SCREENING AGRICULTURAL DIVERSIONS IN THE SACRAMENTO-SAN JOAQUIN DELTA

BY

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INTRODUCTION

The Sacramento-San Joaquin Delta (Figure 1) consists of numerous islands and channels located at the confluence of California's Sacramento and San Joaquin Rivers. The islands are surrounded by levees and are intensively farmed. Channels serve as homes for many resident species of fish and as pathways for migratory species such as chinook salmon and American shad. A resource conflict develops when farmers divert irrigation water from channels by means of pumps and siphons. Because the agricultural diversions are not screened, they entrain various fish life stages, particularly eggs, larvae, and juveniles. The most commonly used irrigation methods in the Delta, subsurface and overhead sprinklers probably result in complete mortality of those organisms entrained in the diversions.

The Department of Water Resources (DWR) examined agricultural diversions in some detail to estimate fish losses caused by entrainment, primarily losses of juvenile chinook salmon and striped bass, and the technical feasibility of screening the hundreds of diversions located in the Delta. This report documents the results of this study. It must be pointed out that there are very few data available on diversion rates, losses through diversions, effective screen designs for the Delta pumps and siphons, or the potential costs associated with installing and maintaining effective screening systems. I was forced to make a lot of assumptions and to stretch the available data past comfortable limits. Because of the above limitations, the report contains only suggestions as to the magnitude of fish losses and the costs of screening. No attempt has been made to extrapolate from losses of small fish to the impact of the projected losses on adult populations.

For purposes of this report, the discussion of fishery resources is generally limited to populations of chinook salmon and striped bass that pass through and/or live in the Delta. The reasons for this limitation are two-fold. First, these two animals are economically the most important fish in the system; second, more data exist for these fish than any others. Other fish species are briefly discussed when data are available.

BACKGROUND INFORMATION

The environmental setting for the Delta and its primary fish and wildlife resources has been thoroughly described in numerous publications (see, in particular, DWR, 1974; PGandE, 1981; and DFG, 1966) and need not be described in detail here. There are, however, a few comments which may provide the

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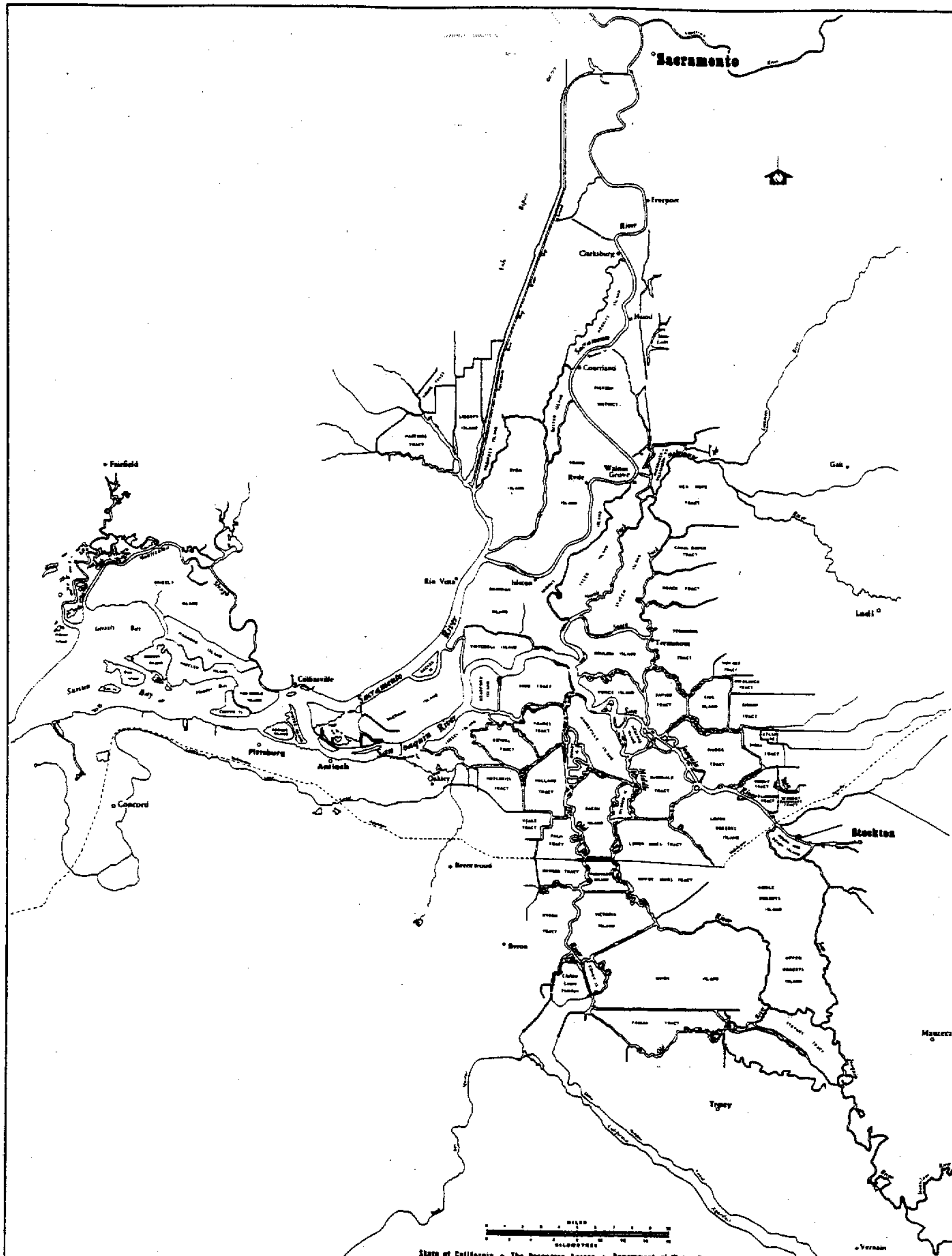


Figure 1. Sacramento-San Joaquin Delta.

background needed to better understand the report. These points deal with the Delta itself as well as the life histories of the striped bass and salmon.

The Sacramento-San Joaquin Delta

From the perspective of this report, the important points to note about the Delta, shown in Figure 1, revolve around its agricultural economy. In terms of water supply, the Delta can be conveniently broken down into two general catagories -- Delta uplands and Delta lowlands.

The Delta lowlands generally lie below an elevation of 5 feet above mean sea level and in some cases the areas inside the levees (the areas enclosed by levees are termed islands in this report) have subsided to as low as 20 feet below mean sea level. Irrigation water is supplied from surrounding surface channels by low lift pumps and siphons, reuse of drainage water, and sub-surface infiltration. Water use within the Delta lowlands has never been measured and is estimated by projecting consumptive use of the various crops grown. Cropping patterns in the region are periodically obtained by interpreting low-level aerial photographs with sufficient ground-truth verification to assure accurate estimates. Delta lowlands consist of approximately 425,000 acres, of which about 385,000 are suitable for agricultural use.

The Delta uplands constitute the area between the lowlands and the legal boundary of the Dleta and generally lie at elevations of +5 feet and greater. Most diversions from surface channels to the Delta uplands are made by pump with additional irrigation supplies coming from wells and diversions from internal drains. There are some data available on amounts of water diverted by pumps; however, the total water use in the uplands is also estimated by the consumptive use method. There are approximately 260,000 acres in the Delta uplands, of which about 185,000 (72 percent) acres are irrigable.

Chinook Salmon

With regard to this report, the important points about chinook salmon relate to how different facets of its life history make migrating fish vulnerable to siphons and pumps that divert irrigation water from the Delta. Spawning runs exist in the Sacramento and San Joaquin systems, although the runs in the Sacramento system are by far numerically greater. Under the assumption that upstream migrating adults are not vulnerable to be diverted by small intakes, the primary concern is with the downstream migrants. Figure 2 shows the time at which downstream migrating juveniles move past Hood on the Sacramento River. Note that fry migration generally occurs in winter and appears to be in response to sudden increases in riverflows. The majority of the smolts migrate downstream in late spring; although some are present during any month of the year. Smolts generally move through the Delta relatively rapidly; however, fry may take up residence in the freshwater portion of the Delta for periods of up to two months (Kjelson, et al, 1981). The migratory patterns described above pertain mainly to wild fish. Superimposed on their distribution is that of hatchery releases. The State hatcheries (Oroville on the Feather and Numbus on the American) release older (yearling) fish near Chipps Island. A release program of this type makes the young salmon less vulnerable to being diverted onto agricultural fields.

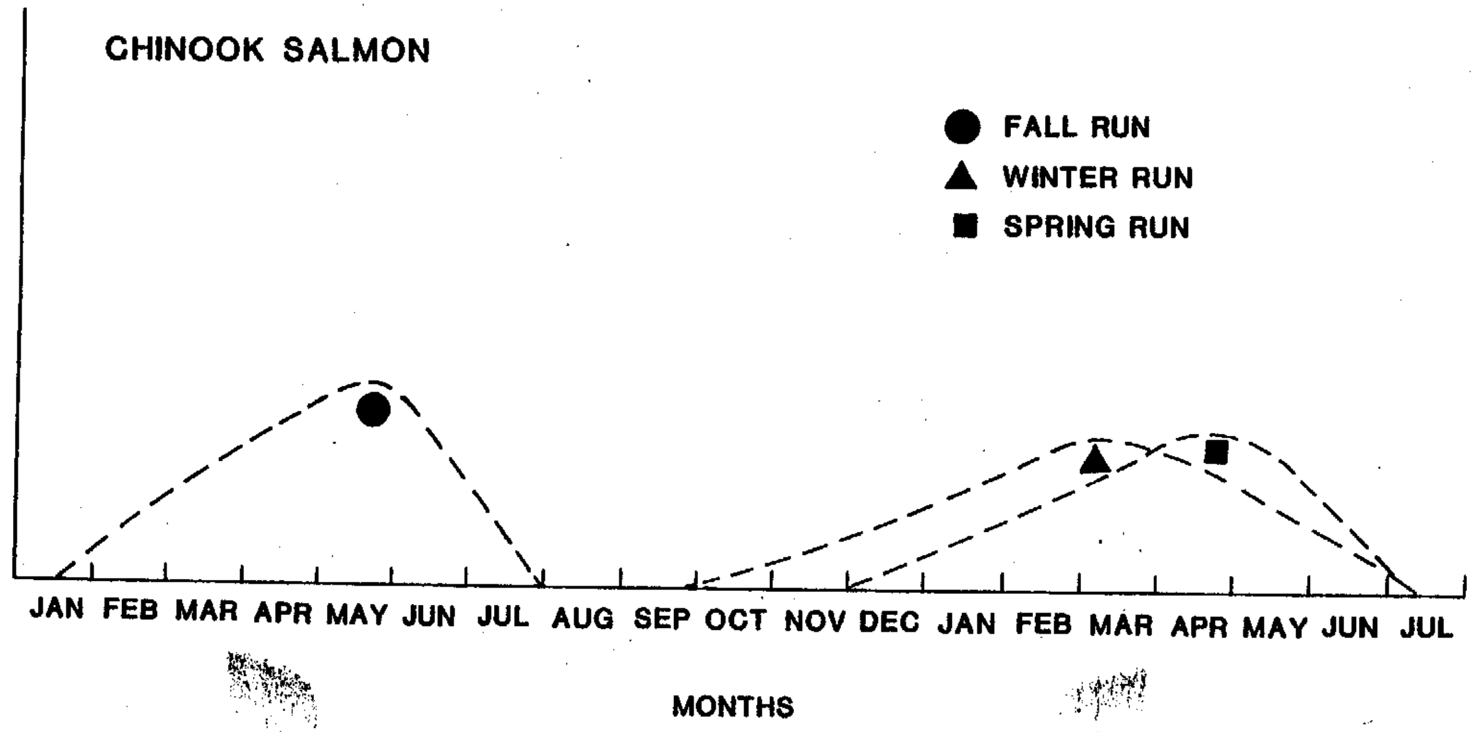


FIGURE 2 SEASONAL OCCURRENCE OF JUVENILE CHINOOK SALMON IN THE SACRAMENTO RIVER NEAR HOOD.

The federal Coleman Hatchery near Redding releases its fish in the upper river. Most of the fish migrating down the Sacramento and San Joaquin Rivers are wild fish.

A complicating factor in assessing a juvenile salmon's chances of being diverted on to farmers' fields within the Delta is the change in migrating patterns associated with cross-Delta flow caused by Federal and State pumping in the south Delta. Fish that would not normally be exposed to agricultural diversions in the interior Delta may become exposed because pumping plants cause the fish to move across the interior Delta with water from the Sacramento River. Some Sacramento River outmigrants may move up the San Joaquin River to the pumps during periods of reverse flow.

Steelhead trout, another important anadromous salmonid which uses Delta waterways in its migrations, can be expected to resemble chinook salmon in the susceptibility of its smolts to being diverted by Delta farmers.

