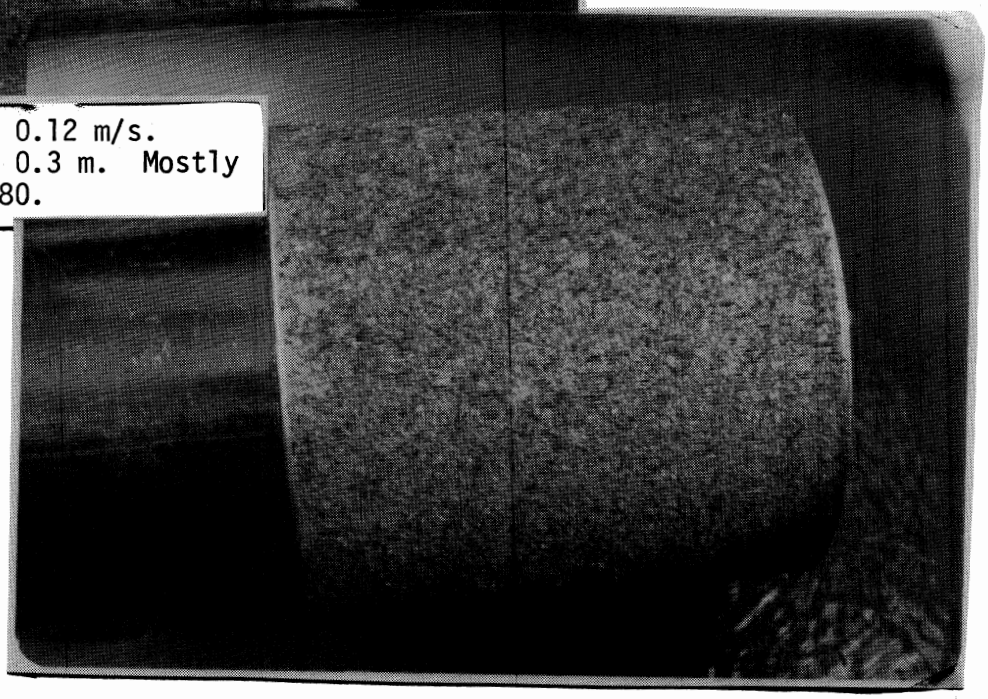


Figure 19. Clogged 2.4 mm welded wedge-wire slotted Tee Screen





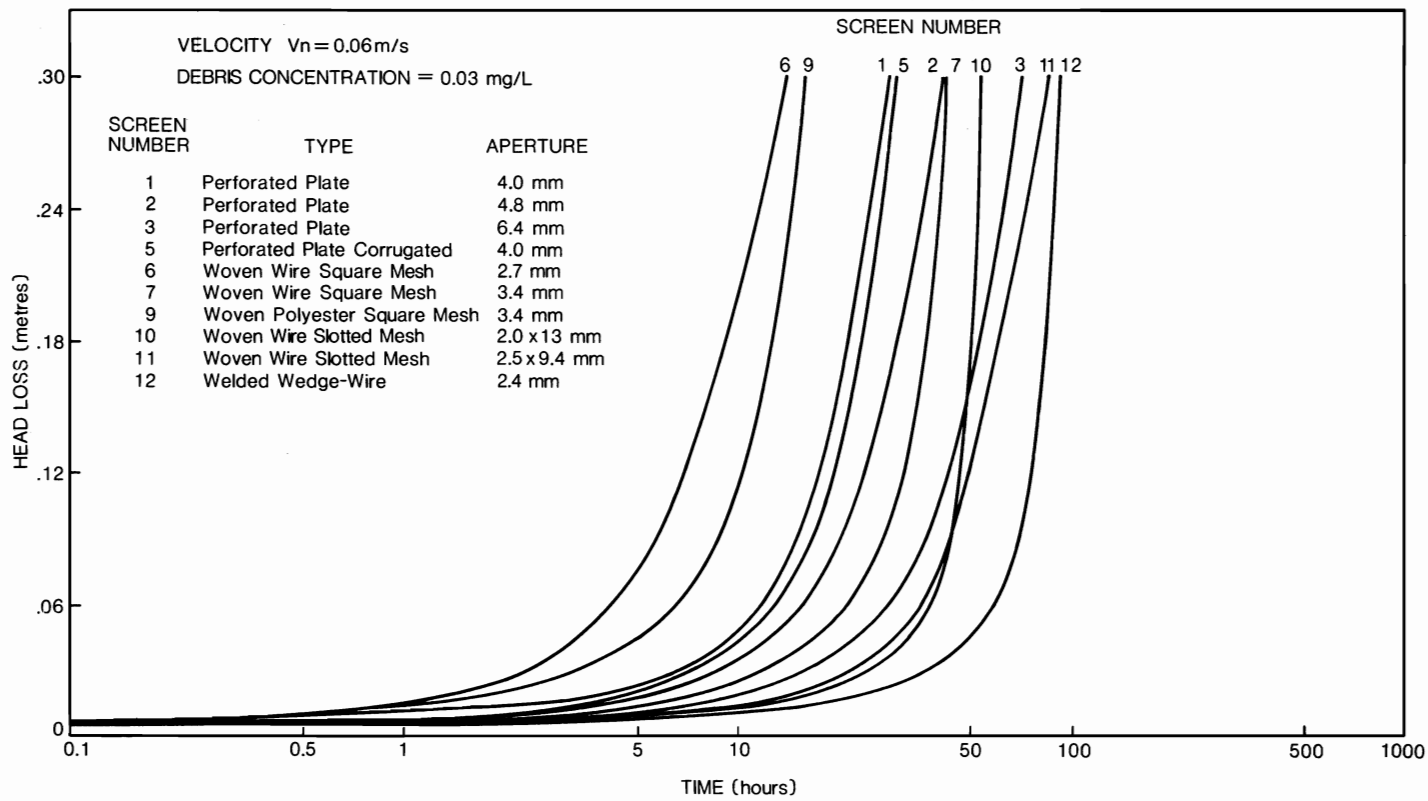
After 43 hours at V_n = 0.12 m/s.
Head loss estimated at 0.3 m. Mostly detritus. March 3, 1980.



The figures indicate that the 2.4 mm WWW screen design, with slots parallel to flow, takes three to five times as long to reach a specified head loss as 4 mm PP. Both screens are equally effective for screening small fish. When the wedge-wire is in the form of a drum screen, the time to reach a specified head loss is further increased. No tests were conducted on a perforated plate drum screen. The following data can be obtained from the graphs:

Screen Type	Time to 0.06 m (0.2 ft) Head Loss
4 mm perforated plate	
flat, vertical	12 hrs
flat, slanted	30 hrs
2.4 mm wedge-wire	
flat, vertical	60 hrs
drum not rotating	140 hrs
drum rotating	290 hrs
"T" drums	46 hrs

Figure 20. Clogging rates of vertical flat screens

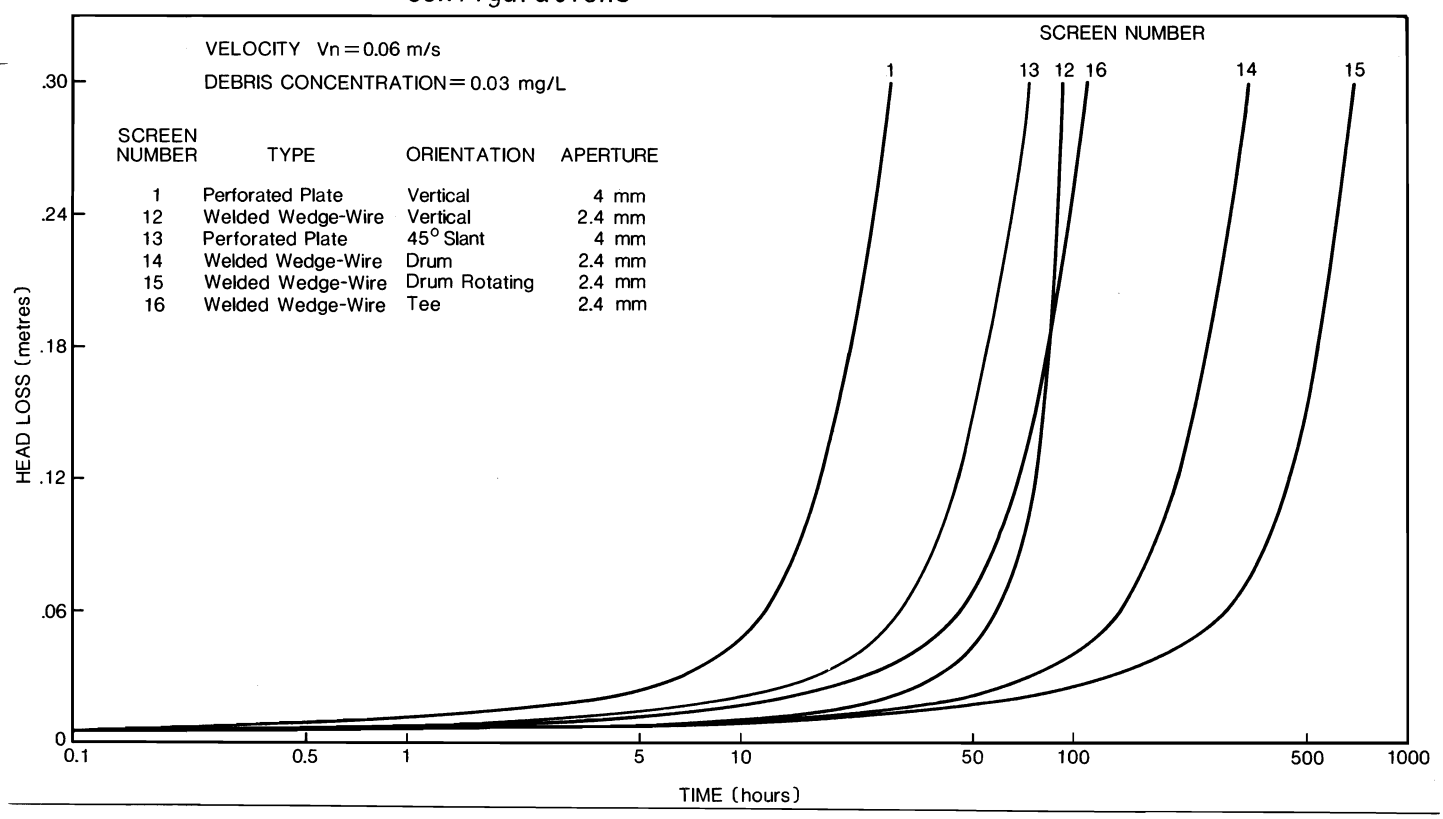


These data demonstrate the potential advantage of slower clogging rates with the use of wedge-wire.

Figures 22 and 23 summarize all the data for the 4 mm PP flat screen. As would be expected, the time to reach a specified head loss decreased with increasing debris concentration and normal velocity. Data from 35 tests of 4 mm PP at V_n = 0.06 m/s (0.2 ft/s) were used to develop Figure 22. Actual debris concentrations ranged from 0.001 to 0.40 mg/L. Regression analysis of concentration on time for each 0.03 metre of head loss yielded curves with average correlation coefficient (r^2) of 0.88. Clogging time to each 0.03 m from the regression curves resulted in Figure 22.

Data from 35 to 52 tests at each test velocity shown were used to calculate each curve on Figure 23. Flume concentrations ranged from 0.001 to 0.41 mg/L. Regression analysis of concentration on time yielded curves with correlations of 0.66 to 0.88.

Figure 21. Clogging rates of various screen orientations and configurations



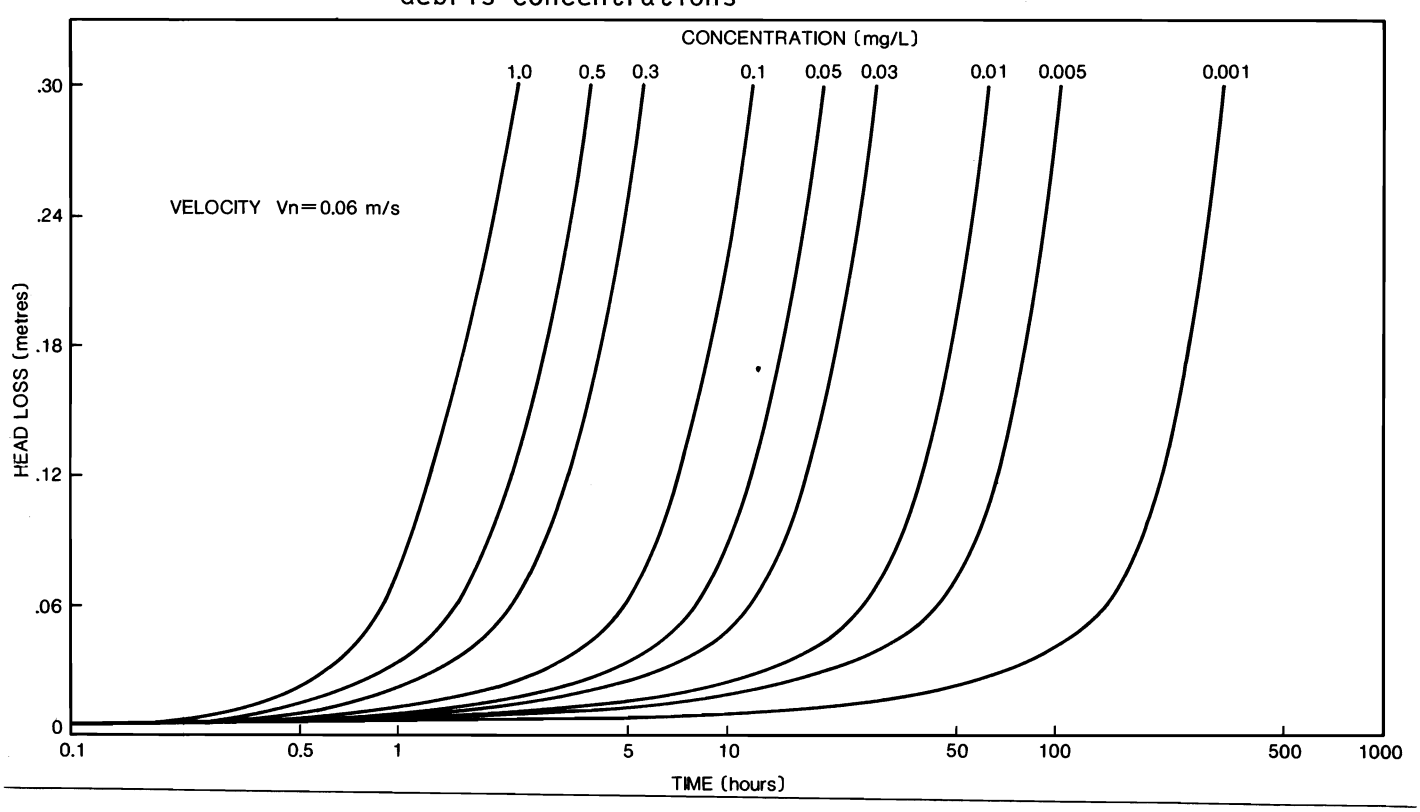
Figures 22 and 23 show that river debris concentration and velocity normal to the test screen both greatly affected the clogging rate. Changing the velocity component parallel to the test screens did not significantly affect clogging rates.

