PRELIMINARY REPORT

FEASIBILITY OF ESTABLISHING UPSTREAM FISH PASSAGE

GAVINS POINT DAM MISSOURI RIVER

Prepared by

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SYNOPSIS

The Corps of Engineers is examining the possibility of restoring fish passage at some of its six dams on the Missouri River. The Omaha District has reviewed available information on potential fish passage designs, and how various fish species would respond to such facilities. Primary consideration was given to pallid and shovelnose sturgeon, along with paddlefish. This evaluation concentrated on applying the fish passage concepts to Gavins Point Dam, the most downstream of the six dams. Information for developing a preliminary assessment of establishing fish passage facilities was taken from literature assembled by the District, as well as discussions with researchers of fish behavior. Preliminary designs for the various fish passage concepts were based on the layout and operation of Gavins Point Dam, resulting in a comparison of the different concepts. This analysis concluded that the most effective ladder-type facility probably is the vertical slot fishway. The fish elevator concept also would be effective. Use of these two types of fish passageway at Gavins Point Dam should be evaluated in detail in any analysis following this preliminary study. A fish ladder such as the vertical slot design would have a cost in the range of six million dollars. The elevator would have a capital cost considerably less than that for the vertical slot, but may require relatively high operation costs. In addition to effectiveness and cost, the potential impact of fish passage facilities on the dam and its operation will need to be addressed.

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INTRODUCTION

The construction of the six dams on the Missouri River from Fort Peck, Montana to Gavins Point, South Dakota, cut off nearly two-thirds of the river's main stem from the lower, free-flowing reach. Even greater stretches of habitat and spawning area were lost on the tributaries upstream of the dams. Since the establishment of the six mainstem dams, the river's value to fish and wildlife has received greater recognition. This is especially true for endangered and threatened species.

Authority to operate the dams for fish and wildlife, along with obligations under the Endangered Species Act, provide the foundation for determining the feasibility of restoring fish passage at some of the dams. Gavins Point Dam was selected as the initial dam for such analysis, since the short transit time (two days) should not significantly interfere with the response of fish to the riverine regime. In other words, the fish should be able to continue upstream through the pool, especially to the Niobrara River. A map of Lewis and Clark Lake is shown in Figure 1.

The fish passage facilities should be designed to enable usage by pallid and shovelnose sturgeon, as well as mid-sized paddlefish. Other native species also should be able to use the passageway, including channel catfish, flathead catfish, sauger and walleye. Some candidate species for federal listing also are to be considered (i.e., sturgeon chub, sicklefin chub and blue sucker).

REPORT OBJECTIVES

This report evaluates the potential for various fish passage concepts for Gavins Point Dam. Its main goal is to draw information from existing literature on fishway designs, migratory behavior of Missouri River fish species, and performance of existing fishway installations. Compilation and review of that information yielded preliminary conclusions on the expected results of fishway facilities at Gavins Point. Further in-depth analysis thus can be based on the preliminary findings presented herein.

GENERAL CONCEPTS

Design of fish passage facilities must consider the swimming characteristics of the targeted fish species, especially the potential swimming speeds. For river obstructions greater than a few feet high, fish achieve upstream passage by using their sprint or burst speed to jump the obstruction or to swim through gaps. In between bursts, the fish can fall back to their prolonged or steady swim speed. A design for a fish passage facility thus needs to keep the water velocity in the system below the typical burst speed capability of the targeted species. This design velocity is significant at the transition points in a passage system, where the high water velocity accompanies an incremental drop in water surface elevation. For example, this velocity would be a design criterion at an orifice between pools in the passageway.

Large obstructions such as dams typically require several steps or pools to achieve the necessary climb. Fish will use their burst speed to move between the pools, then will resume their steady swim speed through the pool before making the next jump. Fish can swim at burst speed for only about fifteen seconds at a time. Biologists have defined a threshold for the steady swim speed, with the term *critical swimming speed* or *critical velocity* as the highest water velocity at which fish can maintain their position in the current for a ten minute interval. The average water velocity through the system thus should not exceed this critical velocity. The different swimming modes are summarized in the following table.

SWIMMING MODE	DURATION
Sprint/burst	15-20 seconds
Prolonged/steady	200-300 minutes
Cruising/sustained	indefinite

The burst speed typically is 3 to 4 times the cruising speed.

Passage over river obstructions is performed differently by different species. Salmon, for example, are noted for jumping over small obstructions. This characteristic is utilized in the design of fish ladders on rivers in the Pacific northwest. Other species tend to work their way through gaps in obstructions. Warm water species in the Missouri River would be more inclined to use this latter method rather than leaping over the obstacles.

Fish are drawn upstream by active flow, and attempt to move beyond obstructions in areas where the water velocity is higher than the average velocity across the channel. A design for a passage facility needs to have adequate high-velocity flow at its entrance (downstream end), in order to attract fish to the facility.

The District has compiled references which address fish characteristics and design concepts. Some documents also describe actual facilities, noting how each design depends on the specific site, stream and fish species. A Table of References is attached to this report.