Striped Bass

Striped bass are unlike chinook salmon in that more of their life is spent in or going through the Delta. Adults spawn in the Sacramento and San Joaquin systems in April and May and the buoyant eggs float downstream. As the fertilized eggs move downstream, they undergo embryonic development so that by the time they reach the vicinity of Suisun Bay, they are fully developed larvae ready for first feeding. Important points about the initial developmental stages of the striped bass are that the eggs and initial larval stages are very small (less than 6-7 mm) and are essentially planktonic. The larval bass are concentrated in the western Delta-Suisun Bay by the interaction of fresh and salt water movements (see for example Arthur and Ball, 1978). When they reach the so-called "entrapment zone" the bass are about 7-10 mm total length and remain in this area of high food availability for the next several weeks until they are large enough (typically longer than 38 mm) to effectively forage for themselves. The Delta itself may have been an important nursery for young bass, but its importance may be less since the State and Federal pumps changed flow patterns in the Delta.

DELTA AGRICULTURAL DIVERSIONS

The Delta irrigation season runs generally from late March-early April through September. DWR and the U. S. Bureau of Reclamation (USBR) estimate Delta agricultural diversions by a series of calculations based on such factors as land use, evapotranspiration rates, leach water, precipitation, and soil moisture depletion. Prior to 1980, the results of calculations made independently by both agencies were not in close agreement. Subsequently, an attempt has been made to reconcile the differences; an attempt which culminated in a 1981 report by Lyford, et al. The effort has resulted in calculations of total Delta water use which are in good agreement, although the monthly values calculated by the two methods do not always agree. For purposes of this study on screening agricultural diversions, I averaged the DWR-USBR estimates. These average values provide an idea of the amount of water pumped and siphoned from Delta channels.

Figure 3 contains a plot of the estimated average channel depletion during the 1968-1977 period. The average yearly total is estimated to be slightly more than 1 million acre-feet, with a maximum monthly value in July of almost 300,000 acre-feet. Because of local precipitation patterns, Delta agricultural diversions are minimal or nil during the December through February period.

The data from Figure 3 have been used to obtain the estimates of average monthly diversion rates plotted in Figure 4. During the period of maximum irrigation, or July for the period of analysis, an average of almost 5,000 cubic feet per second (cfs) are diverted from the channels. During the April through August period, when the eggs and/or young of chinook salmon, steelhead, striped bass, and American shad are present total diversions average from 2,500 to about 5,000 cfs or same general range as both the State or Federal intake in the south Delta.

There are no recent descriptions of number, location, and sizes of the individual points of diversion in the Delta. The most recent complete survey of the diversions was by the USBR in 1963 and 1964. The results of its studies were published in a series of reports -- 10 for the lowlands and 13 for the uplands -- which included sections on water rights and ownership, water supply for irrigation, irrigation and drainage facilities, and land use and water requirements. The reports showed the approximate location of the individual intakes but did not provide any descriptive regarding pipe sizes, available head, rated pump capacity, etc. As part of this study on screening, we did conduct a brief survey of Grand, Bacon, and Ryer to obtain some idea of the pipe sizes for both pumps and siphons, and the available head for the siphons. The Bureau reports and our brief survey constitute the basis for the following information on numbers, sizes, and locations for the intakes.

Based on the USBR reports, there were approximately 850 pumps and 1,000 siphon intakes in the Delta uplands and lowlands, for a total of 1,850 diversions. Although the data are relatively old, the total irrigated acreage has not changed appreciably since the early 1960s and it is unlikely that the number of diversions has changed much either. Our surveys of Grand, Bacon, and Ryer indicated that the intake locations on these three islands were about the same as portrayed in the Bureau maps. One change that may have taken place is increased use of sprinkler irrigation today, as compared to 1960, which could change some siphons to pumps to provide the needed pressure.

Figure 5 contains histograms of pipe sizes for pumps and siphons we found on Grand, Bacon, and Ryer Islands during February 1982. In both cases, the modal size was 12 inches; however, the mean size of the pump intakes was (11.2 inches) slightly smaller than for siphons (13.7 inches). The size frequencies are probably typical of other locations throughout the Delta.

The volume of water diverted by pumps and siphons or a given size varies considerably, depending on such factors as lift, pump type, horsepower, pipe type and length for pumps, and available head, pipe material and length for siphons. For a pump with a 12-inch intake and typical conditions found in the Delta, the pump might be expected to deliver in the range of 10-15 cubic feet of water per second. Chuck Wagner (personal communication) estimated a range of flows in 67 diversions in the Delta uplands, Sacramento to the Mokelumne River. His estimates are:

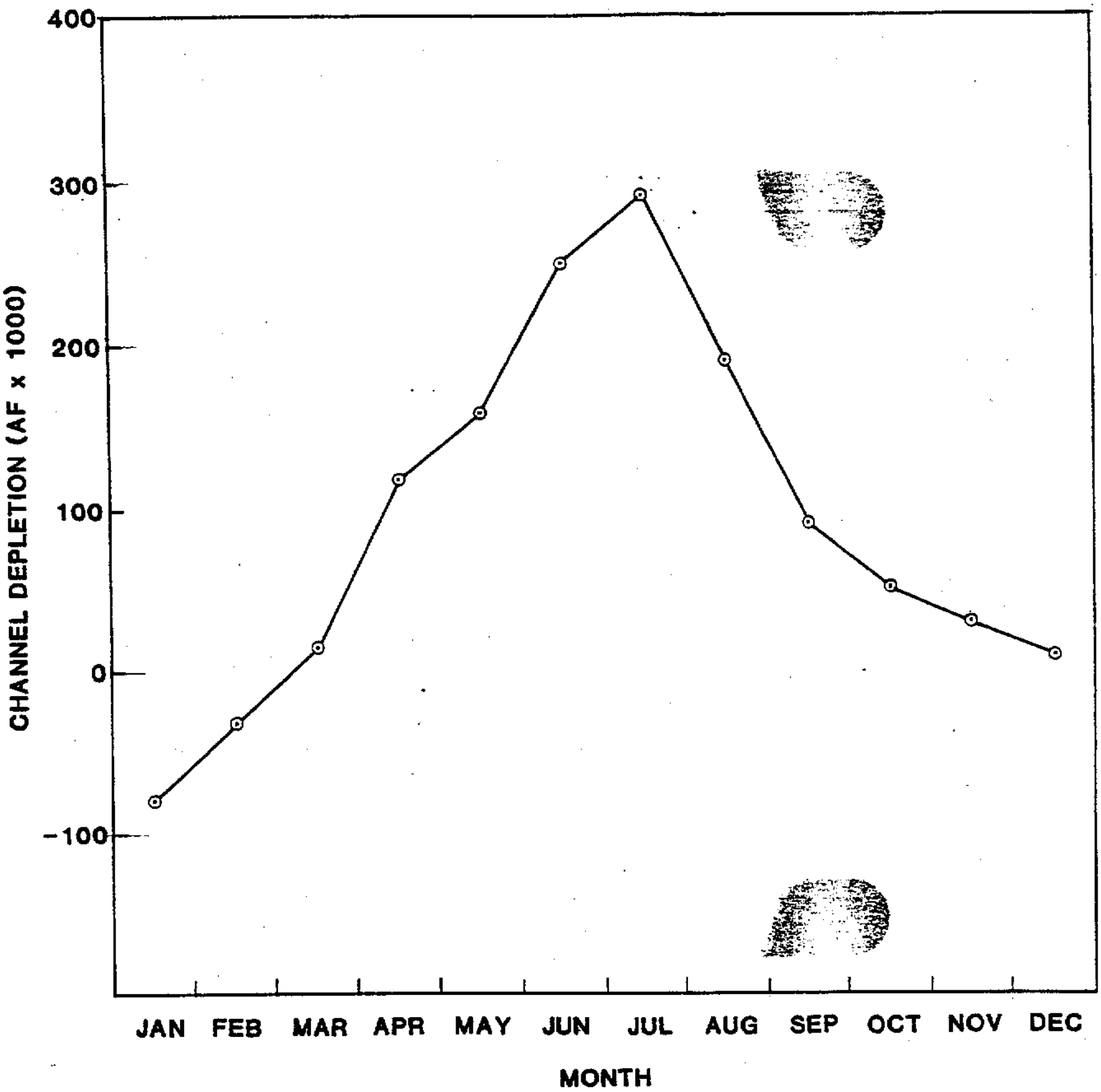


FIGURE 3 AVERAGE MONTHLY CHANNEL DEPLETION IN DELTA SERVICE AREA. (1968–1977 Data using average of USBR and DWR estimates)