Parallel velocities were determined using the continuity equation, $V = Q/A$, and the total flow and area in the approach flume. The same velocity was maintained past each screen by adjusting the flow diverters.

The range of parallel velocities (V_p) tested for each normal velocity (V_n) was limited due to the fixed dimensions of the channel and test screens and the hydraulic capacity of the facility. The test velocities were:

V_n		V_p	
m/s	ft/s	m/s	ft/s
0.06	0.2	0.15 to 0.58	0.5 to 1.9
0.12	0.4	0.27 to 0.79	0.9 to 2.6
0.18	0.6	0.43 to 0.82	1.4 to 2.7
0.24	0.8	0.52 to 0.76	1.7 to 2.5

Figure 22. Clogging rates of 4 mm perforated plate at various debris concentrations



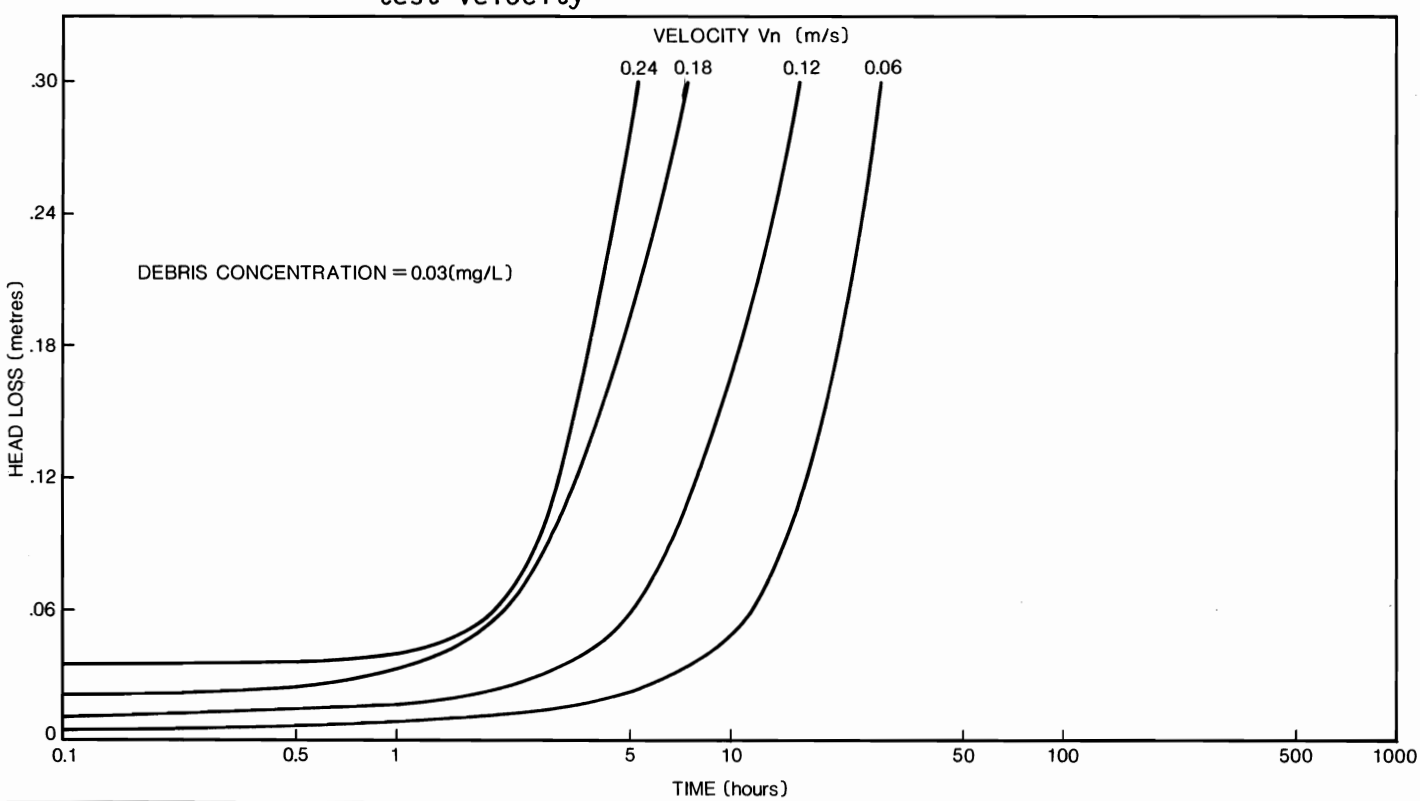
To determine if parallel velocities actually influenced clogging rates, an analysis of variance (ANOVA) was made on the tests of 4 mm PP. The clogging times for tests in which the screen clogged to a full 0.3 m (1.0 ft) head loss were tabulated according to normal velocities and then grouped by parallel velocities. All times were adjusted for a common debris concentration for analysis. An individual analysis was performed for each normal velocity. The results are as follows, significant at the 95 percent level:

ANOVA for Parallel Velocity

V_n	No. of V_p Groups	Total No. of Clogging Tests	Calculated F Ratio
0.06 m/s	3	12	0.99
0.12 m/s	6	23	1.50
0.18 m/s	5	27	1.85
0.24 m/s	4	21	0.16

The F ratios are all less than critical values; therefore, parallel velocities did not significantly affect screen clogging rates.

Figure 23. Clogging rates of 4 mm perforated plate for each test velocity

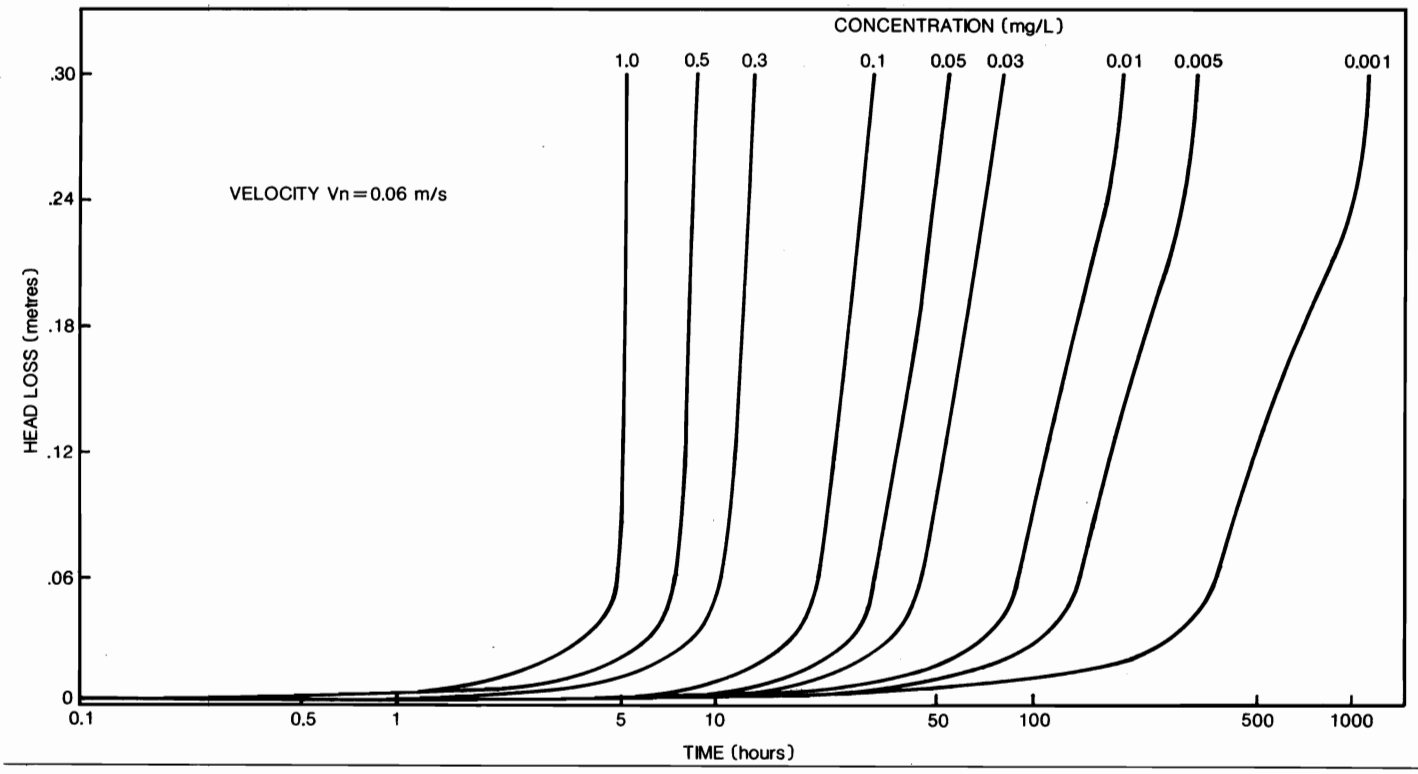


The curves for 4 mm PP on Figures 20-23 are the same. Curves for the other test screens on Figures 20 and 21 are based on data from tests summarized in Table 3. The time for each test was normalized to clogging time at 0.03 mg/L by using the ratio of time required for 4 mm PP at the same concentration and at 0.03 mg/L from Figure 22. The results were further adjusted to clogging time at V_n = 0.06 m/s (0.2 ft/s) by using the ratio of time required for 4 mm PP at the same V_n and at 0.06 m/s from Figure 23.

Sufficient data were collected on 2.4 mm WWW to calculate a complete set of clogging curves for debris concentration and approach velocity. These are presented as Figures 24 and 25.

The "trap efficiency" of 4 mm PP was determined by two special techniques. Trap efficiency is the amount of debris retained on the screen as a percentage of the amount exposed to the screen. One method was to sample for debris in the approach flume upstream of the test screen and in the weir flume downstream

Figure 24. Clogging rates of 2.4 mm welded wedge-wire at various debris concentrations



of the test screen with the plankton nets used in the debris studies. This was done at different screen head losses during a clogging test. The difference in the measured concentrations was assumed retained on the test screen.

The second method was to wash all the accumulated debris from a 0.09 m^2 (1.0 ft^2) section of screen into a special box that was held tight against the screen. The timing was such that aquatic growth did not have time to accumulate on the screen. The approach flume debris concentration was measured and the amount of debris exposed to the screen was calculated. The ratio of the material collected in the box to that exposed to the screen gave the trap efficiency. This method also was done at different screen head losses during a clogging test. The first method gave the trap efficiency at the time of sampling and the second method gave the average trap efficiency up to the time of sampling. The results are plotted in

Figure 25. Clogging rates of 2.4 mm welded wedge-wire at each test velocity

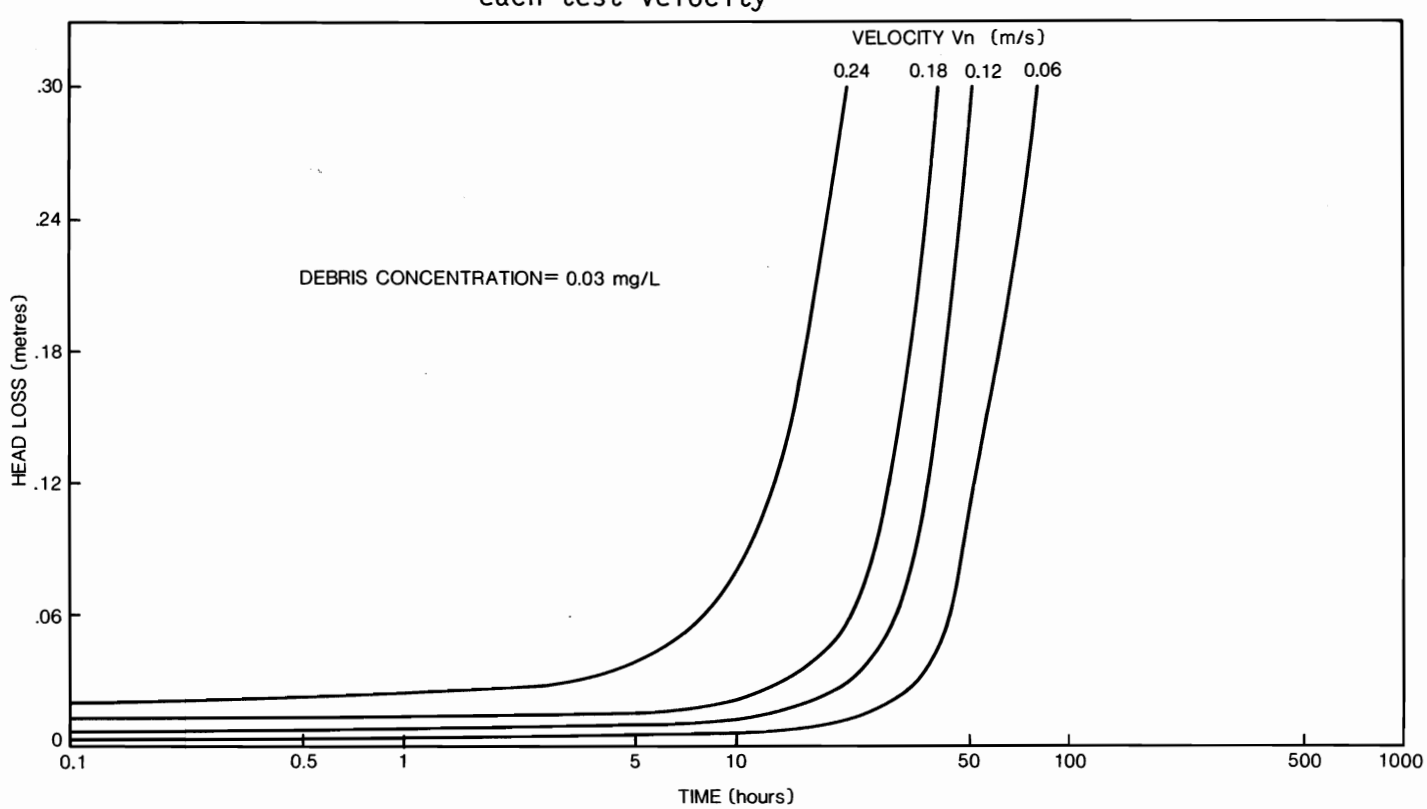
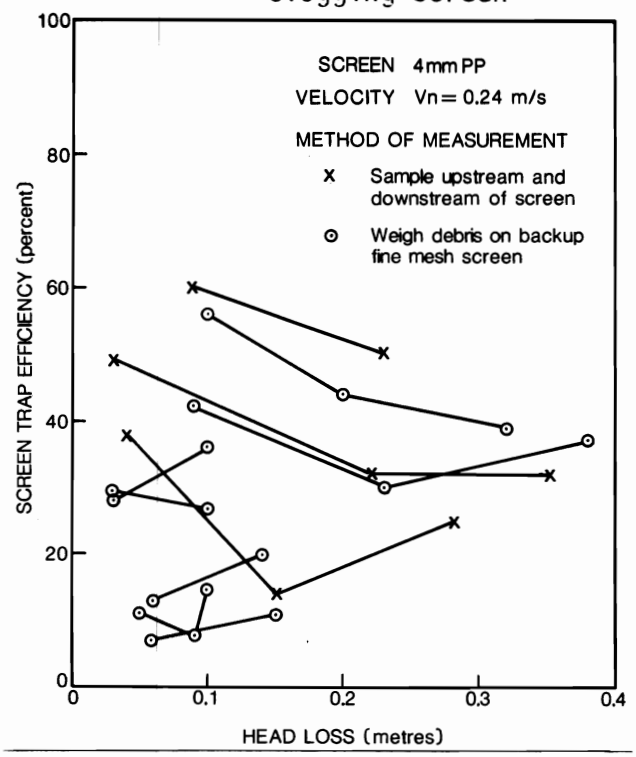


Figure 26. Data collected during the same clogging test are connected by solid lines.