GAVINS POINT DAM

Gavins Point Dam was the fourth of the six mainstem dams to be completed, closing in July 1955. The power facilities went fully on line in January 1957. The power generation facility comprises three turbines, each with three intake gates. The power house is located along the south part of the dam. The spillway is north of the powerhouse, and comprises fourteen tainter gates. The powerhouse tailrace is about 300 feet wide, and is separated from the 664-foot wide spillway by a chalk island. That island is about 250 feet wide at the dam, and tapers down to the tailrace-spillway convergence about 680 feet from the dam. The layout of dam is shown on the attached aerial photo, Figure 2.

The dam historically has moved almost all of its stored water through the powerhouse, which has a rated capacity of 36,000 cfs. The functional maximum flow is about 35,000 cfs. Pertinent records of dam operations began when the six dams were brought under a unified operation, in June 1967. Monthly flow distribution for 29 years of record, through 1995, is summarized in Figure 3. It shows that there was only one year that less than sixty percent of the total flow went through the powerhouse. This occurred from August through November 1975, when a total outflow from the dam averaged up to 61,000 cfs. For the months of April through June, the spillway has been used only about ten percent of the time. Fish migration would be concentrated in these three months, as discussed later.

The reservoir has a maximum operating pool of 1210 feet m.s.l., with a normal operating pool of 1208 feet. Statistical analysis of the pool for the period of 1967-1995 shows that the 50% exceedence for the pool during April through June is 1205.4 feet. This statistical analysis is discussed in the appendix. The tailwater elevation exceeds 1159 feet fifty percent of the time. The range of pool and tailwater elevations between 99.9% and 0.1% is tabulated below.

The *Pool Duration* curve in the appendix shows that during 80 percent of the time, the pool during April through June occupies a narrow range of about 1204.8 and 1206.5. Thus, any fishway facility should be designed around this typical pool elevation. The curve for the average annual pool elevation is nearly two feet higher than for the April-June pool. The lower pool in April through June is the result of the managing the reservoir for flood protection. The reservoir is lowered for those months to provide adequate storage capacity for spring flood waters.

<u>Water Surface Elevation (ft.), Relative to Exceedence Rate</u>
Gavins Point Dam, April-June, 1967-1995

Exceedence	Pool	Tailwater
99.9%	1203.3	1153.2
50.0%	1205.4	1159.05
0.1%	1208.8	1162.1

The lowest pool to be considered in the fishway design would be the minimum operating pool of 1204.5 feet, which is exceeded more than 98% of the time during the April through June period. A fish passage facility should be designed based on the difference between the higher pool, 1208.8', and the lower tailwater, 1153.2', for a total rise of <u>55.6 feet</u>. The average difference in head would be 1205.4-1159.05 = 46.4 feet.

DESIGN CRITERIA RELATIVE TO AFFECTED FISH SPECIES

The proposed fish passage facilities would be geared toward the species identified in this report's introduction. The typical speeds for burst and sustained swimming are key factors in the facilities' design. Tunink's 1977 report indicated that the critical swim speed generally is 20 to 30 percent of a fish's maximum (burst) speed. This correlation of critical speed to burst speed is not specific to the fish species for which the Gavins Point fish passageway would be designed. Research presently is being conducted for shortnose sturgeon, and this research possibly could be extended to river sturgeon prior to the final design work on a Gavins Point facility.

This report constitutes an initial evaluation of fish passage feasibility. The next phase of the study would develop and assemble the specific information needed to arrive at practicable designs. The additional information would include detailed fisheries data, including a review of additional literature on fish swim capabilities. Consultation with noted researchers of fish behavior also should take place at that time.

Tunink's data for critical speed do not specifically include pallid sturgeon, but show 2.5 fps and 1.9 fps for shovelnose sturgeon and paddlefish, respectively. These two species are primary targets for the project, along with the pallid sturgeon. Reports of catches/releases for pallid sturgeon show a probable size range of 15-45 pounds. The occasional shovelnose catch typically is under three pounds. Paddlefish, however, are in great abundance below the dam. Over a three-day period in 1995, 2500 paddlefish were caught. They are being drawn by the high discharges. The sturgeon and paddlefish are highly mobile species, with a strong seasonal migration urge. Migrations of 50 to 100 miles are typical, if there are no major obstructions.

Critical swim speed data for three other species of interest were included in Tunink's report. Channel catfish and sauger had respective speeds of 2.0 and 1.9 fps. Walleye had a critical speed of 2.5 fps. The analysis of various fish passage designs presented below are based on the lowest average critical speed of the five species discussed above. The maximum water velocity for the passageways would be between 6.3 fps (1.9 fps/30%) and 9.5 fps (1.9/20%). The lower value was used, with a 1.1 factor of safety. Thus, the maximum water velocity was set to 6.3/1.1= 5.7 fps. The average water velocity in the unchannelized reach from the dam down to Ponca is approximately 3.6 fps.