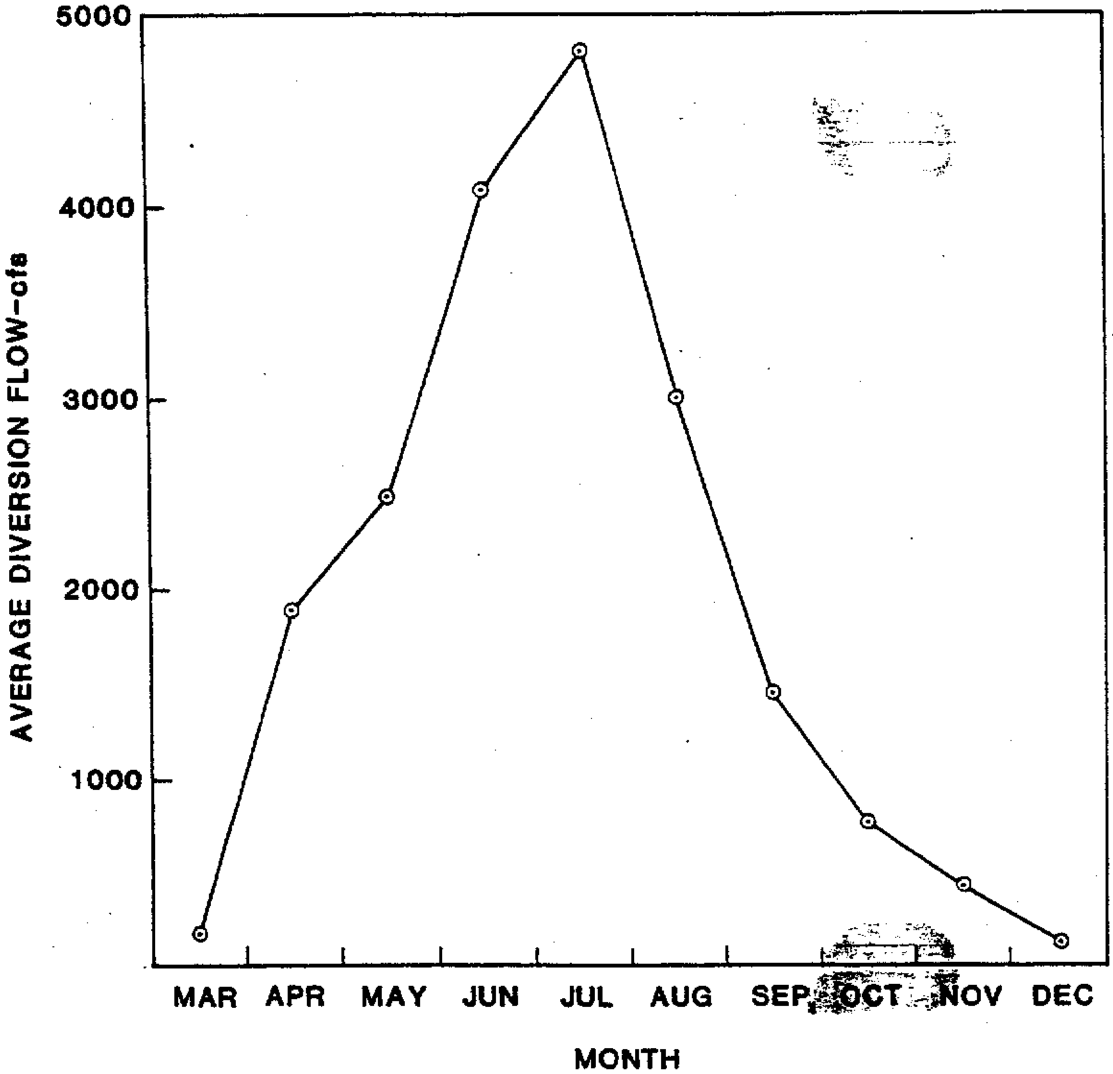


FIGURE 4 ESTIMATED MONTHLY DIVERSION RATES, SACRAMENTO-SAN JOAQUIN DELTA AGRICULTURAL DIVERSIONS, 1968-1977

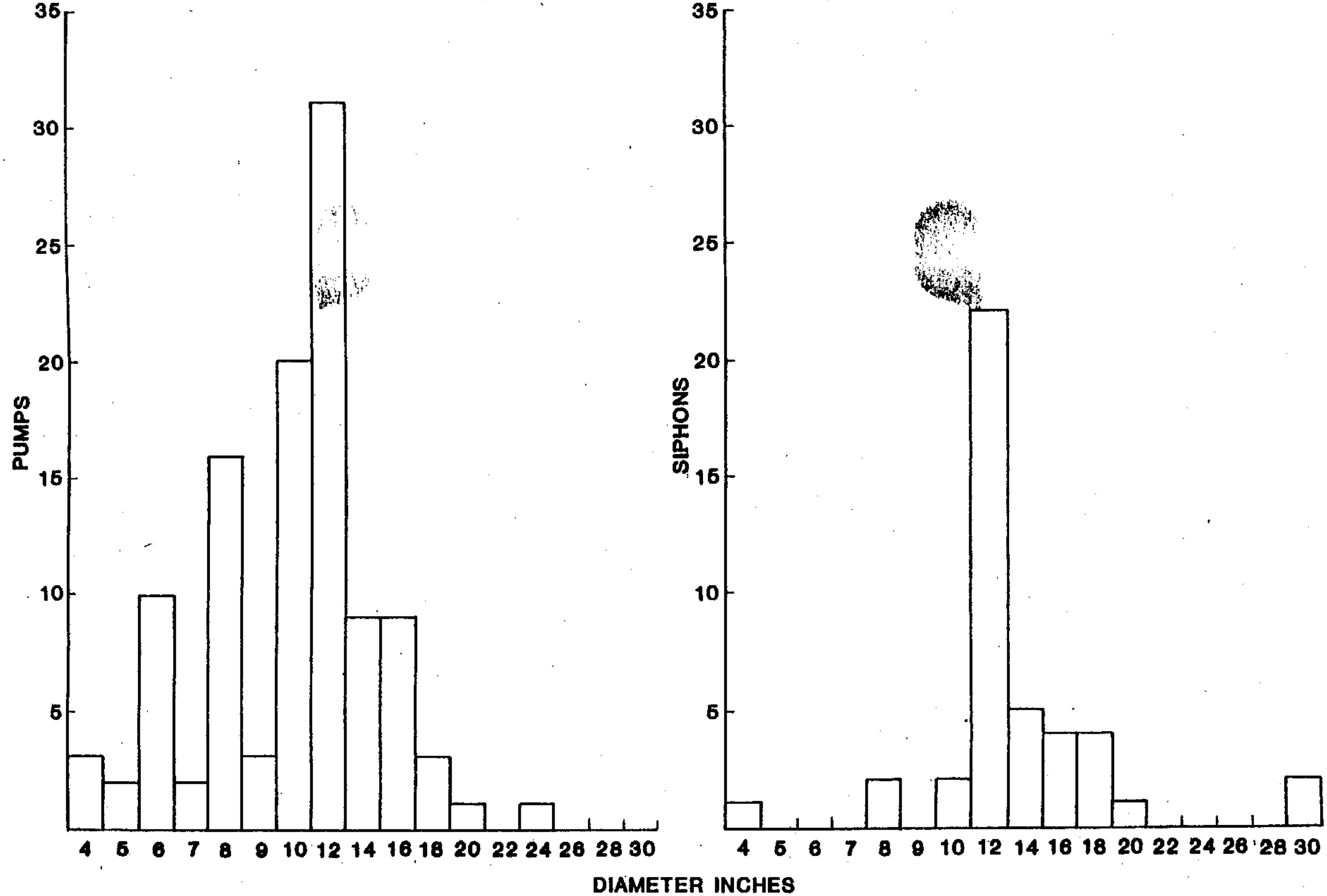


FIGURE 5 PIPE SIZES FOUND FOR AGRICULTURAL DIVERSIONS GRAND, BACON, AND RYER ISLANDS, 1982

0.5 to 5 cfs	57 diversions
5 to 15 cfs	5 diversions
16 to 48 cfs	5 diversions

Based on the above, it appears that most Delta agricultural diversions are fairly small, with maximum flows in the range of 10-15 cfs. Comparing the total average volume pumped in August (about 5,000 cfs) with the estimated numbers of intakes (about 1850), an average flow of 2.70 cfs per diversion is obtained. If the numbers are reasonably correct, this indicates that the diversions operate only intermittently even during peak irrigation season.

LEGAL ASPECTS OF SCREENING

The Office of the Chief Counsel, California Department of Water Resources, researched the question of legal responsibility for screening agricultural diversions in the Sacramento-San Joaquin Delta. The complete text of the legal opinion is attached as an appendix to this report. The results are summarized in this section.

The gist of the legal opinion is that the responsibility to screen existing and future diversions rests with DFG. The State has elected to put into the Fish and Game Code certain provisions on screening diversions which effectively remove screening questions from the realm of common law and place them under administrative law. The importance of this distinction lies in the fact that if the State, local government, or private individuals wish to bring suit against small diverters (under 250 cfs maximum rate of diversion) to install fish screens, the financial burden of such screening falls on DFG. DFG must then determine if fish losses associated with individual diverters warrant the capital and operational expenses associated with the screens.

The specific Fish and Game Code provisions are Articles 3 and 4 of Chapter III, Part 1, of Division 6. Article 3 pertains to diversions of more than 250 cfs and states that DFG is to examine the conduits in question to determine if screening is necessary. If screening is required to protect the resource, then the Department provides the design specifications and pays one-half of the cost. Under Article 4, diversions of less than 250 cfs, the same provisions apply except that the entire cost is paid by DFG.

TECHNICAL ASPECTS OF SCREENING

In the event it were decided to screen agricultural diversions, DFG would provide actual design specifications. Based on experience developed during other screening programs, DFG would require a positive barrier, low approach velocity type of screen. Clogging considerations dictate that some lower limit be placed on the mesh size, and thus the size of fish the screen will protect. Data developed for the Peripheral Canal intake selected about 1 inch as the smallest size fish that could be screened while keeping cleaning within the realm of possibility. Based on salmon and striped bass data, perforated plate with hold diameters of 5/32 inch, on 7/32-inch staggered centers, or profile wire with 3/32-inch slot width will prevent entrainment of fish in the 1-inch size range. It should be noted that it may not be possible to build and maintain screens in the Delta that will prevent the entrainment of striped bass eggs and larvae and will allow the required irrigation flows. Such screening would require mesh sizes on the order of 0.5-1.0 mm and cleaning problems would be severe.

Approach velocity (where approach velocity is defined as the flow divided by screen area) studies for the Peripheral Canal have indicated that velocities of 0.2 feet per second (fps) or lower are required to prevent the impingement and mortality of the most sensitive species tested, juvenile American shad. DFG specified 0.5 fps (maximum) for the screens built to protect the Roaring River intake, Suisun Marsh project, and has indicated that a maximum of 0.5 fps would be acceptable for Delta agricultural diversions (Dan Odenweller, DFG, personal communication).

Another requirement of DFG is that the screen be out in the channel to the extent that there is bypass flow available to move the fish away from the screen. This criterion should not be a problem with typical agricultural diversions in the Delta although there may be a conflict between providing bypass flows and maintaining a navigable channel. Any mid-channel structures would have to permit normal boat traffic. Finally, the maintenance of design approach velocity requires that the screens be kept clean. As holes plug, the velocity through the remaining unplugged holes increases. All screen designs must include a method of cleaning the screens so that head loss is kept to an acceptable minimum and the approach velocity is essentially uniform across the screen face.

From a farmer's standpoint, the design also has to allow for his flow needs even in the event that the screen becomes plugged. Representatives of DFG have indicated that such a failsafe device would be allowed provided that screen cleaning provisions were included in the facility design.

Possible Designs

One of the problems with designing screens of Delta agricultural diversions is the variability of intake sizes, locations, head differential available, availability of power, etc. A few possible designs have been developed and are described below. It should be pointed out that none of these designs has been field tested in the Delta.

Ernie Murphey, retired from DFG's screen shop, developed a design which may be suitable for pumped intakes. The details of the design are sketched in Figures 6, 7, 8, and 9. Essentially, the screen consists of a rotating element on the bottom of an intake pipe which is cleaned by a water jet. Pressure for the water jet is derived from the discharge side of the pump. The drawings show the screen material to be perforated plate; however, welded wedge wire could be used as well. The design incorporates a failsafe device which allows water to be pumped should the screen become clogged.

No scale is shown on the sketches. For an intake with a maximum flow of 30 cfs, it would take 60 ft^2 of screen area which could be achieved by a screen with a diameter of 4 feet and a length of 5 feet. The screen would be submerged to such a depth that, at low water, the pump would not suck air.

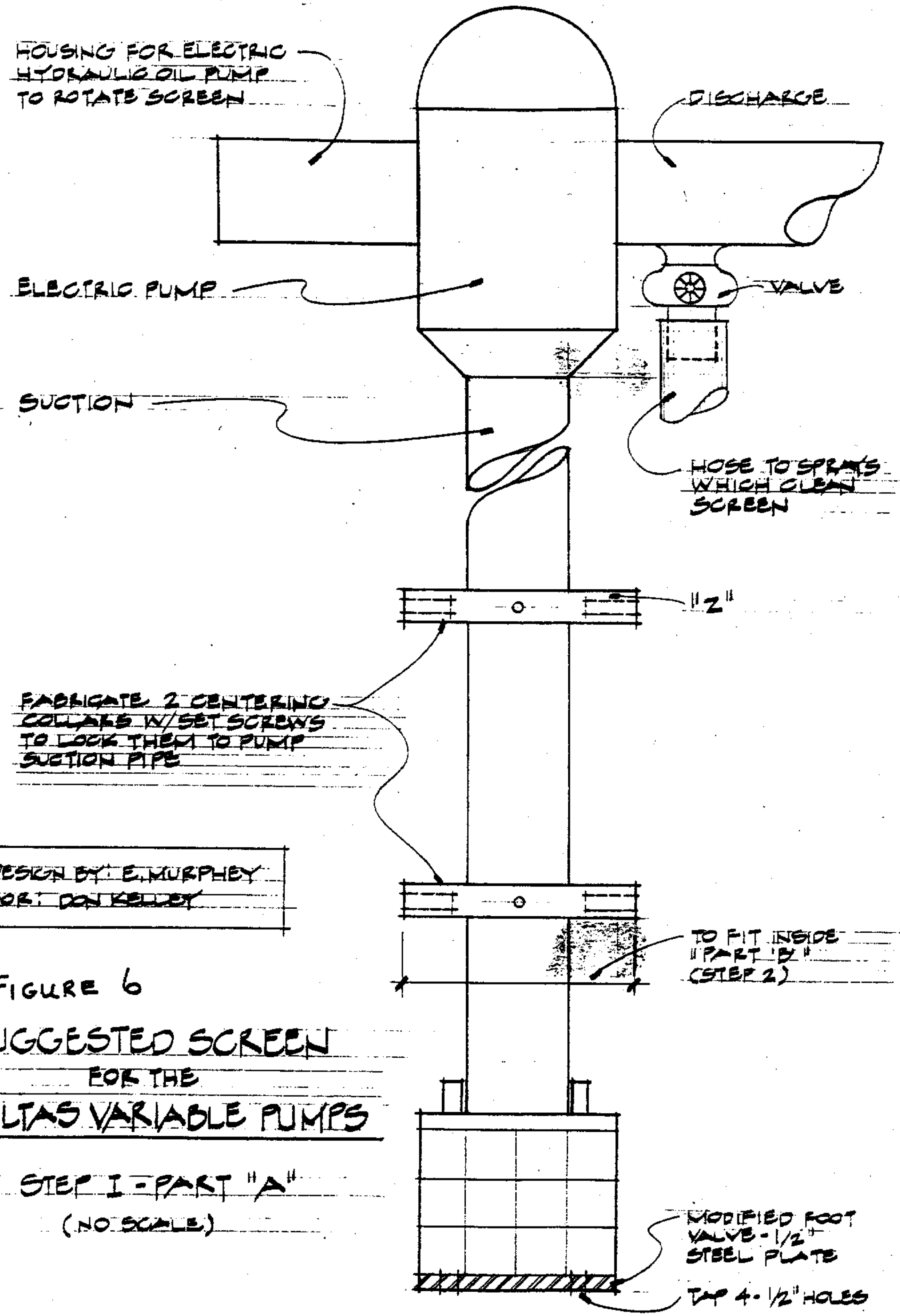


FIGURE 6

SUGGESTED SCREEN FOR THE DELTAS VARIABLE PUMPS

STEP I - PART "A"

(NO SCALE)