Figure 26. Percent of debris in water trapped by clogging screen

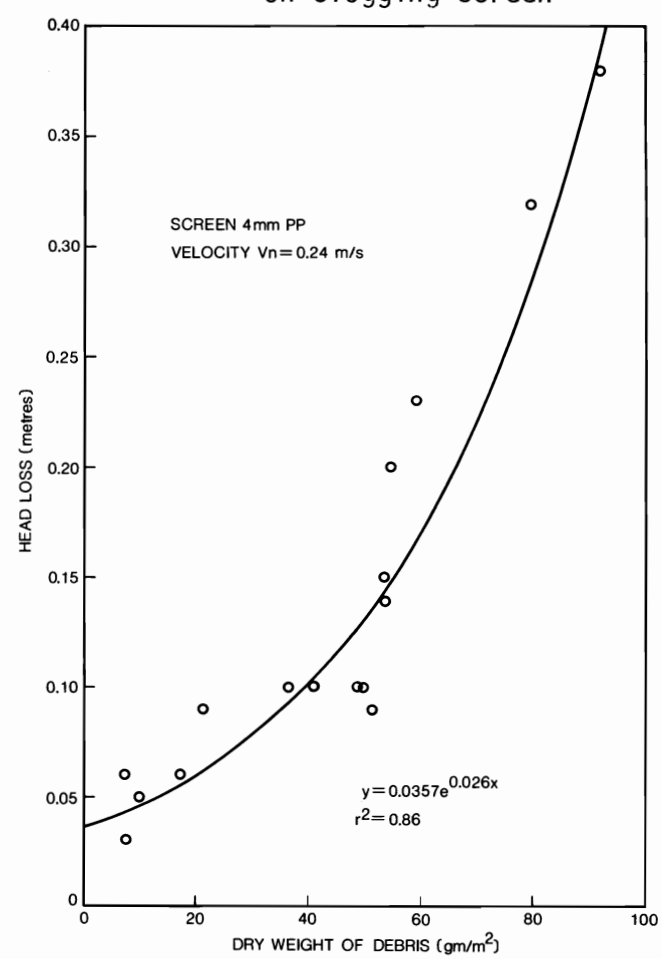


The trend of less trapping of debris with increased clogging during most of the tests was not expected. It may be that as the screen clogged, through-hole velocity increased and some of the previously accumulated debris was washed through the screen. The total amount of material on the screen increased with time and head loss as shown in Figure 27, but it was a smaller percentage of the total approaching the screen. Values in Figure 27 are the dry weight of the samples washed off the 0.09 m^2 of clogging screen at various head loss.

The average trap efficiency for the range of head loss shown on Figure 26 is about 34 percent. This means that two-thirds of the debris in the water was passing through the screen at head loss less than 0.3 metre. There was no apparent overall relationship between trap efficiency and head loss, debris concentration, or accumulated debris load on the screen. Similar results were obtained in a study by Bergstedt et al. (1979). Testing was done with fine sediment and a screen of 0.045 mm openings. Bergstedt could not establish a relationship between head loss and removal efficiency. However, he did establish a trend showing a decrease in removal efficiency with an increase in sediment concentration at head loss less than 0.3 metre.

Fluctuations in clogging rates due to tidal effect on river stage and due to darkness were measured. Faster clogging occurs during low tide because the debris concentration is higher with the faster-moving water. The clogging rate

Figure 27. Accumulated debris load on clogging screen



slows when less light is available. A small difference between day and night is measurable during summer months. A test was conducted for 20 days with a screen and surrounding area under black plastic to simulate a portion of screen in much deeper water. It took twice as long to clog as the other screen, which was not covered. These fluctuations are perhaps of minor importance because they only occur during low flow summer and fall periods when clogging is the slowest and least critical. During high flow and high debris periods, the tidal effect is minimal and the concentration of debris, being mostly detritus, is not affected by differences in light availability.

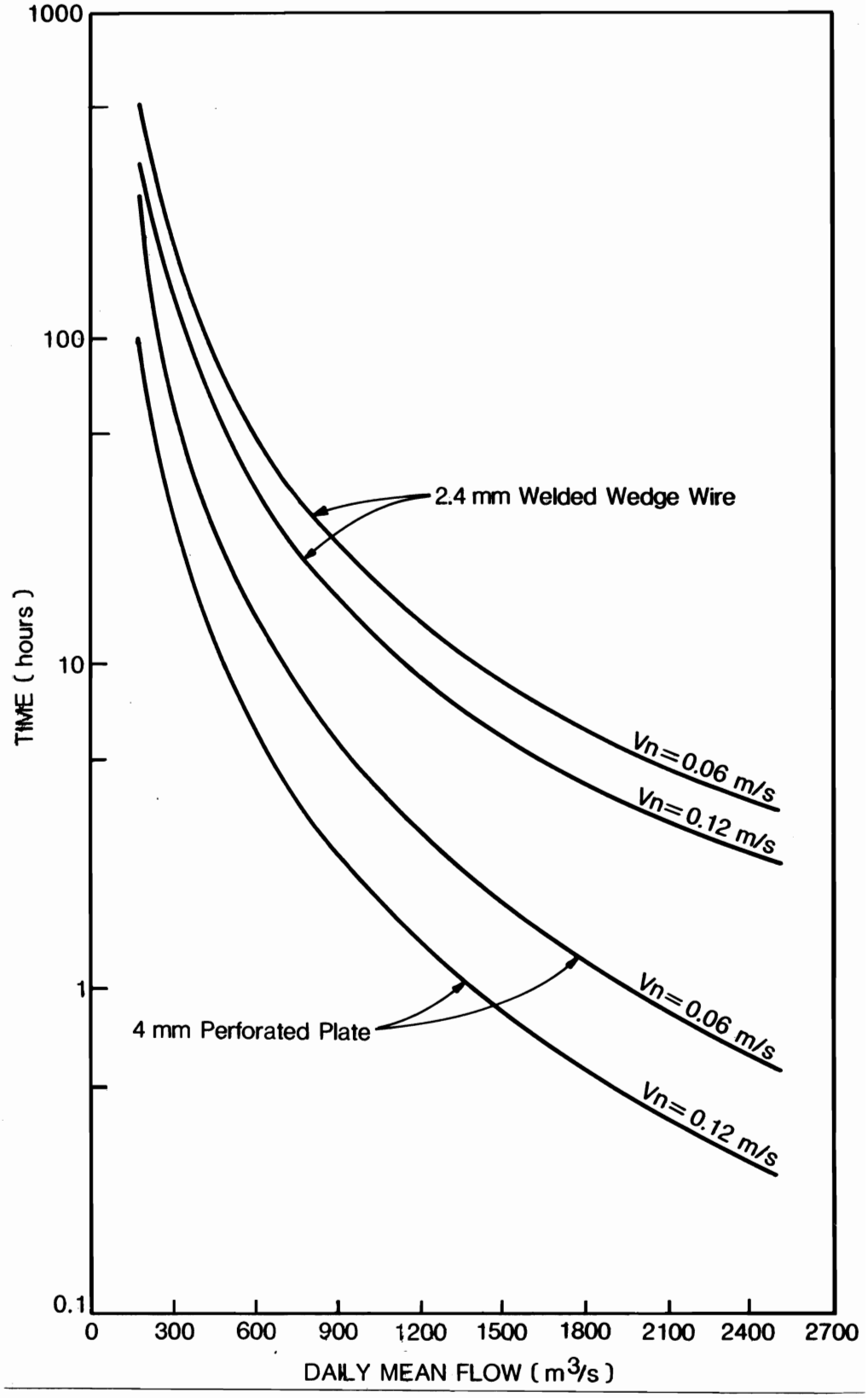
A number of similar screen clogging studies can be found in the literature. The majority, however, were or are being conducted in coastal or estuary waters where the clogging mechanism is very different from that at Hood -- masses of sea grass, kelp, or even fish and barnacles, compared to the detritus and algae sampled at Hood. Most of these studies were testing small round screens and were not comparing different screen concepts. Work by Hanson (1978-1979), Browne (1979), Wiersema (1979), and Vigander (1978), in laboratory and on-site, obtained similar results in that all narrow slotted screens did clog. Although timing was variable, the shape of the curves was similar to those presented herein.

Some tests by others did not maintain a constant flow through the test screen. The flow was allowed to decrease as the screen clogged. This gave a longer clogging time to reach a specific head loss. A test on 2.4 mm wedge-wire was conducted at Hood with the automated gate controls turned off. At 0.3 m (1.0 ft) of head loss, the flow was 80 percent of the initial flow.

The results presented herein are for 0.9 m (3.0 ft) of vertical screen tested in 1.2 m (4.0 ft) of water. How applicable are the results for a prototype screen that may be 6 m (20 ft) or more in water? Clogging during the summer and fall should be slower than tested because most of the prototype screen will be in deeper water with less light available. Clogging during the critical high debris period should be the same as presented herein because river and flume sampling found the debris to be the same in content and similar in concentration. Therefore the tests are applicable and should be a good indicator of what to expect.

The clogging data are needed to determine the feasibility of keeping screens clean during operation of the facility. The frequency of cleaning depends upon the clogging rate. Inspection of the clogging curves shows an accelerated rate change at about 0.06 m (0.2 ft) of head loss. This value is assumed herein as a limit for triggering the cleaning operation. For a particular screen and design velocity, the clogging rate depends on river debris concentration, which has previously been correlated with riverflow. Figure 28 shows the resulting relationship between riverflow and clogging time to 0.06 m for 4 mm PP and 2.4 mm WWW. Figure 28 was obtained by combining data from Figures 22, 23, 24, and 25 with Figure 10, and can be used to determine required cleaning frequency at any riverflow.

Figure 28. Clogging time to reach screen head loss of 0.06 metres (0.2 foot)



Chapter 3. SCREEN CLEANING TESTS

The fish screen cleaning techniques evaluated at the Hood Test Facility were mechanical wiper brush and pressurized water spray. The cleaning operations were conducted on the same flat screens that were used in the debris clogging studies.

General

Methods

The wiper brushes were tested underwater only, whereas the water spray was tested both underwater and out of water. All out-of-water tests were done with a hand-held apparatus. The underwater tests were done with an apparatus that was initially moved by hand, but later by a hydraulic motor and chain drive.

Two types of cleaning tests were conducted: cleaning at the end of a clogging test, and cleaning continuously. The first was a one-time cleaning of a clogged screen -- usually with 0.3 m (1.0 ft) of head loss. The other was periodic cleaning at specified intervals of time or head loss -- usually every 3 hours or every half hour depending on debris load, or at a head loss of 0.06 m (0.2 ft). The 0.06 m head loss, as explained previously, was assumed as the indicator that cleaning was needed.

In all tests, the head loss across the screen was recorded before and after each cleaning sequence. Visual and photographic observations of the conditions of the screen after cleaning were also recorded. A screen was assumed to be clean when head loss approached the initial clean screen value even though at times some debris or algae was observed still on the screen. In these tests, a cleaning cycle consisted of passing the cleaning device from one end of the screen to the other and back to the starting position. Thus, the whole surface of the screen was passed over twice in a rather short time interval.

Results

Results of the cleaning tests on the 0.9 by 3 metre (3 by 10 ft) screens were very good. The heavy winter-type debris did not cling to screen surfaces and was easily removed. The summer algae did stick to screen surfaces but were removed almost as easily as the debris. Leaves tended to ball up and pass under the brushes, but were eventually swept away.

For the screens with 100 percent fish screening efficiency, the 2.4 mm WWW and 4 mm PP were about equally cleaned with all systems. The 3.4 mm woven wire mesh (WWM) was more difficult to brush clean, mainly due to the mesh sagging between the supports.

Based on observations of screen condition after cleaning, the most effective cleaner for removing accumulated debris and algae was the water spray with screen out of water. Spray cleaning and brushing under water usually did not completely remove all debris and algae.

Based on measurement of screen head loss after cleaning, under-water cleaning during winter was as effective as above-water cleaning. Brush cleaning during the summer algae season became less effective because of a gradual buildup of algae on the backside of the test screen.