Determinations of critical speed by Tunink on Missouri River species are listed in the table below. The critical speeds cited above for various species represent all the tested specimens, regardless of age group. In fact, the adults that would be migrating upstream would have higher critical swim speeds. This is reflected in the table.

The maximum velocity determined for the Gavins Point fishway designs ensures facility usability based on average swim data. The average critical speeds for the adult test specimens are in bold type in the table. The minimum critical speed observed for two species (shovelnose, sauger) falls below the selected design velocity. Thus, the facilities would be capable of passing the majority of targeted species, but some sturgeon and sauger probably would not be capable of successfully climbing them. Figure 4 shows the selected design velocity relative to minimum, average and maximum critical swim speeds. Rationale for designing the facility to flow at a rate approaching the critical velocity is to ensure maximum attraction in the fishway.

The table below shows that the populations of fish tested by Tunink are quite small. Although this would contribute to the uncertainty of a fishway design, Tunink's data probably are the best available for Missouri River fish species. Fish passage design is tailored to the swimming capabilities of the targeted fish species. Measurement of fish swim capabilities, however, is not an exact science, for various reasons. Although most biologists agree that upstream migration is triggered by increased flow (such as those produced during spring snow melt) and increased water temperatures, other factors may be involved. These would include the increasing daylight in the spring, and changes in river chemistry, such as increased concentration of organic material and food. Also, the fish themselves may undergo biochemical changes that would initiate the migration urge. Although testing has been conducted in the laboratory and the field on many of these species, the swimming performance of the test specimens may be influenced by factors not being measured. For example, a test specimen may fail to achieve its full swimming potential if its is not ready and willing to spawn. Prior to finalizing a fish passage design, coordination will take place with fisheries biologists that are involved in ongoing fish swim capability research, in order to get the latest available information for the design.

CRITICAL SWIM SPEED TEST SPECIMENS
(For species targeted for upstream passage of Gavins Point Dam)

SPECIES	AGE GROUP	NUMBER TESTED	LENGTH, in. Min.	LENGTH, in. Avg.	LENGTH, in. Max.	CRIT. SPEED, fps Min.	CRIT. SPEED, fps Avg.	CRIT. SPEED, fps Max.
Shovelnose Sturgeon	adult	9	18.1	19.0	20.0	1.6	2.5	3.7
Paddlefish	young of year	4	14.6	15.1	15.4	1.8	1.8	1.8
	immature	1		25.4			2.1	
Channel Catfish	immature	24	5.6	7.6	9.9	1.8	2.0	2.6
	adult	4	12.2	13.8	16.3	2.0	2.3	2.9
Sauger	young of year	3	2.0	2.1	2.3	1.0	1.6	2.1
	immature	6	5.9	7.4	10.7	1.8	2.1	2.5
	adult	6	12.7	14.7	16.7	1.8	1.9	2.1
Walleye	immature	3	6.1	6.5	7.2	1.8	2.3	2.8
	adult	3	15.3	16.4	17.8	2.4	2.6	3.2

Determining the size of the fish passageway relative to the population of fish that would compete for its use does not appear to be a practical factor for this situation. Although the sturgeon are of primary importance for upstream movement, there aren't enough population data to apply to the design. On the other hand, a significant group of paddlefish would gain upstream passage if the facility's design is compatible with the paddlefish's swimming characteristics. Even a small facility would be a significant improvement over the present total obstruction to upstream passage. Thus, the different passage concepts evaluated herein use basic design criteria, with no special consideration for population or estimated use. One approach would be to install a prototype facility, with the outlook of adding another facility later. This would allow for a comprehensive analysis of the facility's usage according to species and fish size.

TYPES OF FISH PASSAGEWAYS

General: There are three basic systems for moving fish upstream past major obstacles. The most common in this country is a series of pools and weirs, where water flows over the weirs in a step-fashion, and fish leap over individual weirs on their way upstream. Variations on this theme incorporate orifices or vertical slots between the pools, to allow passage by fish that have lower tendencies to leap over obstacles. A second system uses a series of baffles on the bottom and sides of a sloping chute, to decrease the water velocity enough to allow the fish to progress up the chute. This concept was designed by G. Denil, and thus bears his name. The third method captures fish in a lock or a lift mechanism, and moves them to the upstream side of the obstruction.

Existing Facilities: The majority of functioning fishways are designed for cold water species, particularly those with demonstrated leaping behavior. Two noteworthy exceptions to those facilities are the Belmont irrigation diversion dam on the North Platte River in Nebraska, and Redlands Dam on the Gunnison River in Colorado. The Belmont fish passage was built in May 1993 based on a Denil design, to be used by channel catfish. That facility may be the first fishway in Nebraska. Its total climb covers only six vertical feet.

The Redlands fish passageway covers a 10-foot difference in water surface elevation, using a vertical slot design and incorporating an orifice in each weir. It flows at a rate of 11 to 17 cfs, compared to 10-15 cfs for the Belmont Denil. The Redlands fishway was completed in early 1996, and was designed for razorback sucker and Colorado squawfish. It provides for a total attraction flow of 83 to 89 cfs. This is achieved with the direct flow through the fishway, augmented by about 75 cfs through a 42-inch bypass pipe.