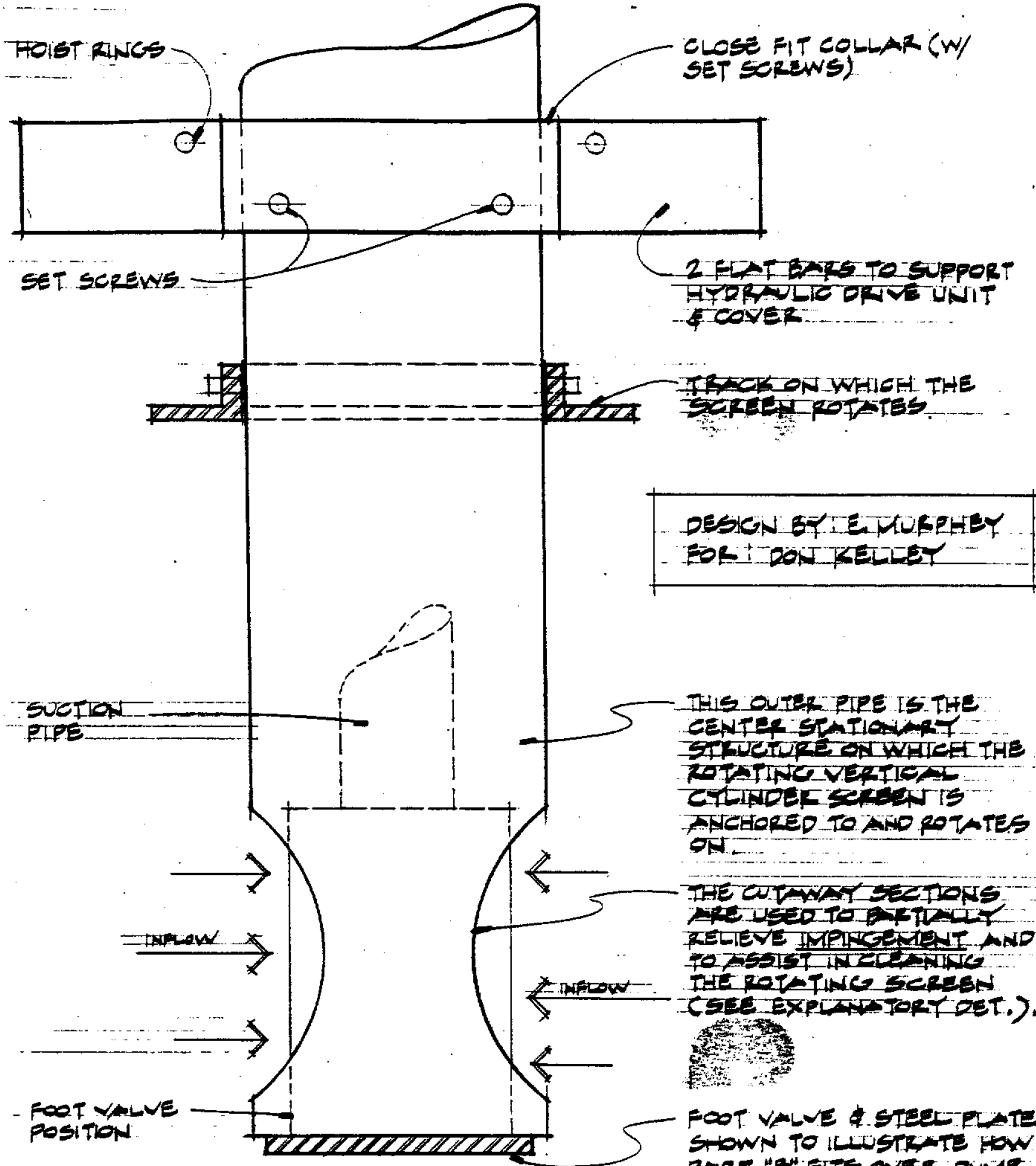


FIGURE 7

SUGGESTED SCREEN
FOR THE
DELTAS VARIABLE PUMPS

STEP II - PART "B"
(NO SCALE)

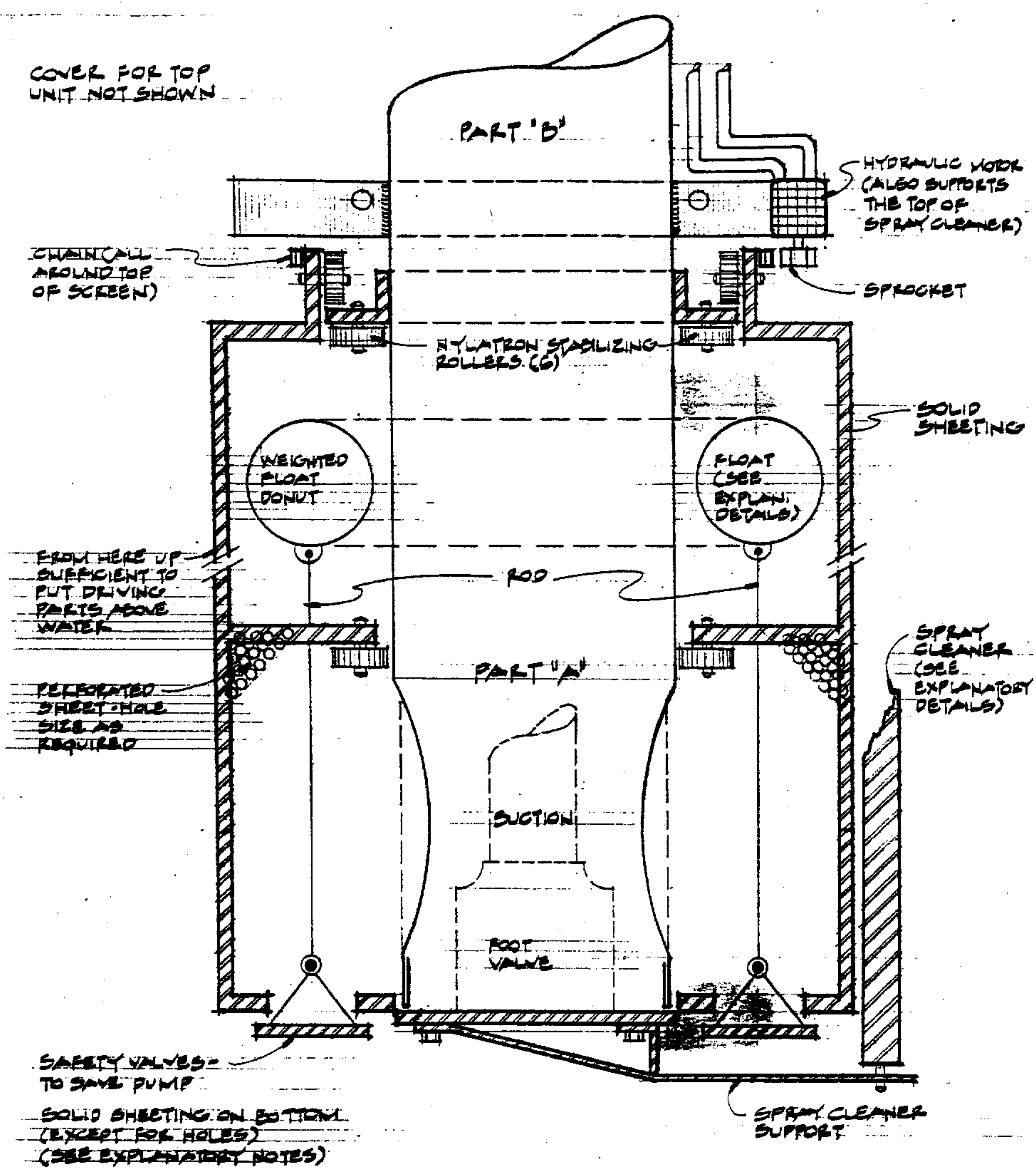


FIGURE 8

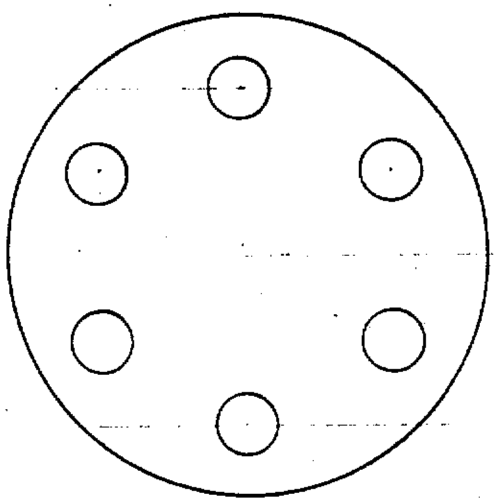
SUGGESTED SCREEN
FOR THE
DELTAS VARIABLE PUMPS

STEP III - PART "C" (THE SCREEN)

FIGURE 1

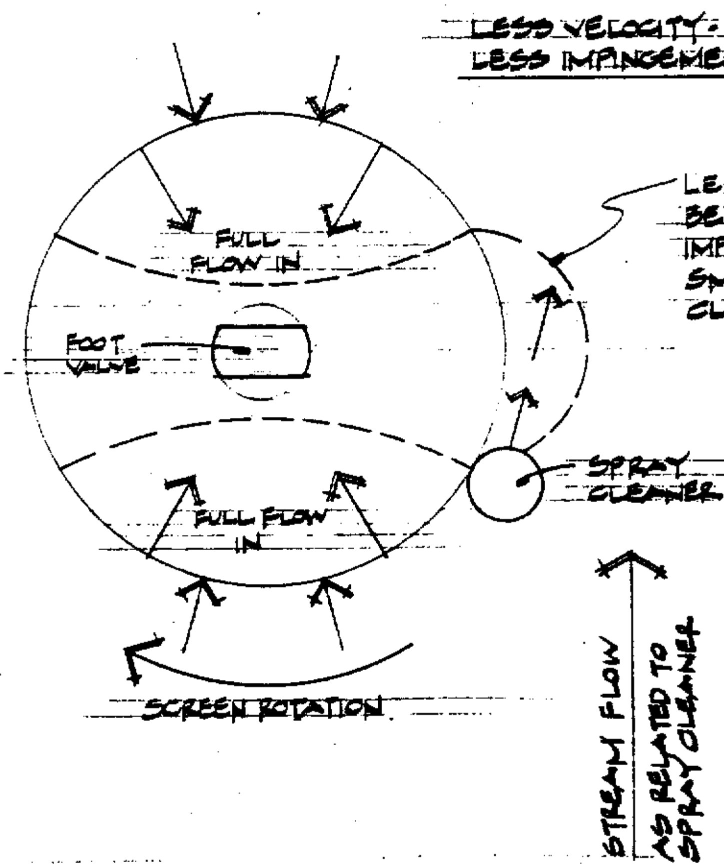
SUGGESTED SCREEN
FOR THE
DELTAS VARIABLE PUMPS

EXPLANATORY DETAILS



THE SOLID BOTTOM WITH SIX (6) ROUND HOLES HELD CLOSED BY THE FLOAT IS A VERY NECESSARY SAFETY FACTOR - BECAUSE - IN CASE OF MECHANICAL FAILURE, THE OPERATING PUMP SOON BURNS UP. BUT WITH THE ENCLOSED WATER GONE, THE FLOAT LOWERS AND OPENS THE PORTS IN THE BOTTOM SO WATER ENTERS. THE PUMPS KEEP OPERATING, THE FARMER KEEPS IRRIGATING - AND WILLING TO NOTIFY THE MAINTENANCE SHOP.

DESIGN BY: E. MURPHEY
WILSEYVILLE, CA. 95257
FOR: DON KELLEY



LESS VELOCITY AREA - ACTUALLY MEANS BETTER & EASIER CLEANING; LESS IMPINGEMENT & GENTLER REMOVAL OF SMALL FISH, EGGS & LARVAE; LESS CLEANING WATER REQUIRED.

NOTES

- ENTIRE ASSEMBLY MAY BE RAISED FOR INSPECTION (OR) REPAIR.
- WATER FOR SPRAY CLEANER COMES FROM VALVE ON DISCHARGE.
- THE HYDRAULIC PUMP FOR THE DRIVING HYDRAULIC MOTOR COULD BE MOUNTED NEARBY OR ON THE MAIN WATER PUMP

Murphey has also prepared a potential design for a device to screen siphons where no electrical power is readily available to operate a cleaning device. Conceptual diagrams of the shiphon system are found in Figures 10 and 11. Note that the power needed to rotate the cylindrical screen past the cleaning device is derived from the siphon itself. An apparent problem with the system as proposed concerns the possible support (guy lines) needed to keep the receiving water end of the siphon tube vertical. The effect of drawing off head to run the hydraulic motor on flow through the siphon also needs study.

Johnson Division, UOP Inc., manufactures surface water screens in several standard designs. The range of flows which can be screened by standard Johnson intake screens range from about 0.50 cfs to 60 cfs, with the 3/32-inch slot width and a 0.5 fps maximum through-slot velocity. A Johnson Screen with 3/32-inch slot width contains about 50 percent open area; thus, the approach velocity would be about 0.25 fps when the through-slot velocity is 0.5 fps. A Johnson Screen with a 3/32-inch slot and 0.5 fps approach velocity and an intake reated at 15 cfs would have the configuration and dimensions shown in Figure 12. The diameter would be 48 inches, the length 61 inches, and would weigh about 1,000 pounds. A typical installation of a Johnson type cylinder screen is illustrated in Figure 13. Note that the pipe is hinged and a lifting device provided to remove the screen assembly from the water for cleaning.

Single cylinders for larger diversions, 40 cfs, for example, are quite large (72-inch diameter and 89 inches long). The cylinder diameter can be decreased by using a tee-screen (Figure 14). For the same 40 cfs, the tee-screen would have a diameter of 48 inches and an overall length of 161 inches. The reduction in diameter might be important in situations where the water is not deep enough to provide the required 1/2 screen diameter depth between the screen and the minimum water surface and between the screen and the bottom. The minimum clearance is needed to prevent the intake from sucking air at the surface and sucking debris and silt off of the bottom.

Cleaning cylindrical screens can be accomplished by one or more of the following means. Johnson Screens can install a manifold for an air backwash system in which periodically a large burst of air (4-5 screen volumes) is released as close to instantaneously as possible.