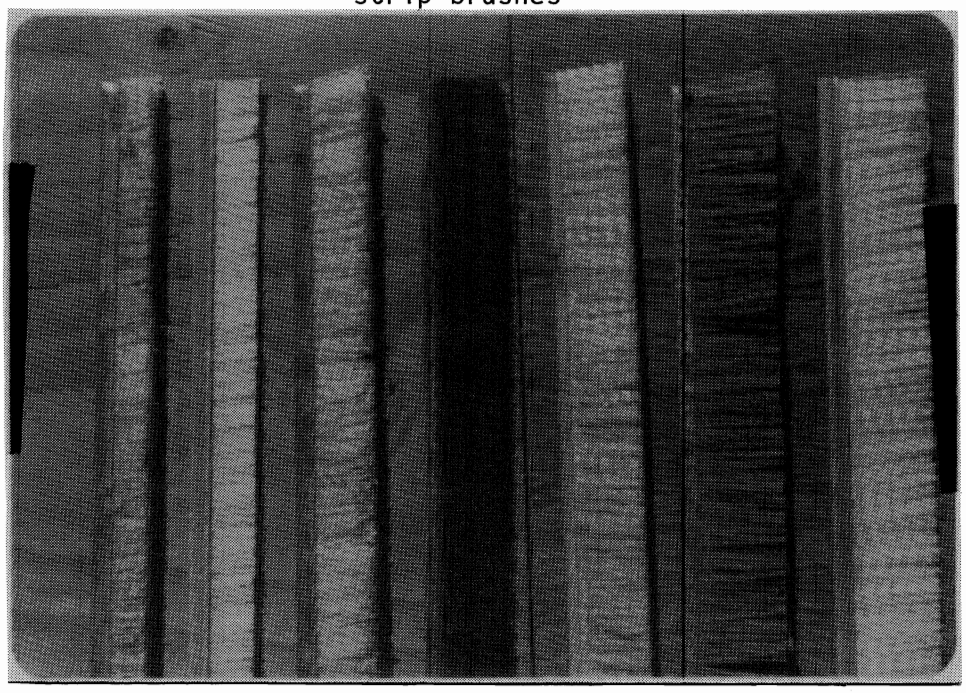
Mechanical Wiper Brush

Equipment and Methods

Discussions with brush manufacturers and experience gained at small diversion screens in the State suggested that nylon or polypropylene strip brushes with bristle length of 38 to 64 mm (1.5 to 2.5 in) could clean screens under water. Eighteen different brushes of nylon and polypropylene and of varying bristle lengths, bristle diameter, and bristle count per inch, were purchased for testing (Figure 29 and Table 4).

The brush assembly that moved the brushes along the screen consisted of a brush holder that held two 0.9 m (3 ft) long brush strips 10 cm (4 in) apart in parallel, an articulated arm, and a support trolley (Figure 30). The arm was lowered in front of the screen until the brushes rested against the screen face. The whole assembly was moved along the screen at a specified speed. For most of the tests, the brush travel speed was 0.25 m/s (0.8 ft/s), which was slower than most of the test bypass velocities. The usual procedure was to cover the 3 m (10 ft) long screen with a pass upstream and a return pass downstream in a total cycle time of 24 seconds. When not cleaning, the brush assembly was at rest at the downstream end of the screen in order to minimize velocity disturbance in front of the screen. Tests were also conducted with brush travel speeds of 0.75, 0.50, and 0.15 m/s (2.5, 1.7, and 0.5 ft/s).

Figure 29. Nylon and polypropylene strip brushes



Three different brush holders and a weight were used to develop different brush pressure against the screen face. The first holder supported the brushes at two points but became unsatisfactory in holding the brush strips straight against the screen. The second and third holders supported the brushes for their full length; one was made of steel and the other of aluminum. The pressure against the screen caused by the whole brush assembly was 4.1, 5.5, and 4.4 kilograms per lineal metre of strip brush (2.8, 3.8, 3.0 lbs/ft), respectively. Tests were also conducted with a 9 kg (20 lb) weight attached to the wiper arm, which increased the brush pressure by 2 kg/m (1.3 lbs/ft).

Results and Discussion

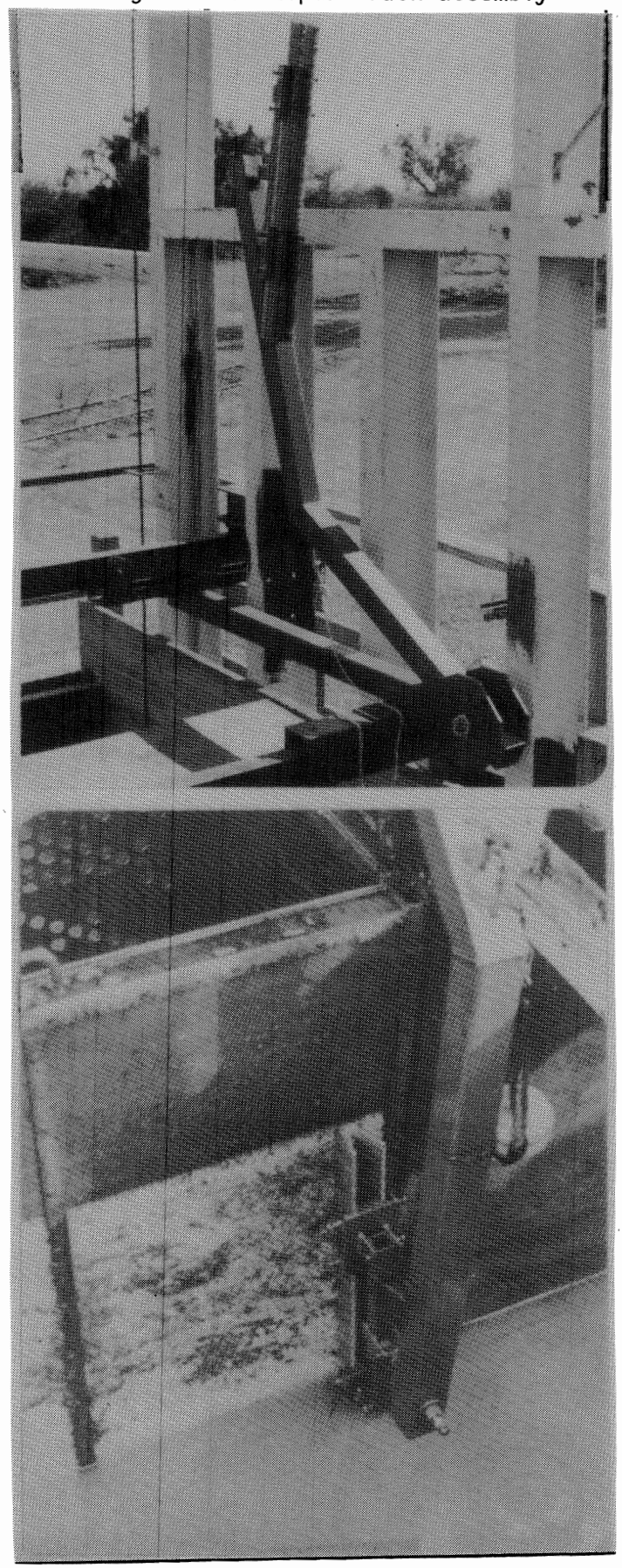
Table 5 contains all the combinations of variables tested with the underwater wiper brushes. The tests took over two years to conduct, during which time the debris load ranged in concentration to 1.2 mg/L. Most of the tests were conducted on 4 mm PP, with a brush travel speed of 0.25 m/s (0.8 ft/s). Time was not available to test all brushes with all test variables against the uncontrolled changing debris conditions throughout the year.

Brush cleaning was performed only on the front side of the test screens because support members and frames on the back

Table 4. Strip Brushes and Specifications

Brush No.	Bristle Material	Bristle Diameter (mm)	Bristle Color	Bristle Crimped	Total Trim Height (mm)	Backing Strip Width (mm)	Bristles Per cm
10	Poly	0.76	Tan	Yes	64	22	56
12	Nylon	0.64	Black	Yes	51	22	65
17	Poly	0.76	Nat.	Yes	51	22	35
18	Poly	0.76	Nat.	Yes	38	22	40
20	Poly	1.14	Nat.	Yes	38	32	31
22	Poly	1.14	Nat.	Yes	64	32	27
23	Poly	1.52	Nat.	No	64	32	19
24	Poly	1.14	Nat.	Yes	51	32	21
25	Poly	1.52	Nat.	No	51	32	26
26	Poly	0.76	Nat.	Yes	51	32	48
28	Nylon	1.14	Nat.	Yes	51	32	34
29	Nylon	0.91	Nat.	Yes	38	22	39
30	Nylon	1.14	Nat.	Yes	38	32	39
31	Nylon	1.14	Nat.	Yes	64	32	31
32	Nylon	0.56	Black	Yes	51	22	71
33	Nylon	0.56	Black	Yes	64	22	65
34	Nylon	0.71	Black	Yes	51	22	65
35	Nylon	0.71	Black	Yes	64	22	59

Figure 30. Wiper brush assembly



side would interfere with brush operation. Usually the complete screen and test area was washed with a fire hose between tests. Brushing while continuing to divert water cleaned a clogged screen during low and moderate debris loads. Apparently, brushing only the front dislodged the debris, which was washed away by the water flowing through or past the screen (Figure 31). During the summer algae period, a gelatinous film accumulated on the back side of the screen. During a series of tests in June, July, and August 1978, the back of the screen was not hosed off between continuous brushing tests of up to one month duration. The continuous tests were brushing once every 3 hours for 16 hours a day. As measured by head loss, the brushes were less effective at the end of the continuous cleaning tests during this period.

Brushing was effective on both the upstream and downstream strokes. Tests were not conducted to determine which stroke was more effective because it was assumed that the prototype brush assembly would always return to the same position when not cleaning. At this position, provision could be made for moving the assembly above water for inspection and maintenance.

All brush cleaning data were entered into computer storage for easier handling. Average after-cleaning head loss was computed for each brush for each test condition. Results from cleaning the 4 mm PP are tabulated in Table 6. Comparisons were made of these values to evaluate each test condition and the effectiveness of each brush.

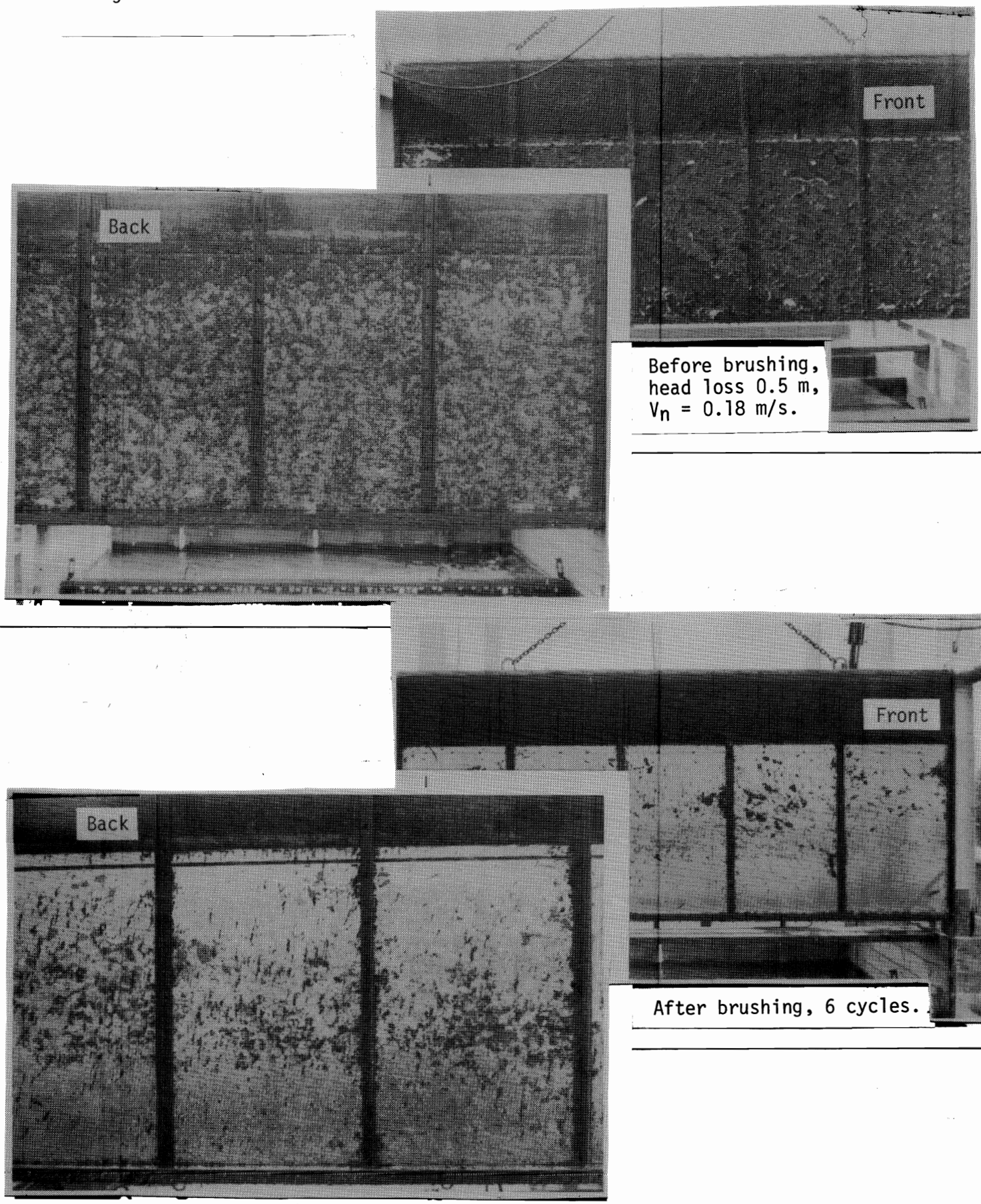
The velocity of water approaching the screen (V_n) significantly affected the effort required to clean the screens. The number of cleaning cycles required to clean a clogged screen and the residual head loss after continuous cleaning both were greater for the high test velocities (V_n). The residual

Table 5. Brush Cleaning Tests

Test Screen	Water Velocity Normal to Screen (m/s)	Brush Pressure (kg/m)	Number of Tests 1/ Brush Travel Speed (m/s) 0.75	0.50	0.25	0.15
4 mm Perforated Plate	0.06	4.1			2	
	0.06	5.5	16		19	15
	0.06	4.4			3	
	0.06	6.1		3	6	2
	0.12	4.1		1	15	1
	0.12	5.5			4	
	0.12	4.4			7	
	0.12	6.1		3	5	3
	0.18	4.1			4	
	0.18	5.5			2	
	0.18	4.4			15	
	0.18	6.1		1	2	1
	0.24	4.1			19	1
	0.24	5.5	26	2	74	28
	0.24	4.4			38	
	0.24	6.1		3	4	3
	0.24	7.5	6	2	25	6
2.4 mm Welded Wedge-Wire	0.06	4.4			1	
	0.12	4.4			10	
	0.18	4.4			23	
	0.24	4.4			18	
3.4 mm Square Mesh	0.06	4.1			2	
	0.12	4.1			2	
	0.18	4.1			2	
	0.18	6.1			1	
	0.24	5.5			4	
	0.24	6.1		2	2	2
4.8 mm Perforated Plate	0.06	4.1			1	
	0.12	4.1			1	
	0.18	4.1			2	
	0.18	6.1			1	
	0.24	4.1		1	1	
	0.24	5.5			4	
	0.24	6.1		1	2	1
6.4 mm Perforated Plate	0.06	4.1			1	
	0.12	4.1			1	
	0.18	6.1		2	2	2
	0.24	4.1		1	1	
	0.24	5.5			2	

1/ Each test represents at least one to as many as two dozen actual test brushings with one or more brushes.