Successful fish passage has been observed in both of these facilities. The short period since their construction, however, is not sufficient to allow for any significant analysis of their effectiveness in terms of targeted fish populations. Indeed, the Bureau of Reclamation is considering design modifications even though their Redlands facility has yet to operate for a full spawning season.

Hydraulic Design Criteria: The literature reviewed herein did not include criteria for quantifying a required attraction flow. As an example, the Redlands fishway uses ten percent of the total flow as its dedicated attraction flow. Nevertheless, there doesn't appear to be any good documentation on the relationship between total discharge at a dam and the extent of attraction flow needed. If a ten percent diversion of flow was required for a fish passage facility at Gavins Point Dam, the loss of revenue from power generation almost certainly would be prohibitive. Thus, 3500 cfs (ten percent of powerhouse capacity) would not be practical for a Gavins Point fish passage design.

Since the powerhouse outflow is the primary attraction mechanism at the dam, a fishway design should include a means of leading the fish from the outflow area to the fishway entrance. Such a powerhouse collection system is discussed later in this report. The design for a collection system may be able to utilize enough of the powerhouse outflow to minimize the need for specifically dedicated attraction flow. Therefore, a relatively low flow will be used for design purposes, basically to ensure that direct discharge through the facility will maintain the desired range of velocities. This minimum design flow was set at 100 cfs, which is in the range of the dedicated flow on the Redlands facility.

The maximum allowable velocity was set to 5.7 fps, as determined above. The recommended maximum value for the average velocity in a fishway is 1 fps.

Designs

1. Pool and Weir: This concept consists of a sequence of rectangular pools from the top of the stream obstruction (reservoir pool) down to the lower stream reach (tailwater). Water flows over the top edge of one pool down to the next lower pool, at a rate that allows fish to progress up the facility by leaping over that pool wall, or baffle. Flow can be allowed over the entire baffle, or it can be concentrated in a notch (weir) at the top of the baffle. Figure 5 shows how the baffles and weirs are arranged in this type of fishway.

The basic pool and weir design would have minimal practicality at Gavins Point, due to the lack of significant leaping behavior in the fish species in this river reach. The "Fisheries Handbook of Engineering Requirements and Biological Criteria" points out that sturgeon have not passed successfully in pool-type fishways. The pool/weir design is sensitive to fluctuating water levels, and therefore requires adjustment relative to the pool elevation (Katopodis, "Introduction to Fishway Design"). Thus, the specifications outlined below are for comparison with the dimensions of the other designs.

Experiments at the Bonneville hydraulics laboratory used a four-foot width for pools eight feet long and six feet deep. The recommended practical minimum width, however, is six feet. The typical incremental drop between pools is one foot. Figure 8 shows the basic pool and weir concept. Such a facility has a theoretical capacity of about 800 fish per hour. A 6-foot width was chosen for the Gavins Point facility. The formula for weir flow was taken from Clay, $Q=3.33LH^{1.5}$, where L=weir length, and H is the head. This design would utilize the entire baffle as the weir, such that the weir length equals the pool width. The head for the velocity of approach, h, is $V^2/2g$, where V is velocity. The weir flow formula then becomes $Q=3.33L[(H+h)^{1.5}-h^{1.5}]$. Preliminary calculations showed that 100 cfs would produce an average velocity higher than the 1.0 fps limit. Therefore, a flow of 45 cfs was considered for the actual fishway flow, with the remaining 55 cfs to be delivered through a pipe as auxiliary flow. With the maximum velocity set at 5.7 fps, the approach velocity head, h, is equal to $5.7^2/64.4 = 0.5$ foot. The height of water above the weir, H, then is determined from

$$Q = 3.33(6)[(H+0.5)^{1.5}-.5^{1.5}]$$
$$H = [45/(6x3.33)+.0.5^{1.5}]^{2/3}-0.5$$
$$= 1.9 - 0.5 = 1.4'$$

The average velocity is $45/(6'x(6'+1.4')) = 1.0$ fps. The incremental drop between pools was set at two-thirds of the typical drop of 1 foot, to account for the limited leaping behavior of Missouri River fish. It would take 84 eight-foot long pools to climb 55.6 feet, using an incremental rise of eight inches. This would require 672 feet of pool and weir fishway.

2. Weir and Orifice: This design is a variation on the pool and weir concept described above. Its transition area between successive pools is located at or near the bottom of the baffle, rather than at a weir at the top. This facilitates the upstream movement of fish that prefer to move along the bottom, rather than leaping over obstacles. The drawings for the pool and weir concept (Figure 5) also show how orifices can be incorporated into the baffle. These orifices can

be round or rectangular, and should be large enough to allow passage by mature members of the target fish population. Orifice size also is determined by restrictions on discharge and velocity. The orifices can be aligned with each other, to keep the fish moving with the least interference. The orifices also can be offset, to reduce the flow rate through the facility.