Air burst cleaning systems generally consist of a small compressor, and accumulator tank, and a manually or automatically operated quick release valve. Since most siphon locations do not have ready access to power, a variation on the air burst approach is to bring a portable air supply to the site, mounted on a truck or boat, and provide periodic cleaning. Because of the small openings, the expected rapid clogging rate due to peat fibres in the water, and the less than satisfactory results experienced with tests of the system at Hood, it is doubtful that air burst cleaning would be an effective way of maintaining flow through screened siphons in the Delta.

The most apparent effective way to clean the cylindrical screens is by spraying with a high pressure hose. The screens must be pulled completely from the water before spraying and with screens of the general size illustrated in Figure 14 above, the physical system for moving them in and out of the water

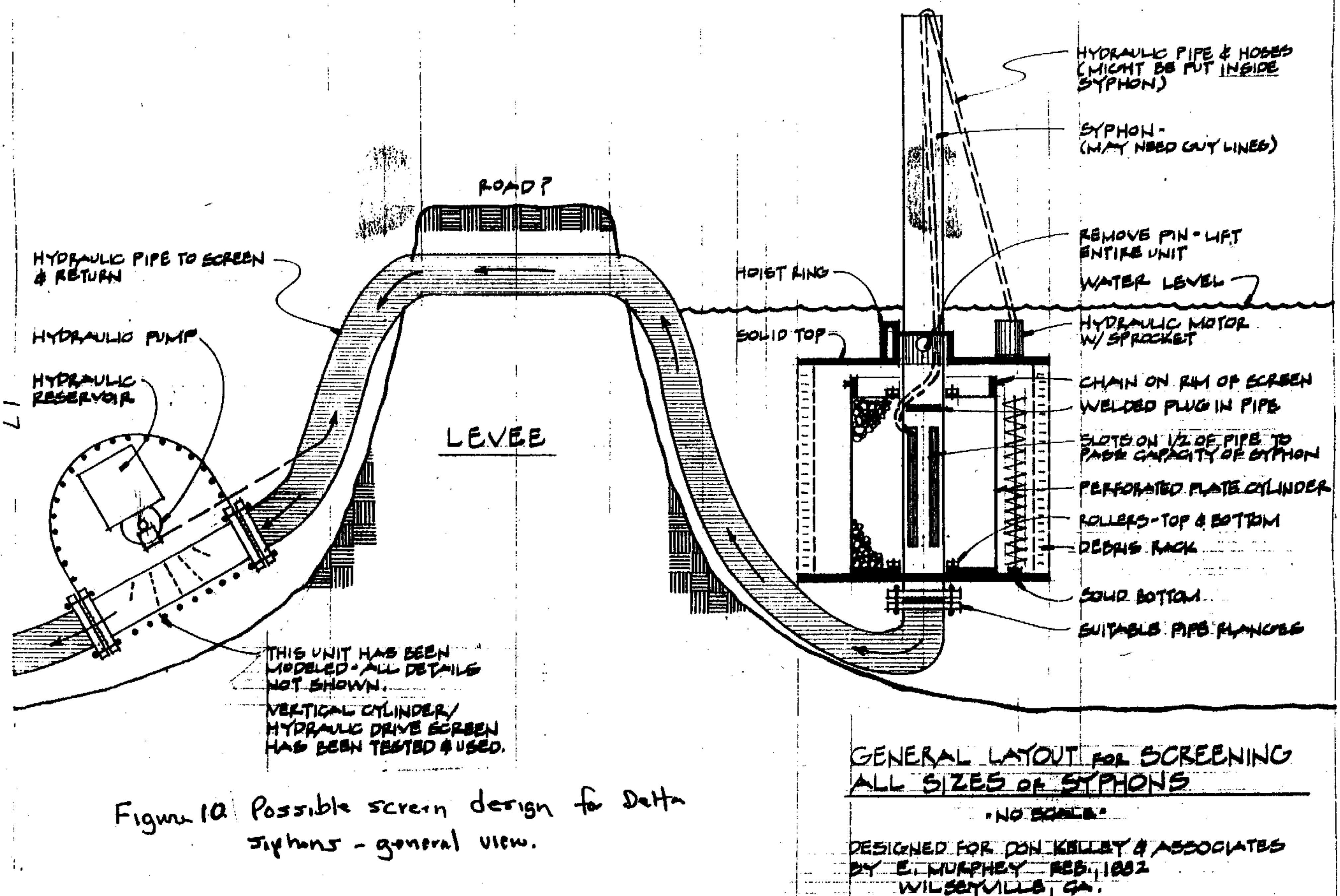
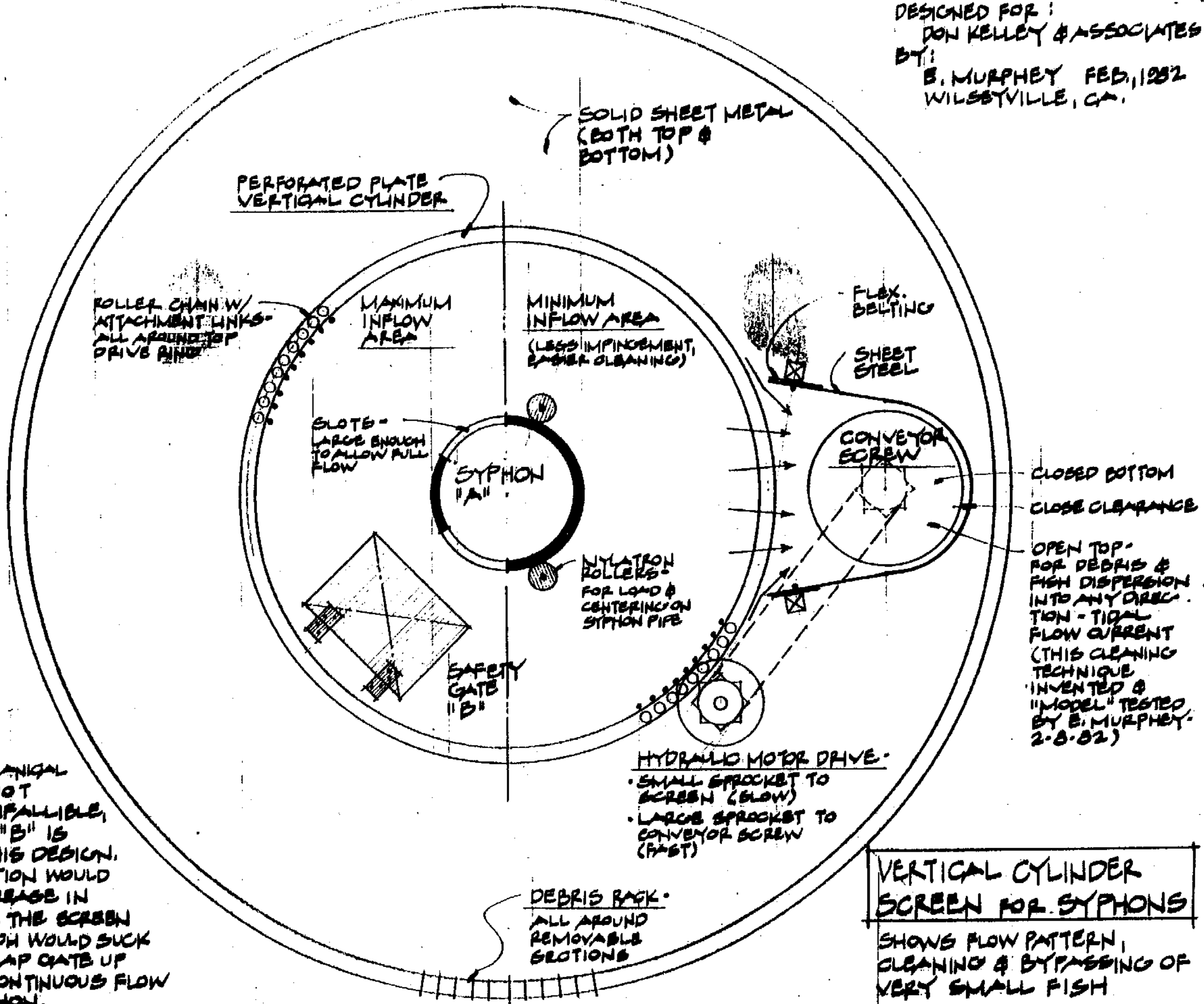


Figure 10 Possible screen design for Delta syphons - general view.



NOTE

SINCE ALL MECHANICAL DEVICES ARE NOT ABSOLUTELY INFALLIBLE, SAFETY GATE "B" IS INCLUDED IN THIS DESIGN. ANY MALFUNCTION WOULD CAUSE AN INCREASE IN VACUUM INSIDE THE SCREEN CYLINDER, WHICH WOULD SUCK THE HINGED FLAP GATE UP TO ADMIT A CONTINUOUS FLOW FOR THE SYPHON.

Figure 11 Possible screen design for Delta pumps - Vertical cylinder screen details.

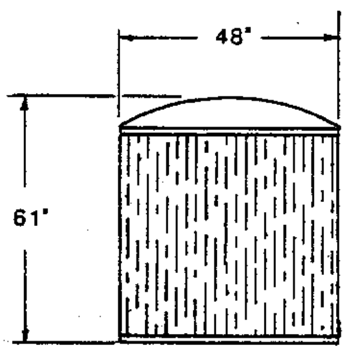


FIGURE 12 STANDARD SINGLE INTAKE SCREENS
LARGE DIA.

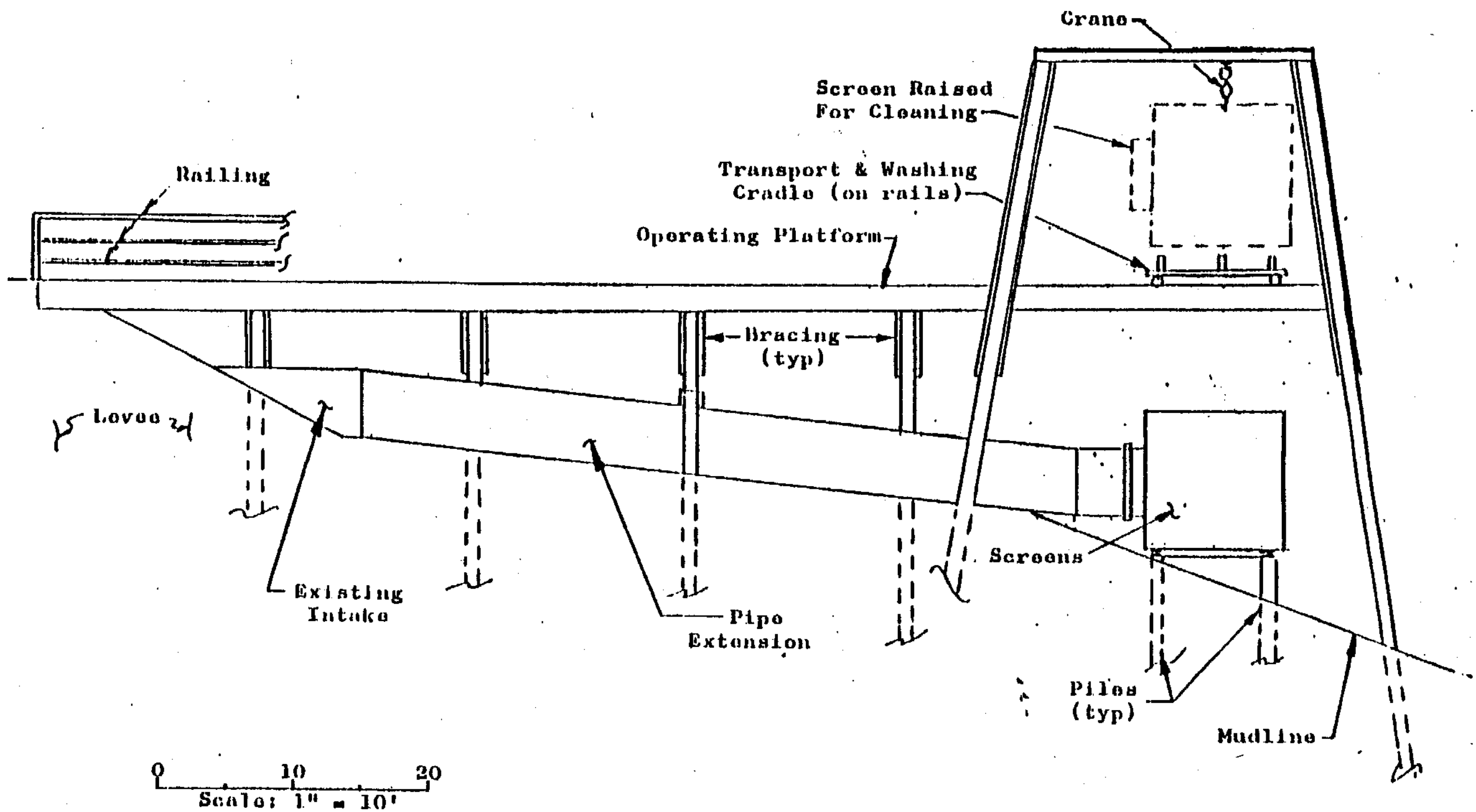


Figure 13 Cylindrical Screen Layout - Profile

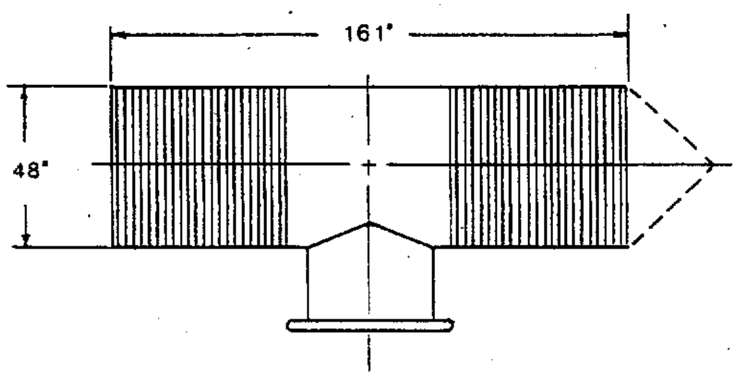


FIGURE 14 STANDARD TEE INTAKE SCREENS

could be fairly elaborate. For most screen locations the spray water would be provided by a water truck or a portable high pressure pump.