Figure 31. Brush cleaned with screen under water



Before brushing, head loss 0.5 m, V_n = 0.18 m/s.

After brushing, 6 cycles.

Table 6. Average head loss on 4 mm perforated plate after brush cleaning

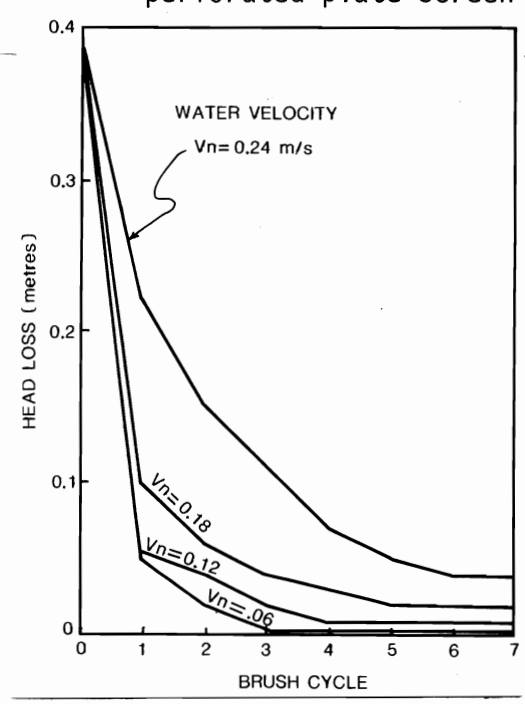
Water Velocity Normal to Screen (m/s)	Brush Pressure (kg/m)	Brush Travel Speed (m/s)	Average Head Loss After Cleaning (mm)																	
			Brush Identification Number																	
			10	12	17	18	20	22	23	24	25	26	28	29	30	32	33	34	35	Average
0.06	4.4	0.25									0		1	1		2				1
	5.5	0.15	3	6	5	6	6	6	6	9	3	3	6							5
	5.5	0.25	6	1	6	3	9	6	3	4	9	6	9							6
	5.5	0.75	6	6	8	6	10	12	6	9	9	6	6							8
	6.1	0.15	3																	3
	6.1	0.25	4																	4
	6.1	0.50	9																	9
0.12	4.1	0.15	23																	23
	4.1	0.25	23																	23
	4.1	0.50	19																	19
	4.4	0.25		6							2		6	1		7				4
	5.5	0.25	4		4			9							9					6
	6.1	0.15	10																	10
	6.1	0.25	21																	21
	6.1	0.50	14																	14
0.18	4.4	0.25		32							33		36	32		45			24	34
	5.5	0.25								20		26								23
	6.1	0.15	22																	22
	6.1	0.25	18																	18
	6.1	0.50	21																	21
0.24	4.1	0.25	31	23	27	28														27
	4.4	0.25		38	133			67			36		38	48		46	31	37	90	56
	5.5	0.15	70	31	36	56	49	51	52	61	42	37	63	31						48
	5.5	0.25	41	36	41	50	54	40	62	48	51	50	53	53		31				47
	5.5	0.50						34	40											37
	5.5	0.75	54		41	57	57	38	61	52	43	57	57	35						50
	7.5	0.15			46	25		55	49		46	34								43
	7.5	0.25	39	32	38	43	63	40	65	58	65	40	55	48						49
	7.5	0.50			58			49												54
	7.5	0.75			52	43	34		43		46	46								44

head loss was the difference between screen head loss after brushing and head loss across that screen when totally clean. Figure 32 contains data for several one-time cleaning tests with Brush 10 and dramatically shows the effect of V_n. The actual number of cycles required to clean the screen varied from two to eight.

Field observations of cleaning tests indicated a decrease in cleaning effectiveness when brush pressure against the test screen was increased. Comparison of after-cleaning head loss data indicated that pressures of 4.4 to 6.1 km/m were the most effective.

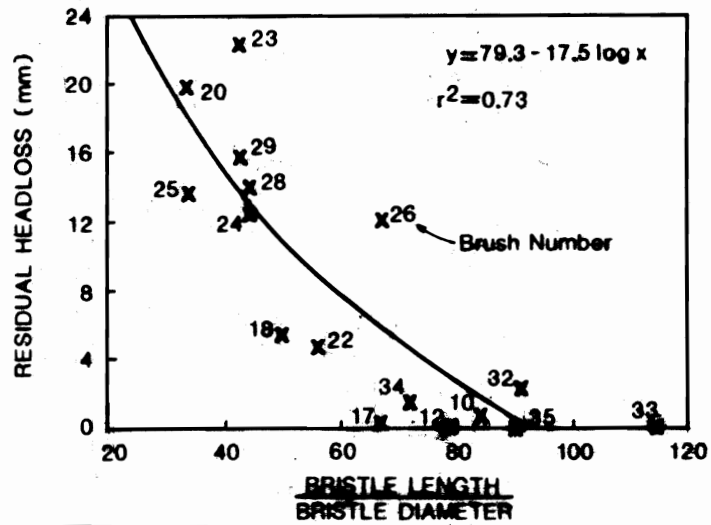
Travel speeds of 0.15 and 0.25 m/s used for the brush assembly during cleaning were generally the most effective. During the heavy debris and leaf period, 0.25 m/s (0.8 ft/s) was the most effective speed. The higher speeds of 0.50 and 0.75 m/s were least effective most of the time.

Figure 32. Brushing cycles required to clean a clogged 4 mm perforated plate screen



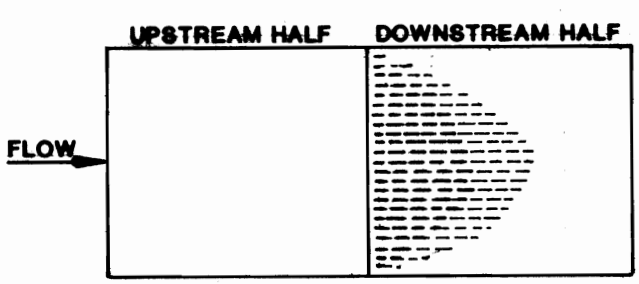
Average head loss for all tests from Table 6 varied among brushes. It appeared that the physical characteristics of the brushes were factors in the variable results. Regression analysis was applied to the brush data using bristle diameter, length, and count per millimetre as the independent variables and the residual screen head loss after brushing as the dependent variable. The highest correlation was achieved with length divided by diameter (Figure 33). Apparently, the longer and thinner bristles (being more limber) were better able to clean around the perforations and wires.

Figure 33. Brush size and average residual head loss



Debris Movement During Cleaning. An attempt was made to determine the movement of debris on the screen as it was being brush cleaned. Due to the turbidity of the river water, direct observation of the movement was not possible.

The downstream half of a dirty screen was brushed under water while diverting flows and then raised and visually inspected. Then the upstream half was brushed under water. Sketches were drawn by the observer of the debris pattern left on the screen. Some debris did move onto the downstream half after cleaning the upstream half. The more dirty the screen, the more debris that appeared to move to the downstream half. This movement tended to concentrate in the pattern shown below:



The debris that was left on the screen did not appear to be all that was originally on the upstream half before cleaning. The question remained as to where the remainder of the debris went -- through the screen or into the bypass.

Three fine-mesh screens of 0.19 m^2 (2 ft^2) each were made to collect debris while cleaning the test screen. One was mounted behind the upstream half, one behind the downstream half, and one at the end of the screen across the bypass. The amount of debris collected on each fine-mesh screen was weighed after cleaning the downstream half and again after cleaning the upstream half of the test screen. The results were quite variable. Most of the debris collected came from either the screen half being cleaned or the bypass. The amounts varied from 2 to 90 percent from one or the other. Although the test velocities were not recorded, they certainly had some effect. Also, the position of the brush assembly may have had some effect on the direction of movement of the debris.

Data on screen trap efficiency of 4 mm PP presented earlier indicates that 50 percent or more of the debris in the water will go through the screen when the head loss is less than 0.3 m (1.0 ft). The percent passing is probably even higher for wedge-wire screen with its greater open area. If this holds true along the total length of screen, then as the debris is brushed off the screen, some will go through and the remainder will be resuspended in the

flow. Upon contacting the screen again, 50 percent or more of this debris will go through the screen. This process will result in a doubling of the debris load at the downstream end of the screen. As the brush sweeps off the end, there will be a plume of debris of very high concentration but of short duration that will move into the bypass.

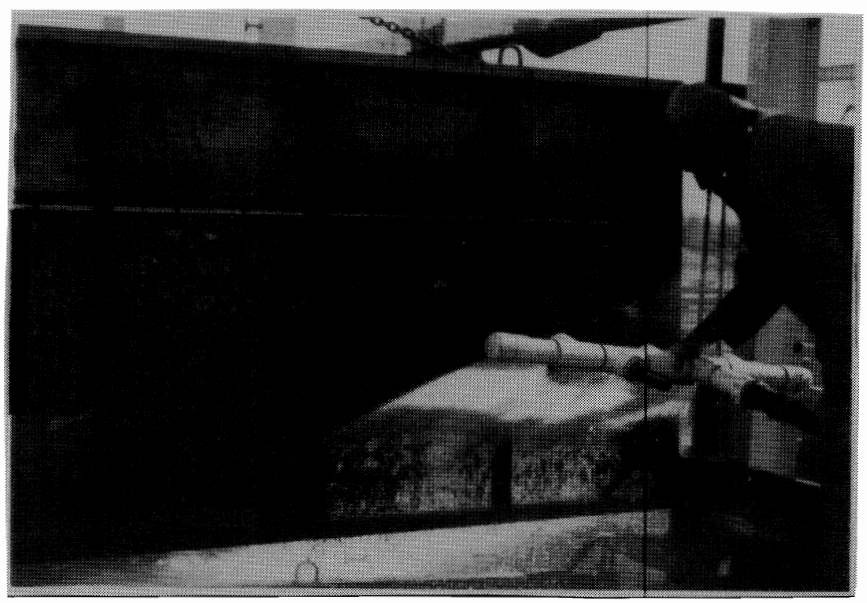
It is possible that the continual resuspension of debris by brushing will tend to separate the fine and coarse material. A greater portion of the coarse material may collect on the screen downstream and be swept into the bypass. This could not be evaluated at the facility at Hood.

Pressurized Water Spray With Screen Out of Water

Equipment and Methods

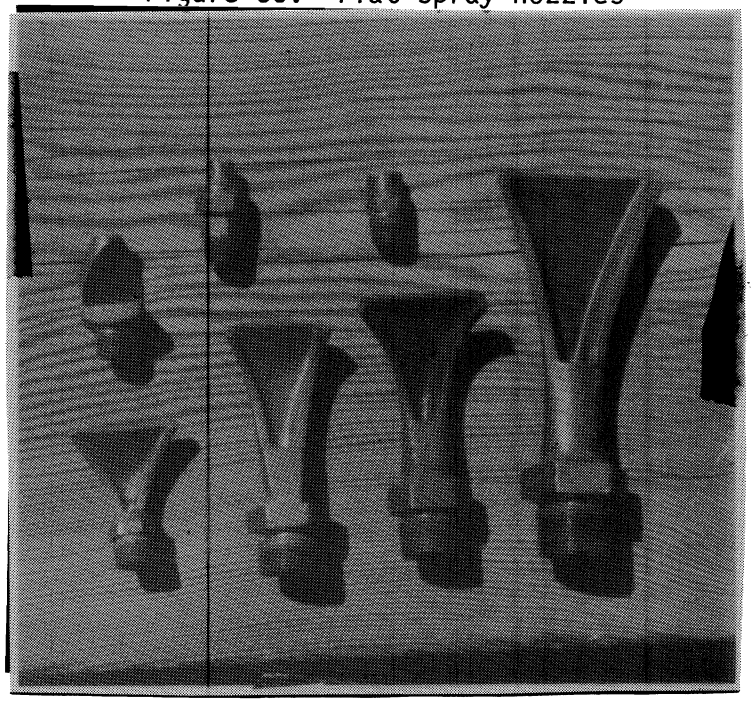
The spray bar assembly consisted of a plastic pipe manifold with a pressure gauge and fittings on which up to three nozzles could be mounted. Water was supplied to the spray bar by a pump rated 380 L/min at 690 kPa (100 gpm at 100 psi). For spray cleaning above the water surface, the clogged screen was raised and washed by an operator with the hand-held spray bar using specified cycle time, pattern, angle, distance from screen, front and/or back, and spray bar pressure (Figure 34).

Figure 34. Manually operated water spray bar



Seven different flat spray nozzles were purchased for testing (Figure 35 and Table 7). Orifice size ranged from 4.8 to 14.3 mm (3/16 to 9/16 in) and output at 414 kPa (60 psi) ranged from 28 to 246 L/min (7 to 65 gpm). The water impact from these nozzles was concentrated in a thin band.

Figure 35. Flat spray nozzles



Results and Discussion

Water spray was very effective in cleaning clogged screens out of water. In fact, one cleaning cycle, which was one pass back and forth across the screen face, front or back, with any one of the nozzles, removed most of the debris (Figure 36). Table 8 contains the number of spray cleaning tests for each test condition. All conditions were about equally effective except the higher pressures were observed to more completely remove the gelatinous film on screens clogged primarily with algae.

Table 7. Flat Spray Nozzles and Specifications

I.D.	Material	Orifice Diameter (mm)	Pipe Thread (mm)	Discharge Angle (°)	Spray Width 1/ (m)	Rated Discharge 1/ (L/min)
Tee	Brass	4.8	9.5	0	0.41	28
Flat	Brass	4.8	9.5	37	0.41	28
Vee	Brass	4.8	9.5	0	0.41	28
873	Mn-Bronze	6.4	9.5	43	0.58	49
608	Mn-Bronze	8.7	19.0	42	0.41	95
493	Super Z	8.7	19.0	62	0.48	95
494	Mn-Bronze	14.3	25.0	30	0.58	246

1/ Nozzle tip 0.40 m from screen surface and water pressure 410 kPa.