The profile view of the weir and orifice in Figure 5 shows all the flow moving through the orifices. These facilities typically include some flow over the weir also, particularly to ensure proper operation as reservoir pools fluctuate. This yields an added advantage in providing passage opportunity over the weir as well as through the orifice. This type of fishway has been used extensively in the Pacific northwest, as well as many other locations on the continent. While the facilities in Washington and Oregon were designed for Pacific salmon and steelhead trout, a variety of other species have used them, including carp, squawfish, sturgeon, suckers and catfish.

An orifice diameter of 2 feet would be appropriate, to accommodate the large paddlefish in this reach. Minimum pool dimensions typically are a length 6 times the orifice diameter, and a width equal to four orifice diameters. Each pool thus would measure 8' by 12'. A drop between pools of 18 inches is recommended. The 2-foot diameter orifice has an area of 3.14 sq. ft., and would be located at the bottom of the 6-foot high baffle. The design water velocity through the orifice of 5.7 fps would occur at a flow of 5.7x3.14 = 18 cfs. The incremental drop in water surface between pools, $h = (Q/CA)^2/2g$, where

Q = discharge
C = coefficient of discharge (assume = 0.6)
A = orifice cross-sectional area
g = gravitational acceleration (32.2)

$$h = (18/(0.6\text{x}3.14))^2/(2\text{x}32.2)$$
$$= 1.4 \text{ foot}$$

The required climb of 55.6 vertical feet would take 40 pools, each providing the 1.4-foot incremental drop. This would result in a 480-foot fishway. The average velocity = 18cfs/(6'x8') = 0.38 fps.

Flow over the weir was set to fifty percent of the orifice flow. The height of flow over the baffle is $(Q/(0.6\text{x}L))^{.67}$, where L is the baffle width, and Q=9cfs. Thus, the flow depth over the weir would be $(9\text{x}(.6\text{x}8))^{.67} = 1.52'$. In order to maintain the selected attraction flow, a pipe could deliver auxiliary flow of 73 cfs to the river at the fishway entrance. While the orifice design compensates for limited leaping capability, there is a lack of documentation for Missouri River species swimming through orifices. The flow over the baffle will need to be kept low enough that it doesn't significantly disrupt the flow moving through the pool from the orifices. If the upper flow impinges excessively, it could impair the fishes' ability to follow the orifice route.

3. Vertical Slot: This design concept again is based on the pool and weir design, with direct passage capability through the baffles rather than over them. It could be considered a weir and orifice design, with the orifice reaching the full height of the baffle. The openings in the

baffles have velocities low enough to allow fish to move up through them. Flow depth is more a function of maintaining sufficient water in the pools rather than regulating velocities. Therefore, the design typically does not include flow over the baffles. This design can handle large variations in water levels with only minor increases in velocity. The vertical slot concept or variations also goes by the terms "pool & jet" and "Hell's Gate" fishways. This system typically has a slope of 10 percent. Typical pool dimensions are listed in the table below, and the layout of the design is shown in Figure 6.

	Typical Dimension
Depth	2' - 4'
Width	6' - 8'
Length	8' - 10'
Slot Width	18"

The larger width and depth are used for this analysis, in recognition of the large paddlefish that might use the fishway. In addition, the slot is made 18" wide, also to ensure passage by the larger specimens. A velocity just below the design maximum of 5.7 fps would occur at an incremental pool drop of 0.6 feet, assuming the fishway is operated to have virtually all of the flow through the slot (minimal flow over the baffle). This relationship is defined by the formula shown below [from "Fisheries Handbook," 1973, Ch. 34].

$$Q = 1.5(4.6D+3)$$

for 0.6' of head at baffle, slot width = 18",
D = depth, Q = discharge

$$Q = 1.5(4.6 \times 4+3) = 32 \text{ cfs}$$

The velocity through the slot is 32/(1.5'x4') = 5.4 fps. The average velocity in the pools is 32/(8'*4') = 1.0 fps. Based on the design flow requirement specified above, an auxiliary flow of 68 cfs may be needed to attract fish to the facility entrance. In order to have a slope near 10 percent based on the 0.6-foot incremental pool drop, the smaller recommended pool length (8 feet) was chosen. The 55.6-foot climb to the high lake pool would require 93 individual pools. The resulting fishway would be 744 feet long.

4. Denil: The Denil is basically a vertical slot design, with inclined rather than vertical baffles. The reduced velocity created by the baffles' turbulence provides fish with a low-resistance passage route. This design combines the effect of adjacent baffles, rather than including pools 6 to 10 feet long between baffles. The result is a facility that provides a climb of nearly three feet, through a facility about 25 feet long. A typical Denil fishway is shown in Figure 7. While the Denil gives fish a direct means of ascent, the fish should be afforded resting pools if the obstacle in the river is greater than about 12 feet. This is due to the fact that the fish must continue swimming throughout the full array of baffles in each denil section, rather than simply moving past each baffle with a momentary burst of speed.