Air burst and high pressure water sprays are not particularly effective at removing some attached biological growth. Our experience in the Suisun Marsh has demonstrated that colonial hydroids and barnacles become attached and must be wire-brushed from the screens. The extent of the problem of attached growth on the Delta screens is unknown. Attached growth was not a problem at the Hood site but has been a problem in the Marsh. The Delta is generally intermediate in salinity between Hood and the Marsh, but generally is fresh water. Biofouling problems are most often associated with marine environments, thus Delta installations should be relatively free of biofouling problems. If Johnson cylindrical screens were used, they should have removable end plates so that the screen interior would be readily accessible for cleaning. Fouling organisms can bridge between bars supporting the screen wires and fill the inside of the cylinders. Cylindrical (or other) screens can be constructed of a copper-nickel alloy which is toxic to many fouling organisms and acts to slow the rate of fouling. A panel of this alloy has been ordered for the Marsh screens to determine if it is effective at preventing fouling. Preliminary results of these studies indicate an initial period of growth retardation; however, the copper-nickel screens eventually foul.

Cylindrical screens similar to those built by Johnson could also be constructed from perforated plate. Based on the clogging rate differential between profile wire and perforated plate shown by Smith (1982), and the expected severe clogging problems in the Delta, profile wires would appear to be the material of choice. If the screens remain in the water for long periods, then 304 stainless would be needed. If the screens were submerged only where the farmer diverts, it would be possible to use less expensive material.

Johnson wedge wire can also be built in the form of flat plate and a screen constructed as in Figure 15. This is the type of screen used by DWR in Suisun Marsh. With this screen type there is the advantage of relatively easy access to the screens for observation and clearning. The major problem associated with the screen is poor velocity control which can result in considerable variability in velocities across the screen face. To make this type of screen installation suitable for Delta agricultural diverters would require that some diversions be consolidated and a common point of diversion constructed. It is unlikely that Delta farmers would be receptive to much replumbing of their intake and distribution lines.

FISH LOSSES THROUGH DIVERSIONS

This section contains an attempt to estimate the numbers of striped bass and salmon lost through local agricultural diversion systems in the Sacramento-San Joaquin Delta. Because of the paucity of data available, the estimates are, at best, only in the order of magnitude range.

Striped Bass

In May, June, and July of 1972, DFG sampled seven agricultural diversions on Sherman Island with the objective of obtaining information on the entrainment

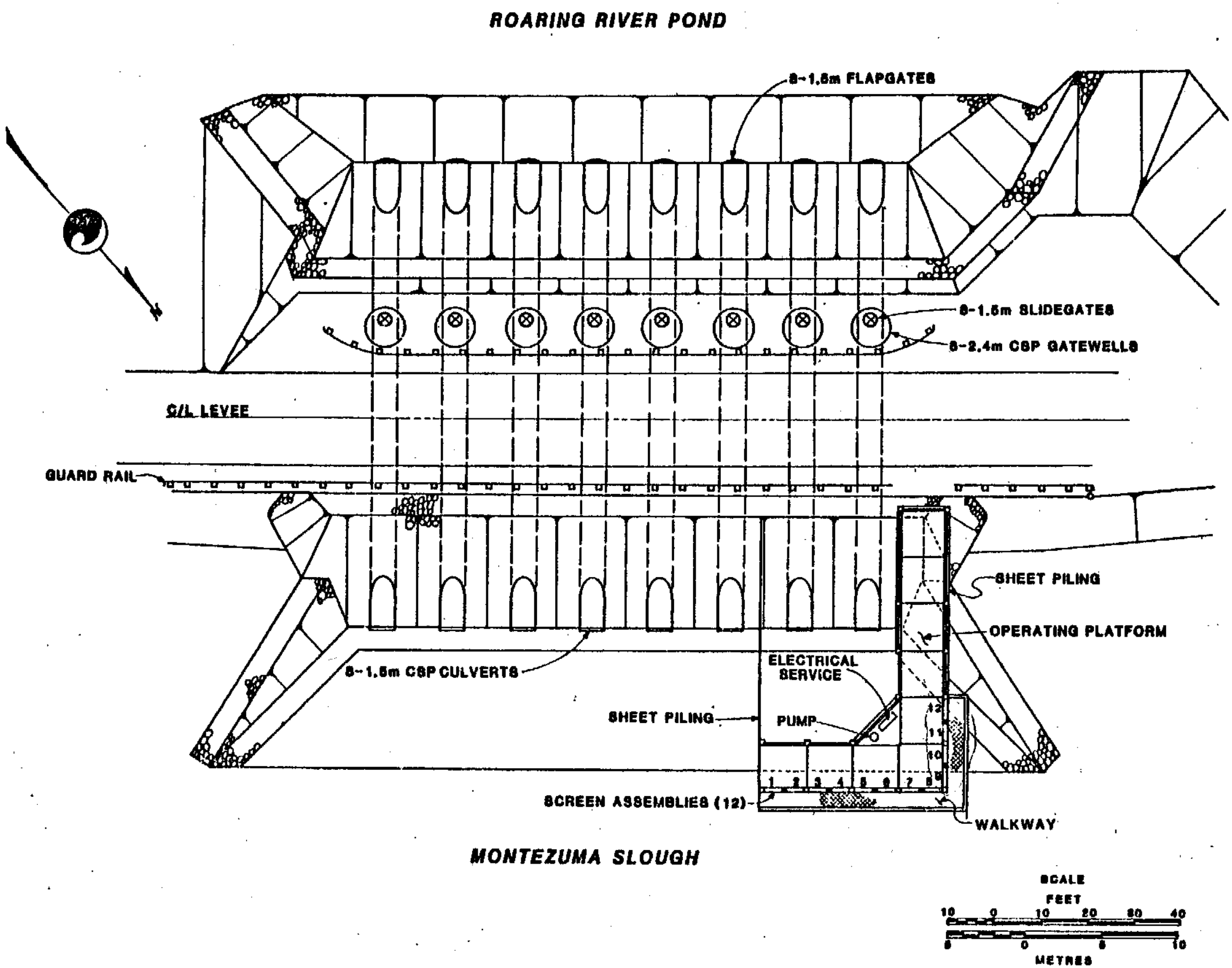


Figure 15. ROARING RIVER INTAKE AND FIRST STAGE FISH SCREEN

of striped bass eggs and young. Samples were also collected in the adjacent channel so that concentrations in the diversion and the source water could be compared. The results of this limited study were described by Allen (1975). The general conclusion reached by Allen was that concentrations in the diversions were statistically identical with those in the adjacent channel. Eggs were present in the river during the period May 3 thourgh June 14 and averaged one per m^3. Peak egg concentrations (in range of .7 - $5.8/m^3$) occurred between May 11 and May 19. Striped bass young peaked at 1 - $2/m^3$ during the period of May 17 to June 14.

Although the average length of the fish caught in the diversions was statistically the same as that of those caught in the channels, no fish larger than 16 mm was found in the diversion samples. Allen postulated that bass larger than 16 mm could swim well enough to avoid being pulled into the siphons. As well be shown later, 80-100 mm salmon are entrained by siphons. It seems unlikely that 16 mm striped bass can avoid being entrained.

Since the nets used to sample both the siphons and the channel had the same mesh size (nominal mesh opening of 920 micrometres), any sampling bias would have to have been introduced by the water in which the discharge was sampled. Without more data it seems likely that bass greater than 16 mm (to some unknown maximum size) are vulnerable to being entrained in small Delta agricultural diversions.

I made some rough estimates of losses of striped bass eggs and larvae through agricultural diversions for 1978 and 1979. The data bases used in these calculations were from PGandE (1981) and Lyford, et al. (1981). The PGandE report contains tabulations of numbers of bass eggs, yolk sac larvae, larvae, and juveniles in several surveys conducted throughout the Delta in 1978 and 1979. DFG has similar, and more comprehensive, data for earlier years but were not available in a ready-to-use format. The consultant for PGandE (Ecological Analysts) attempted to make their data comparable with those of DFG by using identical (or nearly as identical as possible) field sampling techniques.

The PGandE data on concentations of young bass and eggs were broken down by sampling strata within the Delta. In 1978, the following strata were sampled on 10 sample dates from April 20 through July 10:

Suisun Bay/Carquinez Strait
Upper Bays
Montezuma Slough
Lower San Joaquin River
Lower Sacramento River
Ship Channel/Steamboat Slough
Upper Sacramento River
Upper San Joaquin Delta

In 1979, the number of strata was increased (see below) and the number of sampling dates was increased to 13 between April 18 and July 10. As is apparent from the the number of strata, the Delta was fairly well covered, especially in 1979. Because the diversion data from Lyford, et al., were not broken down by area within the Delta, I simply averaged all egg and larvae data for each month to obtain an overall monthly average Delta bass concentration for each year, excluding those stations where agricultural diversions were not expected (i.e., Montezuma Slough, Napa River, Suisun Bay, etc.) or are not part of the study area. The calculated monthly averages, per size class (numbers/m^3) are tabulated in Table 1.

San Pablo Bay
Napa River
Suisun Bay Shoals
Upper Bays/Suisun Slough
Montezuma Slough
Lower San Joaquin Channel
Low San Joaquin River Shoals
Northern Delta
Southern Delta
Lower Sacramento River Channel
Lower Sacramento Shoals
Ship Channel/Steamboat Slough
Upper Sacramento River

Table 1. Estimated monthly average numbers of striped bass eggs and larvae in the Sacramento-San Joaquin Delta 1978 and 1979. Table developed from data reported by PGandE, 1981.

Month	Eggs	Yolk Sac ($\leq$ 6 mm)	Larvae (7-17 mm)	Juveniles (> 16 mm)
		1978		
April	0.12	0.02	0.003	--
May	0.08	1.02	0.65	--
June	0.04	0.10	0.67	0.03
July	--	0.03	0.03	0.025
		1979		
April	0.01	0.06	0.02	--
May	0.03	1.87	0.34	0.01
June	0.012	0.25	0.18	0.01
July	0.004	0.02	0.01	0.02

A couple of comments about the data seem in order. First, the data are not corrected for any possible bias resulting from the sampling procedures used. If appears that the nets were not effectively sampling striped bass eggs, and perhaps not young bass longer than 16 mm. Egg concentrations, in particular, never approached levels reported by Allen (1975) and Shaffter (MS). Second, the two years were considerably different water years and DFG (letter from Don Stevens to the State Water Resources Control Board dated January 27, 1982) estimated that the numbers of 7-10 mm bass were also different. In 1978, there were an estimated 6.59×10^9 bass, which dropped to about 1.25×10^9 in 1980. Finally, the data used also were collected during the post-1976-1977 period when the numbers of bass were typically much lower than in earlier years.

Lyford, et al., provided information on net channel depletions. I used the average of the USBR and DWR estimates for the 1968-1977 period. The numbers are for the entire Delta and have not been broken down by area. Also, net channel depletion is a function of volume diverted from the channels and drainage water returned to the channels., and during the summer net channel depletion is a smaller number than total water diverted. George Sato (DWR personal communication) estimated that net channel depletion should be multiplied by about 1.25 to obtain total volume pumped during the non-rainfall months. For purposes of these calculations, I used the following net channel depletions and did not correct to water actually diverted.

Month	Depletion, acre-feet
April	110,000
May	150,000
June	239,000
July	290,000

Combining the bass availability data with the average net channel depletions, and assuming the bass are diverted at the same concentration found in the channels (Allen, 1975), the following estimates of bass lost during 1978 and 1979 are obtained (Tables 2 and 3).

Table 2. Number of striped bass life stages estimated to have been diverted by Delta agricultural diversions, 1978.