Table 9 contains the average residual head loss on 4 mm PP after cleaning for each nozzle tested. The averages are for all test conditions and are minimal.

Also in Table 9 are the results of an analysis of variance test (ANOVA) on each nozzle and on all nozzles together. Residual head loss was the test statistic. The analyses indicated that, excepting the Flat Jet, there was no significant difference at the 0.05 level between the test variables for each nozzle. The Flat Jet results were not significantly different at the 0.01 level. The analysis on all nozzles indicated no significant difference in cleaning ability between the seven nozzles tested. Apparently, it did not make any difference how the spray cleaning was done.

Based on observation, the variables that had minimal effect were spray angle, wash pattern, and travel speed. Spray bar pressure, screen surface washed, and nozzle distance had the most effect. Of these, spraying from the back side of the screen at a distance of 0.40 m (16 in) appeared to be most effective.

Figure 36. Spray cleaned with screen out of water

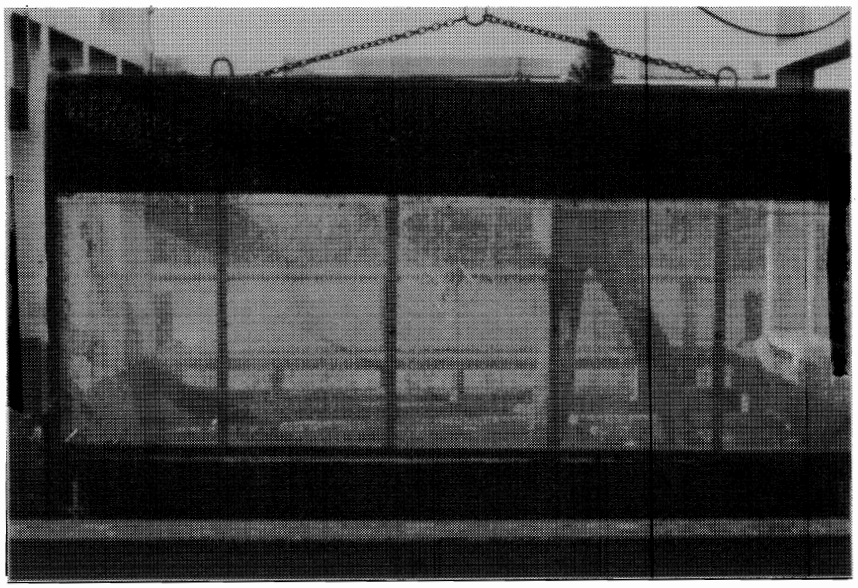


Table 8. Water Spray Cleaning Tests with Screen Out of Water

Test Screen	Screen Surface Washed	Wash Pattern	Nozzle Distance from Screen (m)	Spray Impact Angle to Screen (°)	Spray Bar Travel Speed (m/s)	Number of Tests: Spray Bar Pressure (kPa) 35-140	141-275	276-415	416-550	551-690
4 mm Perforated Plate	Front	Vert.	0.40	45	0.25	2	5			
				45	0.50		1			
				90	0.25		7			
				90	0.50		1			
		Horiz.		45	0.10		2			
				45	0.25		4			
				45	0.50		1			
				90	0.25	1	5	1		
				90	0.50		1			
	Back	Vert.		45	0.10		1	1		
				45	0.25		3	2		7
				45	0.50		1			
				90	0.10		2			
				90	0.25	1	7		2	6
				90	0.50		1			
		Horiz.		45	0.25	1	2		2	
				45	0.50		3			
				90	0.25	1	3			
				90	0.50	3	4			
	Both	Vert.		45	0.25	4	17	7	7	4
				90	0.25	14	75	28	45	54
			0.25	90	0.25	3	12	1		3
			0.75	90	0.25	3	9			2
2.4 mm Welded Wedge-Wire	Back	Vert.	0.40	45	0.25				1	
		Horiz.		45	0.25				1	
	Both	Vert.		90	0.25					5
4.8 mm Perforated Plate	Front	Vert.		45	0.25		1			
				90	0.25		3			
				90	0.50		1			
	Back	Vert.		90	0.25		1			1
		Horiz.		90	0.25			1		
	Both	Vert.		45	0.25			1		
				90	0.25			2		
6.4 mm Perforated Plate	Front	Vert.		45	0.25		2			
				90	0.25		2			
		Horiz.		90	0.25				1	
				90	0.50		2			
	Back	Vert.		90	0.25			1		1
	Both	Vert.		90	0.25			2		2
4 mm Corrugated Perforated Plate	Front	Vert.		45	0.25		2			
				90	0.25		4			
		Horiz.		45	0.25		3		2	
				90	0.25		2		1	
	Back	Vert.		45	0.25		3		3	
				90	0.25		1	1	2	
		Horiz.		45	0.25		4		2	
				90	0.25		3		2	
	Both	Vert.		90	0.25			2		
3.4 mm Square Mesh	Front	Vert.		45	0.25				1	
				90	0.25		2		1	
	Back	Vert.		45	0.25		1			
				90	0.25		1			
		Horiz.		45	0.25		2			
				90	0.25		2			
	Both	Vert.		90	0.25			1		1
2.0 mm Slotted Mesh	Back	Vert.		45	0.25				1	4
		Horiz.		45	0.25				1	
	Both	Vert.		45	0.25				2	1
				90	0.25					1

Table 9. Summary of Results of Spray Cleaning 4 mm Perforated Plate Screen Out of Water

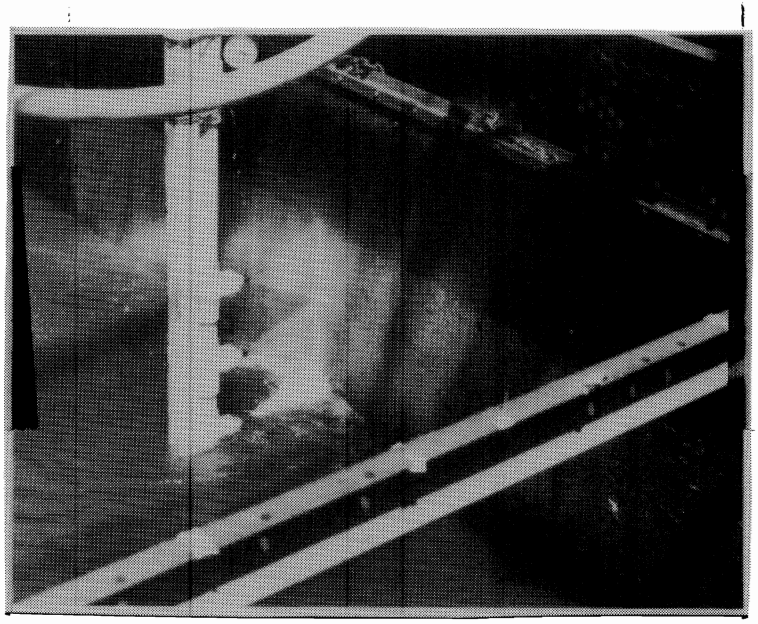
Nozzle	Number of Tests	Residual Head Loss (mm) Mean	Standard Deviation	Range	Anova Test Calculated f	Critical f α =0.05	α =0.01
Tee	32	3	6	0-27	1.73	2.71	4.07
Flat	27	2	4	0-18	4.76	3.03	4.76
Vee	35	1	3	0-15	1.79	2.92	4.51
873	86	3	5	0-24	1.16	1.98	2.60
608	83	4	6	0-27	0.94	1.95	2.57
493	24	2	4	0-12	1.41	4.45	8.40
494	34	1	2	0-6	0.29	2.90	4.50
All					1.74	2.10	2.80

Pressurized Water Spray With Screen Under Water

Equipment and Methods

Cleaning under water was conducted with the spray bar mounted in place of the brush holder and the apparatus operated as in the brush cleaning tests (Figure 37).

Figure 37. Underwater spray cleaning assembly



Results and Discussion

Table 10 contains the number of underwater cleaning tests and the average residual head loss for each test condition. For all tests the vertical spray bar, with spray impact normal to the screen, traversed the horizontal screen length twice in 24 seconds (a speed of 0.25 m/s). The test variables were front or back surface washed, water spray pressure, and nozzle distance from screen face.

Table 10. Water Spray Cleaning Tests with Screen Under Water

Test Screen	Wash Pattern	Screen Surface Washed	Spray Impact Angle to Screen (°)	Spray Bar Pressure (kPa)	Nozzle Distance from Screen (m) 0.03	0.08	0.13	0.18	0.23	0.28	0.33
					Number of Tests / Average Residual Head Loss (mm)						
4 mm Perforated Plate	Horiz.	Front	90	275-415				3/30			
				416-550		21/15	49/18	17/40	47/58	5/12	
				551-690				6/12	6/6		
				691-825				6/3			
		Back	90	275-415	9/49	1	10/0	4/21	40/49	19/24	34/21
				416-550		21/79	85/40	6/15	29/18	50/18	60/24
				551-690					4/34	1/18	3/21
				691-825			8		10/24	30/21	134/27
2.4 mm Welded Wedge-Wire	Horiz.	Front	90	275-415					1		
				416-550			13/27		11/40		
		Back		275-415			7/18	2/15			
				416-550			14/24	14/27			

The results of underwater cleaning were quite variable. The nozzles did clean portions of dirty screen but the fixed spacing of nozzles was such that full coverage up and down the screen face was not possible at all distances from the screen (Figure 38). Head loss was affected by the remaining horizontal strips of debris across the screen face and was inconclusive in determining relative effectiveness. Most of the tests were conducted at the higher V_n's in order to clog the screen as rapidly as possible. This probably had some effect on the effectiveness of the spray. The results are substantially higher than those in Table 9 for cleaning out of water.

During a series of continuous cleaning tests of several days duration in January 1980, the after-cleaning head loss remained about the same, indicating no measurable buildup of debris that was not removed by cleaning.

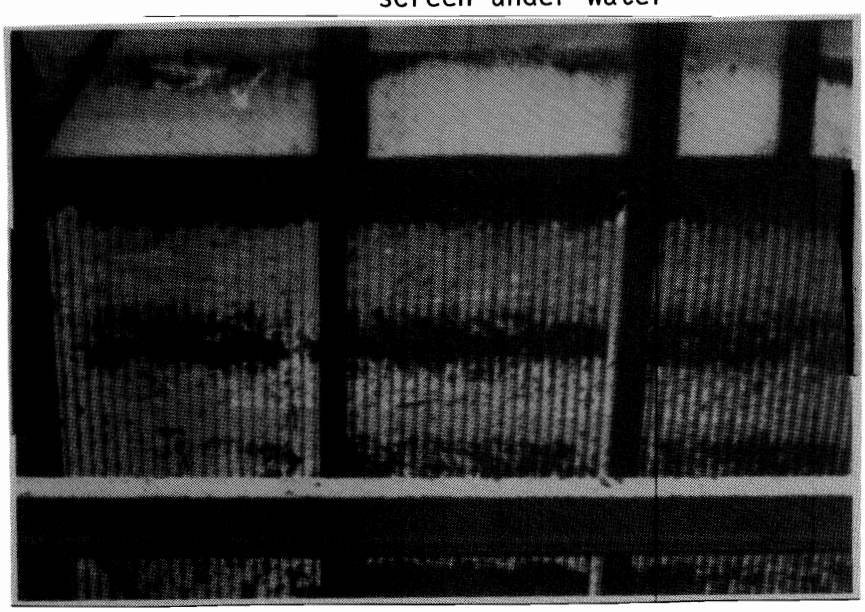
Based on observations of the screen after cleaning, an effective distance from the screen face for the nozzles tested was between 0.15 and 0.3 m (6 and 12 in) with a pressure of 690 kPa (100 psi). This test condition most consistently removed all debris and algae in the path of the spray. The 4.8 mm nozzles would have to be spaced every 10 cm (4 in) along the spray bar for complete screen coverage, and the 8.7 mm nozzles every 23 cm (9 in).

Cleaning Interval and Occurrence

The cleaning tests indicate that fish screens can be kept clean by pressurized spray with screen out of water. Screens can also be kept clean by underwater spraying or brushing, but with a periodic lift-out and cleaning (perhaps weekly to monthly) to remove any long-term buildup of debris or algae. Thus, the required interval between regular cleanings is the same for each cleaning system and is a function of screen material and riverflow, as presented in Figure 28, assuming V_n = 0.06 m/s (0.2 ft/s) and head loss to initiate cleaning is 0.06 m (0.2 ft).

The occurrence (in percent of time) that any flow or less will occur in the Sacramento River at Sacramento with operation of the Peripheral Canal is plotted on Figure 39. This data is taken from a Delta Operations Study with Fish Agreement at 1990 level of development, run December 1981. Also plotted is the required cleaning interval (clogging time to 0.06 m) for each screen, taken from Figure 28. From Figure 39, a design "flow" or "occurrence" can be selected. For instance, if the cleaning system is to be designed for 98 percent probability of occurrence, then the design cleaning interval would be every 0.95 hours for perforated plate and every 5.3 hours for wedge-wire. However, during actual operation, half the time the screens will need to be cleaned only every 27 and 86 hours, respectively, or less often. There is quite a difference between the median and the design interval.