The Denil-type of fishway has been shown to pass salmon and trout, as well as sucker, squawfish, walleye and sauger. In fact, McLeod and Nemenyi describe how the warm-water species researched on the Iowa River show a clear preference for the Denil over the weir-orifice and vertical slot designs. The Denil is able to pass large volumes of water in comparison to other designs of equivalent size, thus giving improved attraction flow. These facilities typically have overall slopes of 10 to 15 percent, and require resting pools between every 9 to 12 feet of vertical climb. A Denil at a relatively low obstacle would result in material economy, due to its having a steeper slope than the pool-weir type. The need for resting pools in higher facilities, however, would minimize this advantage. The Denil has a more complex design than the design based on the pool and weir. Consequently, it would be expected to require more maintenance. At the same time, the relatively high flows through the fishway tends to minimize sediment deposition. The large discharge also provides effective attraction to the fish.

The entrance velocity for this design would be approximately 6 to 6.5 fps, but the velocity through the chute would be only about 1.5 fps. As mentioned above, the Denil exhibits only limited success for higher obstruction, such as Gavins Point Dam. Another problem with the Denil is that the entrance velocity can increase beyond the sprinting capability of the intended species. The basic Denil design typically can handle up to 750 ascents per hour.

The Denil design considered for Gavins Point has a 23-foot run with a 2.94-foot rise, for a 12.8 percent slope on each chute section. They would be 3.9-feet wide and 5.7 feet deep. The 55.6-foot climb would take 19 denils, with 18 resting pools. The length of the resting pools would match the length from the pool and weir design (8 feet). Resting pool width and depth would be the same as for the Denil chutes. The total horizontal length of the Denil system thus would be:

$$19 \times 23' + 18 \times 8' = 581 \text{ feet}$$

The estimated discharge through this Denil system is 10 to 15 cfs, based on the project constructed in 1993 at the Belmont Diversion on the North Platte River. Adequate attraction flow thus may require an auxiliary flow of about 90 cfs.

5. Mechanical Lifting Facilities: The above discussion has described four concepts that provide fish with the means to move upstream past obstacles. The basic idea in those schemes is to divide the difference in water elevation at the obstacle into small head differences that fish can overcome. This relies on the fishes' urge to migrate upstream past the obstruction, and on limiting local water velocity to levels that the fish can overcome. Higher obstructions can overtax the capabilities of fish, either because of inherent physical limitations, or through a inadequate urge to complete the passage. Also, the providing an ascent route past a major obstruction often requires a more complex design, thus decreasing a project's economy. Mechanical means of moving fish past obstacles have been employed at many dams, mostly after 1945. These facilities rely on the fish to move into confined pools, using attraction flows. Once the fish are concentrated in those pools, the pooled water itself is raised above the obstruction. Swim capabilities and other fish behavior thus is not critical.

Lock facilities involve a fairly simple means of moving a pool of fish over the dam. The most notable lock design is called the Borland Lock, after its inventor. It was first built in Ireland in 1949. The lock typically is considered an option for dams higher than thirty feet. For lower obstructions, fish-ladder type passageways are more effective and economical. Fish are drawn into the lock by an attraction flow. After the chamber is closed and the water level rises to lake pool, the chamber is opened to the lake. A period of about 25 minutes is allowed for the fish to move into the lake. An advantage of locks is their relatively low capital costs. One inherent problem is difficulty in clearing the fish from the chamber into the lake pool. Mechanical fish lifts in the United States usually favor elevators over locks.

Fish elevators can be as simple as a series of buckets that lift the fish from a concentration area to the lake pool. However, most elevators move the fish into a tank that can be hauled above the dam. The typical fish elevator incorporates a series of pools, allowing for the concentration, horizontal pool transfer, and lift of the fish. The first pool attracts the fish by bringing in flow from the pool floor. An adjacent pool has a floor made of a framework of slats. The floor can be tilted up by using a cable (a brail mechanism), to force the fish toward a hopper that will be lifted from the tailwater. Flow from the adjacent brailing pool draws the fish out of the first pool. Water flows from the hopper in a third pool into the brailing pool, to maintain fish attraction. When enough fish have made their way into the brailing pool, the floor is tilted up, forcing the fish into the hopper. The hopper exit is then closed, and the hopper is lifted by cable from the river to a tank truck. The basic concept of the elevator system is shown in Figure 8.

The tank on the truck is filled with water prior to receiving the hopper contents. The hopper is placed into position on the tank's inlet, and the hopper's exit is opened. Water then is bled from the truck tank until the hopper's contents have been transferred into the tank. The truck then promptly hauls the fish to a practical discharge area in the lake.

The elevator's obvious advantage is that it relies on only one behavioral characteristic of the targeted species. Namely, it is effective as long as the fish can be attracted into a concentration pool below the dam. There is no need to consider swimming ability and other behavior. In addition, flows can be controlled, without significant problems from fluctuating pool levels. In the process of moving the fish, there is a potential for the equipment to injure the fish. Other disadvantages are found in the added reliance of mechanical equipment and human resources. These latter features add operating costs not included in the ladder-type designs.