	Numbers of each life stage lost - millions			
Month	Eggs	Yolk Sac Larvae	Larvae	Juveniles
April	16	3	--	--
May	15	187	119	--
June	12	29	196	9
July		11	11	10
Total	43	230	326	19
			GRAND TOTAL	618

Table 3. Number of striped bass life stages estimated to have been lost through Delta agricultural diversions, 1979.

	Numbers of each life stage lost - millions			
Month	Eggs	Yolk Sac Larvae	Larvae	Juveniles
April	1	8	3	--
May	6	340	62	2
June	3	73	53	3
July	--	7	4	7
Total	10	428	122	12
			GRAND TOTAL	572

These data suggest that the agricultural diversions are cropping large numbers of bass life stages. To put these numbers in perspective, the following estimates of losses of 7-10 mm bass for 1978 are available (Table 4).

Table 4. Numbers of striped bass (7-10 mm) estimated to have been lost to various diversions in the Sacramento-San Joaquin Delta, 1978.

Item	Number	Reference
Total 7-10 mm bass in system	6.59×10^9	DFG, 1982 (1)
Loss to PGandE Plants (range)	$.5-.6 \times 10^9$	DFG, 1982 (2)
Loss to Federal and State Pumps (range)	$.22 \times 10^9$	Sitts, 1982 (3)
Loss to Delta Agricultural Diversions	$.4-.5 \times 10^9$	This report

(1) Letter from DFG to the State Water Resources Control Board, January 29, 1982.
(2) Memo report to State Water Resources Control Board, January 1982, commenting on PGandE's estimates of power plant cropping at their Pittsburg and Contra Costa power plants.
(3) Rick Sitts, personal communication.

From the screening standpoint, the bass being entrained in the agricultural diversions are mostly in the size ranges that cannot be effectively screened with existing technology. Using the criteria developed at Hood (3/32-inch perforated plate) fish less than about 25-30 mm are not screened. To screen the larvae being shown as lost through the agricultural diversions would require mesh openings in the size range of 0.5-1.0 mm.

Chinook Salmon

Estimating losses of young chinook salmon is even more difficult than making similar estimates for striped bass. Except for Hallock and Van Woert (1959) there has not been much work conducted to determine losses of salmon through agricultural diversions. This early DFG study was conducted in 1953-1955 and the results are not particularly relevant to the estimating losses of salmon, mainly because the authors did not quantify losses in terms of fish per volume of water diverted and because the timing of the ocean migration has apparently changed since then.

The discussion which follows is based on data collected during fish salvage operations of the State and Federal pumping plants in the south Delta, a study conducted by the U. S. Fish and Wildlife Service (USFWS) and DFG, and some data on fish occurrence and distribution reported by Shaffter, 1980.

During the May-June period of 1976, DFS and USFWS conducted a limited study of the losses of chinook salmon through six agricultural diversions on Grand and Sherman Islands. The results of this study were never published; however, there are some unpublished notes with brief descriptions of the methods and results. The following material was extracted from those notes.

The six water intakes included five individual siphons (20, 30, 18, 14, and 20 inches in diameter) and one combined intake consisting of two 18-inch siphons and one pump with an intake pipe 14 inches in diameter. The notes listed average flow rates for each intake, although no indication was given as to how these flow rates were determine or over what period the flows were averaged. The flow rates were 10, 19, 4, 6, and 14 cfs for the intakes listed above.

Fyke nets with live boxes were used to sample the discharges. Analysis of the data is complicated somewhat by the fact that the investigators used three different nets to capture the fish. The first net had stretched mesh sizes varying from 1/2 inch to 1-1/2 inches. Next, a net with a uniform 1/2-inch stretched mesh was experimented with. Finally, a net with 1/4-inch stretched mesh was experimented with.

Each net had a different efficiency at capturing salmonids. To estimate net efficiency, marked chinook fingerlings were released into the discharge in front of the net. Efficiencies tabulated below are from individual tests at each siphon and were obtained with releases of approximately 50 chinook salmon during each test.

Net Efficiency (% Captured) of Three Net Types

	Net	
Variable Mesh	1/4 Inch	1/8 Inch
22	25	100
60	85	
27	17	
66	29	
85	50	
8	58	
38	52	
$\bar{x}$ = 43.7	45.1	100
s = 27.5	23.4	

As the above data indicate, the capture efficiency was extremely variable. For the two most commonly used nets capture efficiency appraently averaged about 50 percent.

A 1/8-inch mesh beach seine was used to determine if the fish caught in the fyke nets were the same size as those in the river. At one location on Sherman Island, a total of 58 fish was caught with the seine and the fish averaged 80.2 mm (standard deviation of 6.6 mm). The 56 fish caught in the fyke nets during the same period averaged 81.5 mm, with a standard deviation of 7.6 mm. These data indicate that the two gear types caught fish of essentially the same size.

The catch data are summarized in Table 5, along with estimates of losses of salmon per acre-foot of water diverted at these intakes during the months of May and June 1976. These data can be extrapolated to the entire Delta by assuming that the fish/acre-foot data also hold for April and July and using the estimated diversion rates for the Delta. The results of these calculations are:

Month	Ac-Ft Diverted	Fish/Ac-Ft	Fish Diverted
April	110,000	0.09	9,900
May	150,000	0.09	13,500
June	239,000	0.09	21,510
July	290,000	0.09	26,100
		TRAND TOTAL	71,010

The estimate of 71,000 fish lost is so low in relation to the millions of young salmon passing through and around the Delta that there are immediate questions about its validity. Other data were examined to determine if the number could be supported or refuted.

Table 5. Estimated numbers of chinook salmon trapped in six agricultural diversions -- San Francisco-San Joaquin Delta, 1976.

	Diversion No.					
	1	2	3	4	5	6
No. of fish caught (1)	152	28	30	66	0	0
Average flows, cfs	10	19	4	6	14	10
Numbers of hours fished	1,196	621	713	1,012	575	430
Total ac-ft sampled (2)	984	971	235	500	662	354
Fish/ac-ft	0.15	0.03	0.13	0.13	0	0.02
					$\bar{x}$ =	0.09 (3)

(1) Numbers corrected for net efficiency. Efficiency of 50 percent was assumed.
(2) Based on average flow and number of hours fished.
(3) Does not include 0 catch.

The most complete set of entrainment data for the Delta area comes from the State and Federal water projects which divert from the south Delta near the towns of Byron and Tracy, respectively. Figure 10 contains plots of the average number of chinook salmon salvaged at the two fish protection facilities for each month during the 1968-1980 period. These salvage values, which because of screen efficiency probably only represent 70-80 percent of the salmon entrained, are somewhat higher than reported for the diversions sampled by DFG and USFWS in 1976, but still the same order of magnitude. It should be noted that both sets of data suffer from a similar deficiency in that the estimates were made in areas where one would not, a priori, expect high concentrations of salmon smolts. In both cases, the use of these estimates should result in entrainment losses that are biased low. Using average federal salvage (somwhat higher than similar values for the State facility) for April through July for the 1968-1980 period and the volume of water estimated diverted by Delta agriculture, the following estimates for the entire Delta are derived:

Month	Ac-Ft Diverted	Fish/Ac-Ft	Fish Diverted
April	110,000	0.28	30,800
May	150,000	0.37	55,000
June	239,000	0.11	26,290
July	290,000	0.003	870
		GRAND TOTAL	112,960

Although the use of the salvage values increases the estimated losses over those from the 1976 data above, still the total numbers of fish estimated lost are very small. The last piece of data that seemed applicable was from the fish occurrence and distribution study conducted near Hood in 1973-1974 by DFG (as reported by Shaffter, 1980). In 1973 and 1974, approximate catches of chinook salmon per acre-foot of water sampled by midwater trawl were:

Month	1973 Fish/Ac-Ft	1974 Fish/Ac-Ft
April	4	1
May	4	5
June	1	1
July	1	5

If fish were diverted according to flow in the Sacramento Fiver the fish/ac-ft figures would suggest high diversion losses in this part of the system. We have no information on how a 70-80 mm salmon reacts to a siphon intake, but certainly not all fish coming down the Sacramento River and approaching an intake are entrained. A 12-inch diameter siphon delivering 15 cfs of water – flow actually 7.5 cfs would have an in-pipe velocity of about 3 fps. The velocity field around the end of a pipe is unique for each specific configuration; however, at two pipe diameters from the end the velocities will be very slow. Strong swimmers like salmon smolts should be able to avoid being entrained. PGandE (1981) estimated that in 1978 only about 18,000 smolts were entrained in the cooling water intake to their Pittsburg power plant. The relatively small losses were

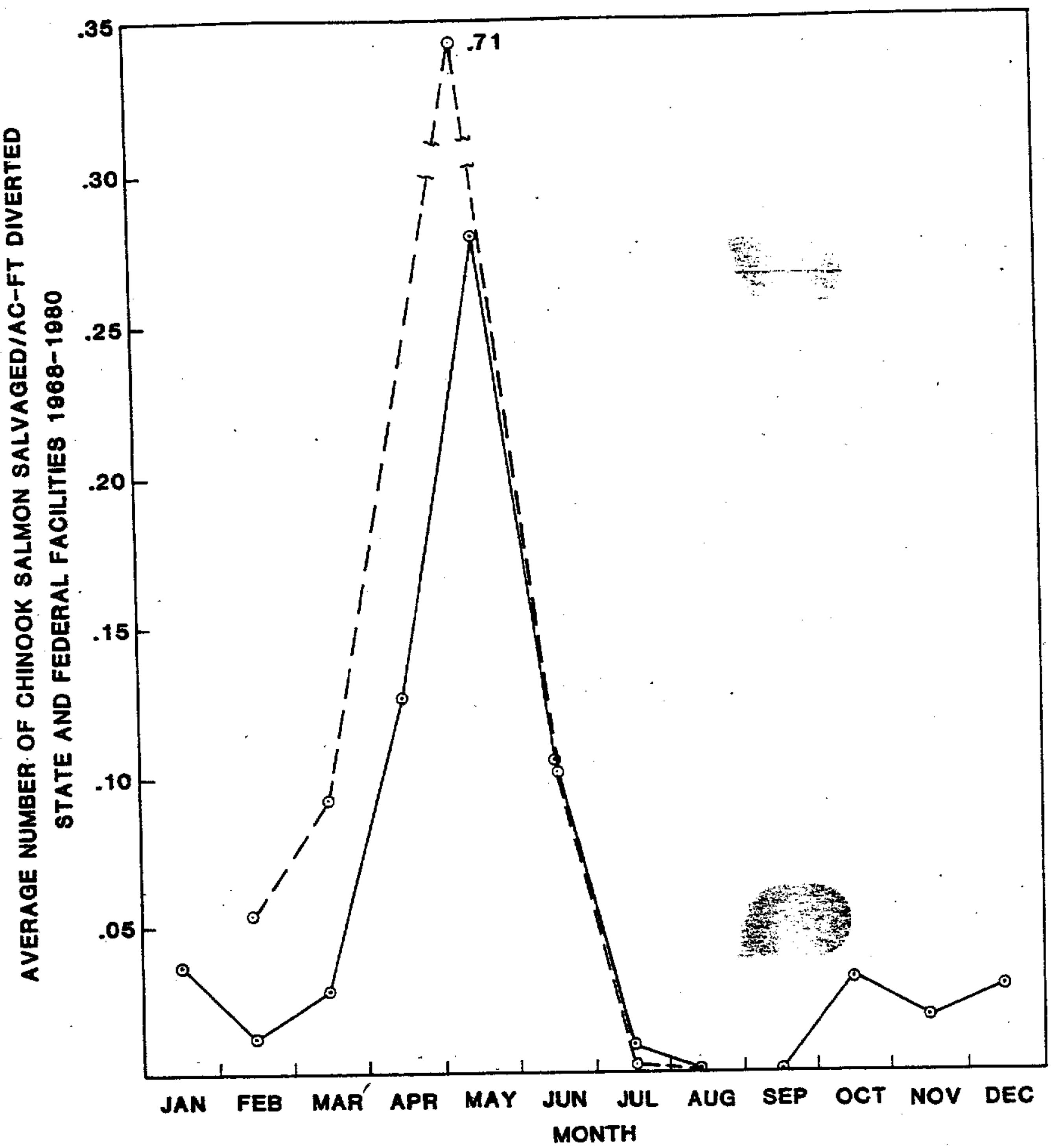


FIGURE 16 AVERAGE NUMBER OF CHINOOK SALMON DIVERTED, FISH/AC-FT, STATE AND FEDERAL FACILITIES, 1968-1980

attributed to ability of the downstream migrating juveniles to actively avoid the intake.

If the numbers of salmon entrained in Delta agricultural divresion is in the magnitude of a few hundreds of thousands, as indicated by the calculations, the benefits of screening these diversions to chinook salmon populations would be low. The same degree of protection for hatchery fish could be achieved by slightly increasing hatchery production or by trucking more salmon for release in the western Delta. Given the technical and economic problems associated with screening numerous small diverions, the above alternatives would be a cost-effective way of getting more hatchery smolts to the ocean.