Figure 38. Spray cleaned with screen under water

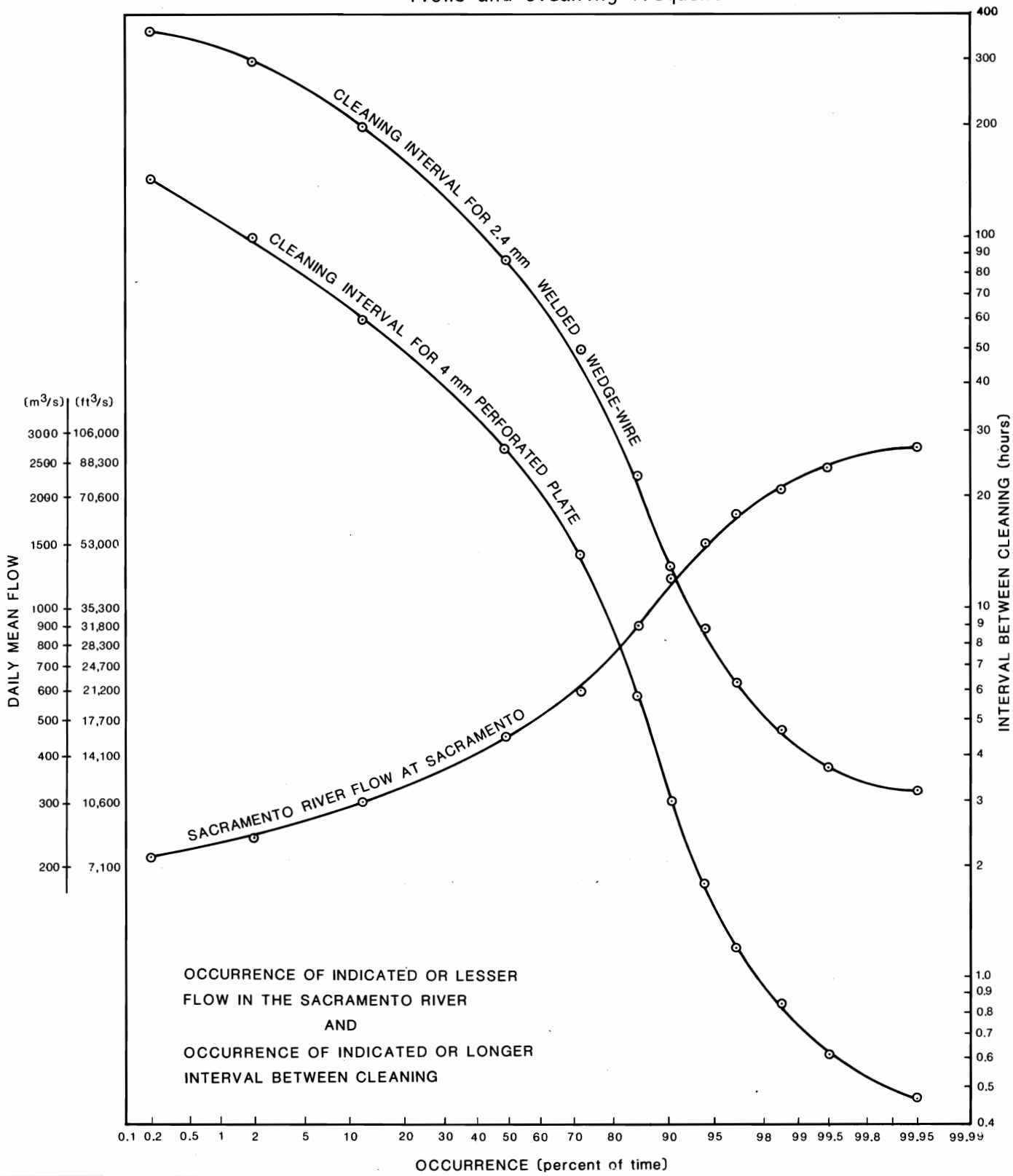


Assuming the underwater brush or spray cleaner travels at 15 m/min (50 ft/min), then for the interval selected above, one cleaning apparatus can maintain a total length of 425 m (1,390 ft) of 4 mm PP, or 2 380 m (7,800 ft) of 2.4 mm WWW. Spray cleaning one screen bay out of water with a traveling wash house can probably be done in 15 minutes. That is the time necessary to position the assembly, lift and clean the screen on one side, and lower while cleaning the other side. For the same design cleaning interval, one wash house can maintain 4 bays of perforated plate or 20 bays of wedge-wire.

These design examples are based on curves of regression on many data.

Continuous cleaning tests were being conducted during the first major storm of the year in January 1980. The riverflow was above 2 270 m^3/s (80,000 ft^3/s) for several days. At times the required cleaning was twice as often as indicated by the regression data presented herein; however, it lasted for only a day or two. This was probably due to the higher debris load with the first high water and the range in the actual test data. During such relatively rare occurrences when the river exceeds 2 270 m^3/s, it may be necessary to reduce diversions for a brief period. From 1976 through 1981, the reported Sacramento River flow at Sacramento exceeded 2 270 m^3/s for only 19 days.

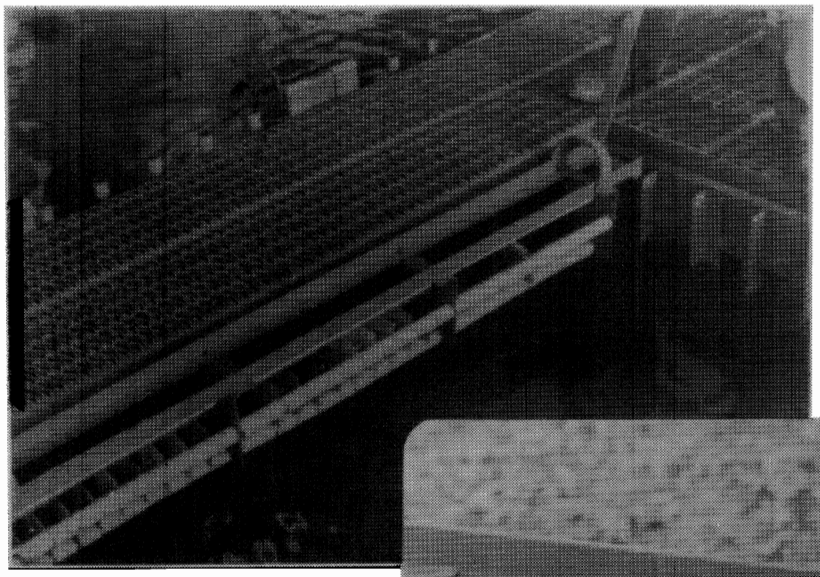
Figure 39. Occurrence of Sacramento River flows and cleaning frequencies



Samples of materials for possible use in fish screen construction were tested in the Sacramento River.

Equipment and Methods

A float was constructed at the Hood Test Facility to house the samples under water in an environment similar to that in which the fish screens would actually be operated. The float was attached to the structural framework of the pump platform. Four racks, each capable of holding up to thirty 102 by 102 mm (4 by 4 in) samples, were suspended from the float at depths of 0.6 to 0.9 m (2 to 3 ft) so that the samples were exposed to the water flowing under the float. Each rack contained about the same set of sample materials and each set had two samples of each material. The samples were spaced 50 mm (2 in) apart on the rack and were supported on all four edges with PVC pipe (Figure 40). Each was identified as to material type and rack location by use of notches cut in the sample. One sample of each material had a fastener of rubber grommet and bolt through the center to allow crevice-type corrosion on the samples to be studied.



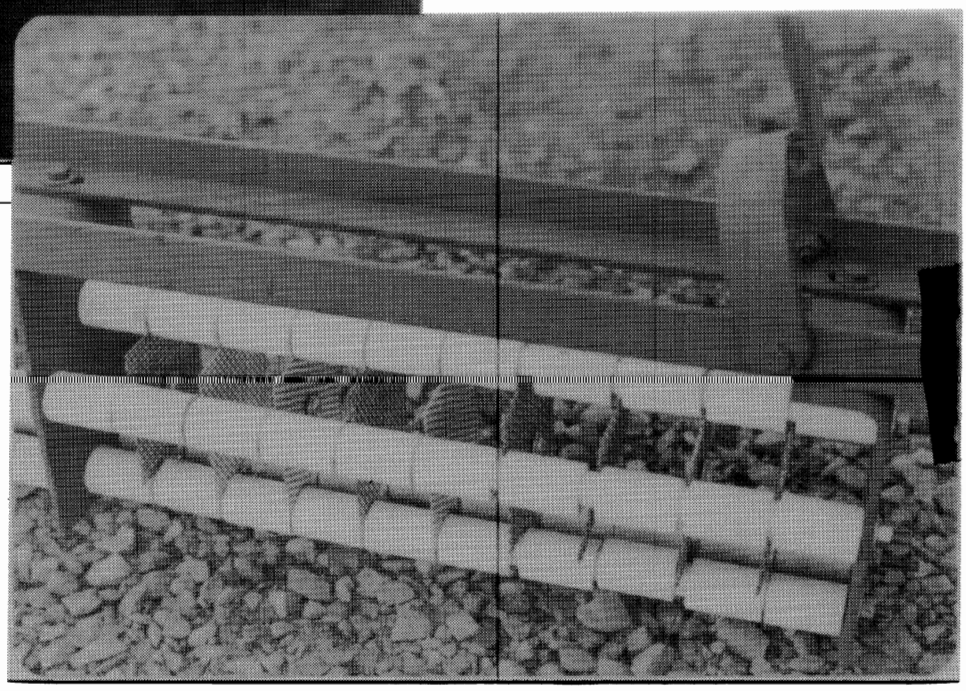


Figure 40. Corrosion Float, Rack and Samples

Each rack remained in the water for a specified length of time before it was removed for inspection. The first rack was inspected after 6 months and about every 6 months thereafter; the second after 12 months; and the third after 18 months. All four racks were removed for final inspection after 4 years of exposure.

The procedure for thorough examination of the samples at the time each rack was removed was as follows:

1. Inspect and photograph rack and samples.

2. Hose down rack to remove excess debris.

3. Remove samples from rack.

4. Examine samples by a corrosion engineer and record notes.

5. Photograph both sides of samples.

6. Clean samples (grommets and bolts removed) by rubbing with a large rubber stopper. Clean inside the holes and around wire crossing with a nylon brush.

7. Photograph samples again.

8. Examine samples by a corrosion engineer and record notes.

9. Weigh samples.

10. Reassemble and replace in float.

The difference in cleaned sample weight from the original weight was loss of material due to corrosion.

The samples that were inspected at 6 months were subsequently removed from the river every two weeks, washed down with a hose, and placed back into the river. This procedure was to determine if regular washing of the screen material changed the corrosion rate.

Results and Discussion

Results of the corrosion measurements for each screen material tested are in Table 11 as percent weight loss per 1,000 days. The stainless steel samples of perforated plate, woven wire mesh, and wedge-wire had no evidence of corrosion. There was some staining of the area under the rubber grommet on most samples from the tubercle of rust that formed over the mild steel bolt that held the grommet in place. A zero corrosion rate is shown for 304 stainless perforated plate and wedge-wire. Actually, most of these samples had a slight weight gain during the time of exposure, probably due to traces of attached debris that were not removed during the cleaning process.

The aluminum samples were subject to pitting. They had numerous pits to 75 percent of sample thickness and a few 95 to 100 percent of thickness. The pitting was generally evenly distributed over sample surfaces. There was also some crevice corrosion around the grommet and some thinning of the samples under the grommet. The aluminum samples also accumulated deposits of aluminum oxide in the holes, which were difficult to clean. Any deposits remaining after cleaning biased the data for aluminum in the direction of less apparent weight loss. To an undetermined degree, the corrosion rate of the aluminum samples was actually faster than as calculated and presented herein.

Also tested were samples of mild steel perforated plate and wire mesh with various coatings. The coatings included a clear sealer, a heat-set enamel, and an algaecide. The coatings slowed the initial corrosion rates compared to samples with no coating. However, bubbles and fractures in the coating soon allowed corrosion of the sample, particularly at the edges of the round perforations and at scratches on the wire mesh from handling.

Table 11. Corrosion of possible fish screen materials

Material	Screen	Percent Weight Loss per 1000 Days				
		All Samples	Samples With Fasteners	Samples Without Fasteners	Samples Washed	Sampled Not Washed
Titanium A 70	Punched Sheet	0.00	- -	0.00	0.00	- -
Stainless Steel 304	Perforated Plate	0.00	0.00	0.00	0.00	0.00
Stainless Steel 304	Welded Wedge-Wire	0.00	- -	- -	0.00	0.00
Stainless Steel 347	Perforated Plate	0.02	0.00	0.04	0.02	0.02
Stainless Steel 304	Woven Wire Mesh	0.04	0.04	0.05	0.05	0.04
Stainless Steel 304/202	Welded Wedge-Wire	0.05	- -	- -	0.05	- -
Stainless Steel 316	Woven Wire Mesh	0.09	0.07	0.11	0.12	0.09
Stainless Steel 316	Perforated Plate	0.20	0.19	- -	0.24	0.17
Aluminum 5052-H32 (Sealed)	Perforated Plate	2.23	- -	2.23	- -	2.23
Aluminum 5052-H32	Perforated Plate	2.28	2.39	2.17	3.49	1.88
Mild Steel (Algaecide Coated)	Woven Wire Mesh	2.86	- -	2.86	2.86	- -
Aluminum 6061-T4 (Sealed)	Perforated Plate	4.60	- -	4.60	- -	4.60
Aluminum 6061-T4	Perforated Plate	9.33	8.92	9.75	8.76	9.53
Mild Steel (Enamel Coated)	Perforated Plate	10.82	- -	10.82	11.24	10.68
Mild Steel	Perforated Plate	1/				
Weathering Steel	Perforated Plate	1/				

1/ Samples were lost because of disintegration.

Table 11 also contains the corrosion rates for samples with and without the fasteners and for samples washed and not washed every two weeks. The results were mixed: some rates were increased, some not affected, and some decreased. Figures 41 to 45 show some of the cleaned samples after being submerged in the river for 4 years.