APPURTENANT FEATURES

The above discussions have touched on some of the key features of fish passageways, such as high velocity flow to attract the fish. The entrance, or lower end of the fishway, needs to be located where the flows attract the fish, without excessive velocities that would force the fish away. The water surface elevation at the entrance generally must be within a narrow range in order for the fishway to retain optimum effectiveness. Once the fish have progressed to the lake pool, measures should be in place at the exit to keep them moving away from the fishway so that they aren't swept back to the tailwater. The trash racks at the powerhouse inlets probably are adequate for minimizing this regression, but special screening measures would be warranted if the fishway exit is in the vicinity of the spillway. Another additional feature is a sorting/counting station at the top of the fishway, to gather data prior to releasing the fish into the lake. This feature often incorporates a viewing window, both for official monitoring and for public viewing.

A critical feature of a fish passageway at a dam is a means to lead the fish toward the fishway entrance. Oftentimes, the discharge at a powerhouse or spillway is so great that it overcomes the attraction of flows going through the fishway. As the fish follow the riverbank, the flows down a tailrace may move along that bank in such a way that a well-placed fishway entrance can efficiently gather the fish. Typically, however, a collection system is needed at the spillway or powerhouse outlet, to ensure that the high attraction discharges from the dam do not overcome a fish's interest in continuing to search for an upstream passage. Otherwise, the fish would remain near the powerhouse outlet, and would not be successful in getting past the dam.

Elevators often use low barrier dams, to direct the fish into the concentration pools. Such barrier dams also could be effective for standard (non-mechanical) fishways.

Mention has been made of the suitability of the vertical slot design to perform effectively over a wide range of flows. The length determinations for each of the fishway designs was based on the largest potential range of head differential (highest pool to lowest tailwater). The curves in the appendix for these two water surfaces show that for about 80 percent of the time, there is only a small change in the water elevation during the spawning season. So, a fishway typically could be set for such "standard" conditions. When the water elevations would deviate significantly from their average values, measures would need to be employed to regulate the flow, so as to maintain favorable discharge and velocity in the fishway. The specific means of achieving such flow regulation will be evaluated in the detailed analysis to follow this feasibility study.

EFFECTS OF SPILLWAY DISCHARGE ON FISHWAY ENTRANCE

In "An Investigation of Fishways", McLeod and Nemenyi provide observations on optimum usage of fishways by a number of species. In general, the fish do not begin migrating upstream until the water temperature rises to approximately 65°F. Although no evaluation on water temperature was done for this investigation of potential fishways at Gavins Point Dam, McLeod and Nemenyi's data indicate that the fish movement up fishways doesn't begin until late April. The peak months are May and June. Their observations were made on the Iowa River, a tributary of the Mississippi. The primary species observed in their studies were quillback, channel catfish and carp, with lesser numbers of gizzard shad, mooneyed herring, buffalo, and sheephead perch. They noted that the correlation between water temperature and fish migration was in agreement with observations in a fish study in Switzerland.

With flows going through both the powerhouse and spillway, the fish could be attracted to an area away from the fishway entrance. But since outflow through the spillway at Gavins Point is relatively infrequent, the spillway discharge shouldn't cause a major, long-term detriment to the fishway's effectiveness. In fact, the chart on outflow distribution (Fig. 3) shows that the spillway was used in June only six times during the 29 years of record, with only one of those years taking more than 15 percent of the flow in June (1971, 75% through the powerhouse). May had only three years of spills over the 29 years, with the spillway taking less than 20 percent of the flow each time. The only instance of spillway use before May was in April 1972, when the powerhouse could take only 88% of the flow. Thus, the fishway entrance should be located at the powerhouse outflow, and no special measures should be necessary to push the fish away from the spillway. Such special measures could be considered if the outflow regime changes from that of the period of record, or if fish behavior at the fishway later shows that extra features are warranted.

FISHWAY LOCATION, GAVINS POINT DAM

Hesse's report on Missouri River fishes suggests that the fish passageway at Gavins Point Dam should be located on the south side of the powerhouse tailrace. This recommendation is based on observations that the fish seem to be concentrated more to the south wall of that outflow channel. Mr. Hesse explained that migrating fish typically use the river bank as a reference as they move upstream. So at Gavins Point, powerhouse outflow at the south end of the dam would attract the fish, and they would move toward that attraction using the nearest bank (south). The attraction of the water would be about the same on the north side of the powerhouse tailrace (along the bank of the chalk island), but the lack of a continuous reference up to the island would mean that fewer fish would be found there. Therefore, the ideal location for the fishway entrance in terms of fish attraction is in the powerhouse tailrace, at the south bank.