Increased hatchery operations do little to enhance natural salmon production, although some straying of hatchery fish may result in mixing of the gene pool between hatchery and wild populations. Screening could help maintain wild populations by eliminating losses through diversions. DFG is already planning to, or has, screened major diversions on the Sacramento River. Instead of screening Delta diversions, protection of wild fish might better be achieved by making some of the present screens more effective (for example, Glenn-Colusa) and/or collecting the bypassed fish for trucking to the western Delta for release.

Other Species

As might be expected, there is practically no information on losses of species other than chinook salmon and striped bass in Delta agricultural diversions. The State Water Project diversion near Byron has entrained at least 43 species of fish with an average of about eight fish per acre-foot during the 1968-1980 period (California Department of Fish and Game, 1951). Of these 43 species, five species accounted for 96 percent of the total number of fish collected: striped bass, 62 percent; threadfin shad, 16 percent; white catfish, 7 percent; American shad, 7 percent; and Delta smelt, 4 percent. None of the species entrained was on the rare and endangered species list.

In their 1976 study of six intakes on Grand, Sherman, and Ryer Islands, the U. S. Fish and Wildlife Service and the California Department of Fish and Game collected several species of fish in addition to chinook salmon and striped bass (Table 6). In this study, five species made up 90 percent of the catch; white catfish, 52 percent; longfin smelt, 18 percent; Sacramento hitch, 8 percent; tule perch, 8 percent; and green sunfish, 4 percent. Note that the dominant species collected in these intakes are much different than for Byron, probably reflecting the different location in the system, the particular season these intakes were sampled, and perhaps the difference between a particular water year and a 13-year average. The overall average number of fish diverted in these six siphons and pumps was about 0.5 fish per acre-foot. This average, uncorrected for net efficiency, is much lower than the 8.4 average for Byron. Without more data it is impossible to determine if there is a valid difference or simply an artifact of sampling method and timing. Based on intuition alone, one would expect a large diversion to entrain more fish than a small diversion because, at times, all flow in channels leading to the diversion end up being diverted. The agricultural diversion study did collect two species, the river lamprey and Pacific staghorn sculpin, not collected at Byron.

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Table 6. Summary of fish collected at Ryer, Grand, and Sherman Islands, 1976. From the unpublished notes of a Department of Fish and Game-U. S. Fish and Wildlife study.

SPECIES		NUMBERS/SITE					
		Ryer Island				Grand Is.	Sherman Is.
Common Name	Scientific Name	1	2	3	4		
Pacific lamprey	*Entosphenus tridentatus*	2	--	10	4	3	4
river lamprey	*Lampetra ayressii*	3	2	--	1	1	--
American shad	*Alosa sapidissima*	--	--	1	4	--	2
threadfin shad	*Dorsoma petenense*	--	--	3	--	--	7
longfin smelt	*Spirinchus thaleichthys*	8	68	17	4	--	183
chinook salmon	*Oncorhynchus tshawytscha*	164	14	32	16	--	4
steelhead trout	*Salmo gairdnerii gairdnerii*	1	--	1	--	--	--
carp	*Cyprinius carpio*	21	--	6	--	--	--
goldfish	*Carassius auratus*	5	3	11	--	--	--
Sacramento blackfish	*Orthodon microlepidotus*	--	6 1/	--	--	--	--
Sacramento hitch	*Lavinia exilicauda*	8	16 2/	4	--	93	--
Sacramento squawfish	*Ptychocheilus grandis*	17	23	5	--	1	--
White catfish	*Ictalurus catus*	143	225	271	66	24	96
channel catfish	*Ictalurus punctatus*	--	--	1	--	--	--
yellow bullhead	*Ictalurus natalis*	--	--	--	2	--	--
mosquito fish	*Gambusia affinis*	--	--	2	--	--	--
starry flounder	*Platichthys stellata*	--	--	--	--	--	1
striped bass	*Morone saxatilis*	1	1	2	--	--	--

Table 6. (continued)

SPECIES		NUMBERS/SITE					
		Ryer Island				Grand Is.	Sherman Is.
Common Name	Scientific Name	1	2	3	4		
largemouth bass	Micropterus salmoides	1	--	--	--	--	--
smallmouth bass	Micropterus dolomieui	--	1[3]	--	--	--	--
green sunfish	Lepomis cyanellus	23	20[4]	16	--	3	2
bluegill	Lepomis macrochirus	--	1[5]	--	--	--	--
black crappie	Pomoxis nigromaculatus	2	--	--	1	--	--
log perch	Percinia caprodes	2	4[6]	3	--	--	--
tule perch	Hysterocarpus traskii	43	13	40	21	4	--
Pacific staghorn sculpin	Leptocottus armatus	--	3	1	3	1	6

1/ 2 taken with electro-shocker.
2/ 9 taken with electro-shocker.
3/ 1 taken with electro-shocker.
4/ 7 taken with electro-shocker.
5/ 1 taken with electro-shocker.
6/ 2 taken with electro-shocker.

Allen (1975) also sampled agricultural diversions in the spring and early summer. Perhaps because the study was designed to capture eggs and larvae, Allen captured only three kinds of fish other than striped bass. There may have been several species involved since the fish were listed only as smelt, shad, and catfish. A total of 19 fish other than striped bass was collected during this study.

COST OF SCREENING

As with most sections of this report there is very little to go on when trying to determine the potential cost of screening the agricultural diversions. Screening costs have three major components. First, there is a cost associated with modifying the diversion so that it can accept a screen. In general, pump diversions would be easier to modify for screening than would siphons. Many siphons are simply pipes through the levee and angled into the water. The heavy weight of the screen would require that the pipe be supported. In many instances the pipe itself might need replacing with a heavier material. The costs associated with this portion of the screening would be site specific and cannot be estimated.

The second screening cost is that of the screen assembly itself and any associated cleaning mechanism. We have no information on the two screen designs by Ernie Murphey; however, Johnson Division, UOP Corporation, does have some fairly specific information regarding its screens. For estimating purposes, the following numbers were provided by the company on December 4, 1981 (dollars/cfs):

CFS Diverted	Standard Single Screen	Standard Tee Screen
1-5	1,240	2,050
6-12	1,050	1,170
13-33	860	1,140

The screens for which the above numbers apply are wedge-wire with 3/32-inch slots, an average through slot velocity of 0.5 ft/sec and constructed of 304 stainless steel. Using these criteria, a square foot of screen will pass 0.28 cfs of water. The quoted costs do not include any cleaning equipment such as air compressors, air accumulators, or air delivery systems. The screen costs would double if copper-nickel alloys were used in screen construction to minimize fouling by plant and animal growth. If the average Delta farmer diverts a maximum of 10 cfs at each site, the screen itself would cost about $10,000-$15,000. With approximately 2,000 locations to screen in the Delta, costs for the screens might be in the order of 20 to 30 million dollars. There might be another $5,000 per site for adapting the intakes to accept the screens which would add 10 million dollars to the screening systems.

The final cost aspect of screening is those costs associated with operation and maintenance of screens (i.e. periodic cleaning, replacement of screen components, seasonal installation and removal charges, etc.). About the only idea we have regarding these costs comes from Dan Odenweller (personal communication), DFG, who reported that one of their screen shops spend $250,000 per year to maintain 12 screens. Certainly $20,000 per year appears to be excessive when applied to Delta screens; however, we might be talking a few thousand per screen per year and spread over 2,000 screens the total per year quickly enters into the millions of dollars per year range. The initial costs of stainless steel wedge wire screens is high relative to other screen types and materials but might be cheaper in the long run because of lower operation and maintenance costs (clog more slowly and the screen material should last indefinitely).

The overall impression which might be obtained from the above discussion is that screening Delta agricultural diversions would be a costly process. If such a program were undertaken, it is highly unlikely that all, or even most, diversions would be screened. The total program costs could thus be reduced significantly. Without more data on the impact of specific diversions on specific fish populations, it is not possible to assign a realistic cost estimate to a Delta screening program.

SUMMARY

1. There are about 1,900 agricultural diversions in the Sacramento-San Joaquin Delta which, during the irrigation season, collectively divert from 2,000 to 5,000 cubic feet per second (cfs) of water from Delta channels.

2. The peak diversion season, April through August, in the Delta coincides with the months when large numbers of young chinook salmon, striped bass, American shad and other fish are present in the system. ?

3. There are very few data available on the losses of resident and migratory fishes as a result of agricultural diversions. Some very rough estimates indicate that the losses of young bass (generally less than 16 millimetres (mm) in length) is in the order of several hundred million and the loss of chinook salmon may be in the range of a few hundred thousand. Data on other species are essentially absent.

4. The technical feasibility of screening diversions to meet salmon criteria in the Delta (0.5 fps maximum approach velocity and 5/32-inch openings for perforated pipe) has not been demonstrated. Screening to salmon criteria would not prevent the entrainment of most striped bass now lost to agricultural diversions, but should protect juvenile American shad, especially during daylight hours.

5. The potential costs associated with screening Delta diversions are largely unknown; however, it will probably cost several thousand dollars per intake (average maximum flow of about 10 cfs) to purchase and install a screen. In addition, there will be operation and maintenance costs in seasonally installing and removing the screens, keeping them clean, and maintaining the structural integrity of the intake and screen.

6. Practially all agricultural diversions in the Delta have flows less than 250 cfs. If the California Department of Fish and Game (DFG) determines that the diversions are having an adverse impact on fishery resources, and that screening would minimize or eliminate that impact, DFG is required to pay for all screening costs.

RECOMMENDATIONS AND RATIONALE

1. Delta agricultural diversions should not be screened at this time. Points leading to this recommendation are:

   a. Available data indicate that losses of striped bass due to entrainment in Delta agricultural diversions are in life stages that cannot be easily screened. Losses of juvenile (> 16 mm) bass are largely unknown and may be low because of their ability to avoid being entrained in small intakes.

   b. Available data indicate that losses of juvenile chinook salmon due to entrainment in Delta agricultural diversions are relatively low. There are methods other than screening to mitigate losses of both wild and hatchery salmon.

   c. DFS has established a priority list for screening major diversions (> 250 cfs) on the Sacramento River and would be financially hard pressed to undertake any additional screening projects.

   d. The technical feasibility of effectively screening large numbers of small intakes in an aquatic environment such as found in the Sacramento-San Joaquin Delta has yet to be demonstrated.

2. The most effective way to minimize losses of young bass to agricultural diversions would be voluntary curtailment for short periods in May and June.

3. In recognition of the distinct possibility that measures may be required to restore fish populations, certain concepts should be agreed on and programs established regarding screening Delta agricultural diversions.

   a. The Department of Water Resources (DWR) and the water contractors should accept screening agricultural diversions as a potential mitigation measure for project impacts, in concept no different than hatcheries and operational measures. Under this concept, screening costs would be paid entirely by DWR. Screening could be an important step in maintaining wild populations of resident and migratory fishes.

   b. More work is needed on the technical aspects of screening small diversions in the Delta. One place to start might be to construct models of the two Murphey Screens and test them at Hood for mechanical operation. If the devices operate as designed, then they could be field-tested at a suitable location (near the cross channel at the new pump facility?). If preventing the entrainment of striped bass is deemed necessary, consideration should be given to use of small mesh (0.5-1.0 mm) and only screen for the relatively short period when the largest numbers of bass are vulnerable to entrainment.

LIST OF REFERENCES

Allen, D.H. 1975. Loss of striped bass (Morune saxatilis) eggs and young through small agricultural diversions in the Sacramento-San Joaquin Delta. Cal. Dept. Fish and Game, Admin. Rpt. 75-3.

California Department of Fish and Game. 1966. Ecological Studies of the Sacramento-San Joaquin Delta, Part 2. J. L. Turner and D. W. Kelley, comp.

California Department of Fish and Game. 1981. The John E. Skinner Delta Fish Protective Facility, 1968-1980. A summary of the first thirteen years of operation. Admin. Rpt. No. 81-6.

California Department of Water Resources. 1974. Draft Environmental Impact Report, Peripheral Canal Project.

Hallock, R. J. and W. F. Van Woert. 1959. A survey of anadromous fish losses in irrigation diversions from the Sacramento and San Joaquin Rivers. Cal. Fish and Game 45:4 (225-296).

Kjelson, M. A., P. F. Raquel, and F. W. Fisher. 1982. Life history of fall-run juvenile chinook salmon. Oncorhynchus tshawutscha, in the Sacramento-San Joaquin estuary, California. pp 393-412 in Estuarine Comparisons, V. S. Kennedy, editor. Academic Press, New York.

Lyford, G., G. Sato, and P. Schreiner. 1981. Joint DWR and WPRS Delta Channel Depletion Analysis.

Pacific Gas and Electric Company. 1981. Pittsburg Power Plant Cooling Water Intake Structures - 316(b) Demonstration. EA Report PGE60H1.

Schaffter, R. G. 1981. Fish occurrence, size and distribution in the Sacramento River near Hood, California during 1973 and 1974. Cal. Dept. Fish and Game, Admin. Rept. No. 80-3.

Smith, L. W. 1981. Clogging, Cleaning and Corrosion Study of Possible Fish Screens for the Proposed Peripheral Canal. Tech. Rpt. 1. Interagency Ecological Study Program for the Sacramento-San Joaquin Delta.