Figure 41. Stainless Steel Type 304

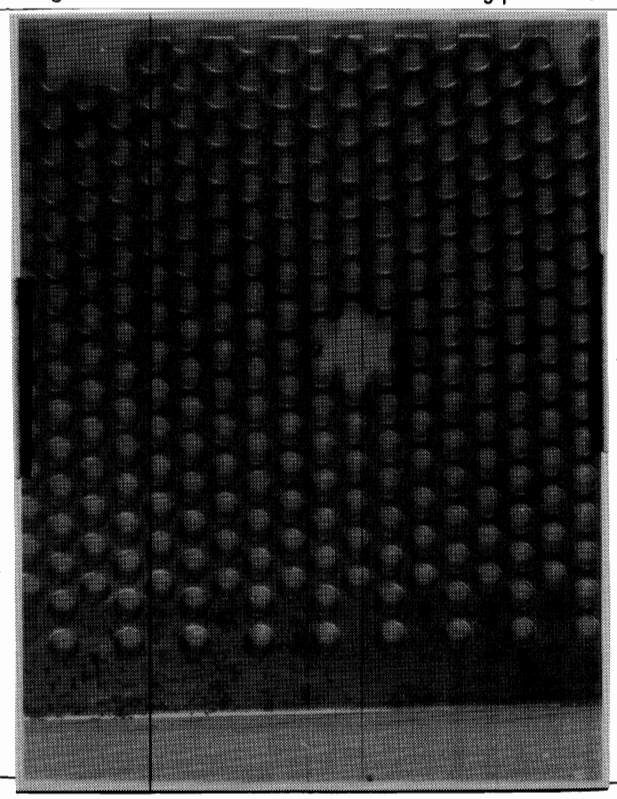


Figure 42. Stainless Steel Type 304

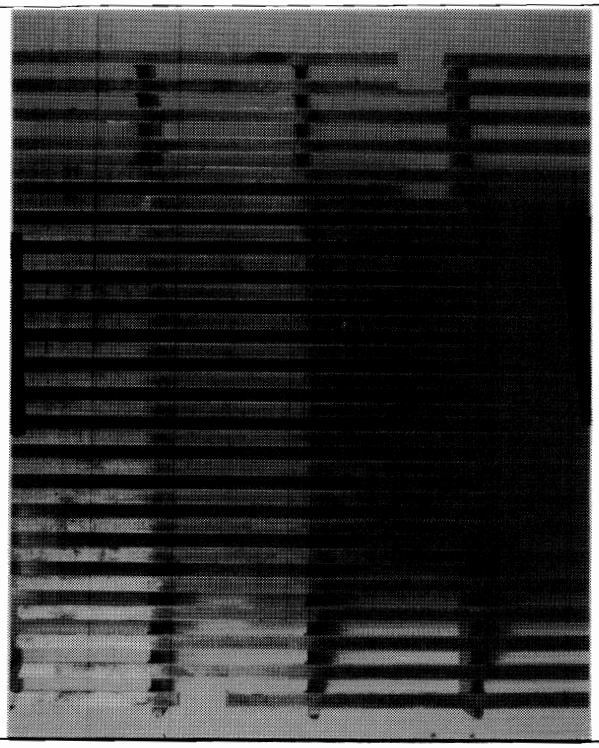


Figure 43. Stainless Steel Type 304

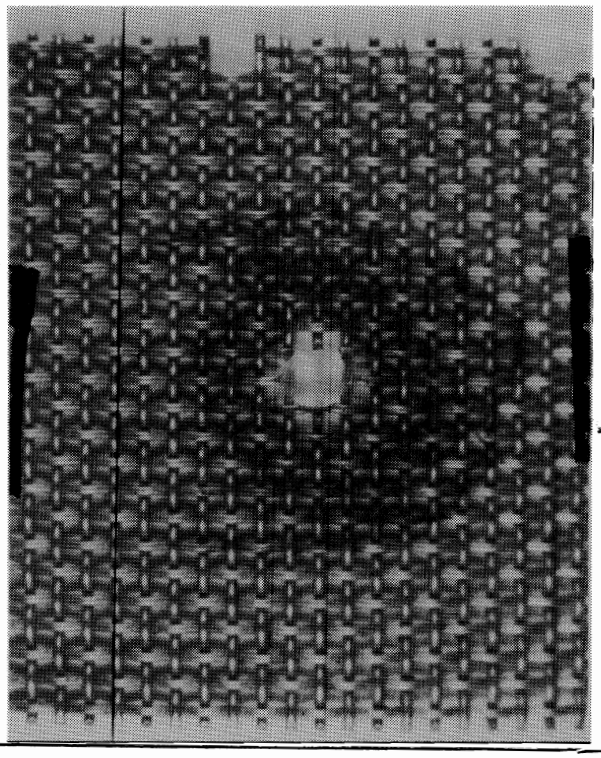


Figure 44. Aluminum Type 5052-H32

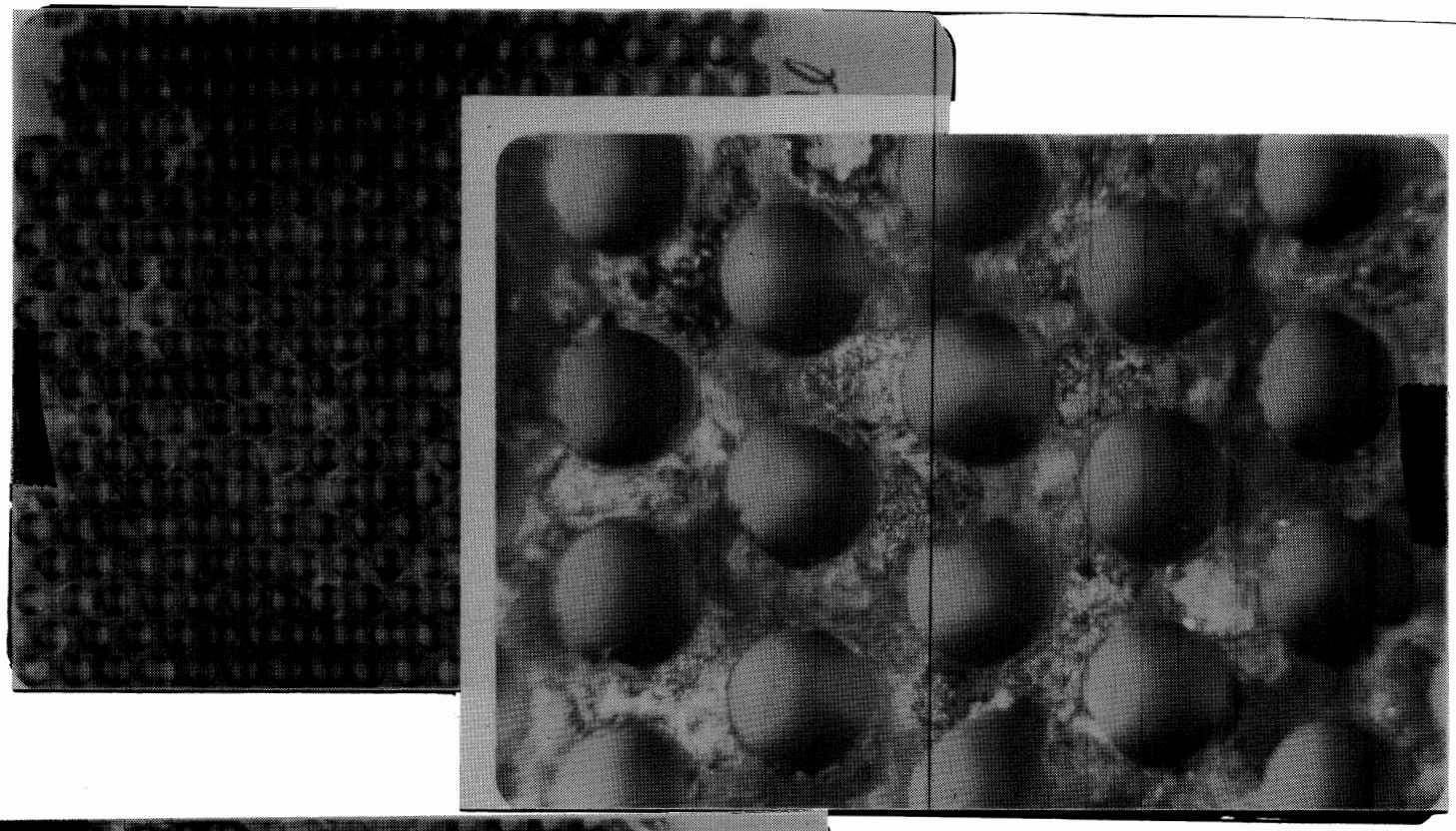
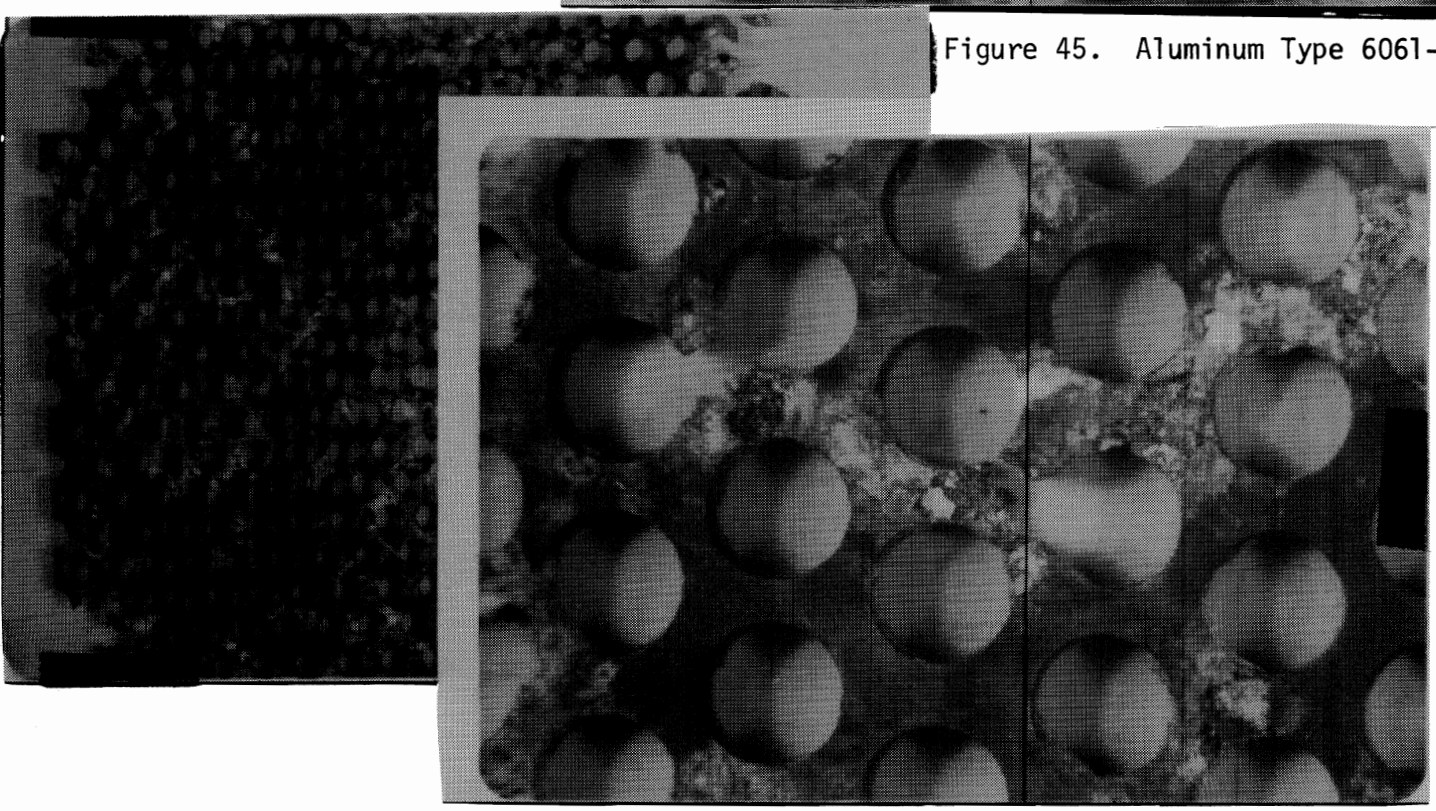


Figure 45. Aluminum Type 6061-T4



Chapter 5. CONCLUSIONS

- Aquatic growth on the Paintersville and Hood test units demonstrated that various plants and animals accumulate on screens submerged in the Sacramento River. However, the screens also trapped suspended material (debris, sediment, and living organisms) that made it impossible to determine the actual growth rates of components of the fouling communities and their contribution to the overall problem of screen clogging. Cleaning tests indicated that attached aquatic growth may not be a problem on the intake fish screen (routine cleaning removed such growth); however, these were short-term tests and the screens were never left in the water more than one month without being thoroughly cleaned.

- The debris sampling program demonstrated considerable annual variation in river debris concentration, with values ranging from about 0.001 to 1 mg/L dry weight. The plankton nets used in this study captured large particles of debris, which in turn trapped some suspended sediment, reported to range to 2 000 mg/L (Graves, 1977). Debris concentration correlated quite well with the reported Sacramento River flow.

- The seasonal variation in composition of captured material during 4-1/2 years of sampling was predominantly detritus in December-June, algae in June-September, and mixed detritus and algae in October-December, with leaves being occasionally abundant.

- Debris concentrations were generally uniformly distributed across the river cross section near Hood, and increased with depth.

- Debris concentrations in the test flume were about the same as those found in the river for flows less than 680 m^3/s (24,000 ft^3/s) (75 percent of the time, flow in the Sacramento River will be less). Above 680 m^3/s, flume concentrations were less than those in the river.

- The clogging rates of uncleaned screens were a function of screen type, pore size, approach velocity, and debris concentration. Using 4 mm (5/32 in) diameter hole perforated plate as an example, the clogging time to 0.3 m (1 ft) head loss varied from 50 minutes (March 1978) to about 22 days (September 1977).

- As approach velocity and measured debris concentration increased and as screen opening size decreased, the time to reach 0.3 m (1 ft) of head loss decreased.

- The composition and organic content of material was about the same for the suspended material in the river and flume and the material scraped from the test screens.

- The 2.4 mm (3/32 in) wedge-wire flat screen clogged at a significantly slower rate than the 4 mm (5/32 in) perforated plate. The wedge-wire clogged even more slowly when fabricated as a vertical axis drum.

- Cleaning a screen out of water with pressurized spray was the most effective method for removing debris. Flat spray nozzles, 0.4 m (16 in) from the screen, were effective at pressures from 35 to 690 kPa (5 to 100 psi), depending on debris type.

- Cleaning the front side of a flat plate screen under water with a wiper brush effectively removed materials causing screen clogging. To maintain head loss at less than 0.06 m (0.2 ft) and to design for a 98 percent probability of occurrence of riverflows and debris loads, a 4 mm perforated plate with an approach velocity of 0.06 m/s (0.2 ft/s) may have to be brushed as often as every hour during winter and spring and periodically, maybe once or twice a week, during the summer. The wedge-wire screen may require cleaning as often as 5.3 hours during winter and spring and periodically during the summer.

- Results of cleaning a screen under water with pressurized spray were less conclusive due to physical limitations of the test apparatus. Portions of clogged screen were cleaned equally well when sprayed from the front or the back. For the nozzles tested, the effective distance was 0.15 to 0.23 m (6 to 9 in) at about 690 kPa (100 psi).

- To remove any gradual buildup of debris and algae, periodic above-water cleaning will be required on screens that are routinely cleaned with an underwater device.

- Results of cleaning tests indicate that 15 m/min (50 ft/min) is an effective travel speed for the brush or spray bar cleaning mechanism.

- The assumed design velocity for water approaching the screen is 0.06 m/s (0.2 ft/s). An increase to 0.12 m/s (0.4 ft/s) would result in little change in cleaning efficiency based on the cleaning tests, but would increase cleaning frequency by 50 percent for the wedge-wire and by 100 percent for the perforated plate, based on the clogging curves.

- The corrosion tests demonstrated that no corrosion occurred on type 304 stainless steel perforated plate and welded wedge-wire during 4 years of exposure to the waters of the Sacramento River. Other stainless steels had minimal but measurable corrosion. Aluminum samples had substantial corrosion with much pitting. Aluminum oxide in the perforations was very difficult to remove.

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