The south bank poses a couple of major conflicts for siting a fishway. First, the top of the bank is essentially fully developed with power facilities such as transformers, access road and transmission towers. Secondly, the only practical option of getting to the lake pool south of the powerhouse would be to tunnel or cut through the embankment. The fishway wouldn't be efficient if it extended completely over the dam crest. Since such a facility directly connects the lake pool to the tailwater, the fishway should go no higher than the maximum pool. Cutting through the embankment would temporarily compromise the structure's integrity, and could pose a risk of uncontrolled flow of flood water through the dam. Additional problems are possible in terms of keeping the fish away from the powerhouse intakes, which are very near the south bank.

Much of the risks discussed above would be minimized if the fishway was located on the chalk island at the north side of the powerhouse tailrace. This island extends about 680 feet downstream of the dam, separating the spillway from the powerhouse tailrace. It doesn't have any existing facilities that might conflict with a fishway. The fishway exit would be established on the north side of the island in the lake pool. The island extends 130 feet into the lake. This arrangement for the fishway exit would move the fish away from the immediate vicinity of the powerhouse intakes, as compared to a south bank fishway. This location on the chalk island has another potentially significant advantage in its proximity to the spillway. Fourteen tainter gates presently operate to control spillway discharge. Since these openings in the dam are in place, it may be possible to convert one of these 30-foot wide bays to support the fishway. This would mean that there would be a minimum of cutting needed in the embankment. Figures 9 and 10 show possible alignments for fishways on the chalk island.

For the expected period of fishway usage (April-June), the spillway has been used in only twenty percent of the years of reservoir system operation. Discharging the fish in front of the spillway thus would be effective four out of five years, on average. A screen or barrier between the fishway exit and the rest of the spillway should be considered, to account for the spillway drawing the migrants back down river in twenty percent of future years. A typical fishway lends itself to easy observation by incorporating a well-lighted viewing window toward the fishway's exit. Construction of a facility on the chalk island possibly could include a parking area for visitors, so that the dynamics of fish migration could be readily observable. This would reinforce the visualization of the multi-purpose nature of the dam (for example, the transformers and transmission towers already show the dam's hydropower component).

The primary drawback to placing the fishway on the chalk island is the difficulty in moving the fish from the south bank, across the tailrace to the island. The two most likely means of directing the fish to this entrance would be a powerhouse collection system and a barrier dam. Collection systems essentially are conduits through which attraction flows continue to move fish that have been drawn by the powerhouse outflow. Designs for such systems are fairly complex, and thus are beyond the scope of this feasibility study.

The design for a barrier dam in the tailrace would require a thorough analysis in terms of backwater characteristics, scour potential, and effectiveness in directing fish. Determination of the orientation, dimensions and practicability therefore also would be outside this study. In either case, the potential exists to overcome the lack of a natural means of directing the fish to the fishway.

The developed situation on the south bank that would interfere with a ladder-type passageway actually would be beneficial to a fish elevator there, since the existing road would allow easy ground transport of the fish to the reservoir. Figure 11 shows a likely location for the fish elevator on the south bank. Assuming that a sorting operation will be needed, the sorting station should be located where it can send fish not wanted for upstream migration back down to the river below the dam. The north end of the embankment appears to be practical for this operation, since it could send the undesirable migrants through a conduit down to Lake Yankton (see Fig. 12). The exit from the sorting station into the reservoir in this area also would be well removed from the powerhouse and spillway, thus lessening the risk of the successful migrants being taken back down river. In fact, transporting the fish to the north end of the dam for release would situate them along the bank, so that they are reoriented for their continued migration through the lake.

ALTERATION OF EXISTING DAM OPERATIONS

Incorporation of various appurtenant features obviously has the potential for conflicting with existing facilities and activities. For example, a barrier dam might cause an unacceptable risk of scour, or might negatively affect the discharge characteristics at the powerhouse. Similarly, establishing a new facility may require that some transformers or other facilities be relocated. A primary consideration, however, would be whether the basic designs suggested herein may interfere with the design purpose and function of the dam. Specifically, would the loss of a small percentage of power generation due to a diversion of water be acceptable, and would the flood pool operation be significantly affected by the loss of one of the fourteen tainter gates?

The outflow table in the appendix shows that total outflow exceeds the powerhouse capacity (about 35,000 cfs) about 13 percent of the time. Any time that the outflow would be greater than this rate, the fishway would be diverting water from the spillway rather than reducing the flow through the turbines. The outflow table also shows that the average condition, at 50 percent exceedence, is a dam outflow of 30,000 cfs. Fishway diversion of 100 cfs at this typical powerhouse flow would reduce that flow by only 0.3%. The following table lists the reduction for various fishway diversions (including auxiliary flow).

Percent of Powerhouse Flow Lost to Fishway Facility Diversion

Fishway	Powerhouse Exceedence, Flow (cfs)			
	13%	50%	75%	90%
Diversion, cfs	35,000	30,000	25,000	20,000
100	0.3%	0.3%	0.4%	0.5%
500	1.4%	1.7%	2.0%	2.5%
1000	2.9%	3.3%	4.0%	5.0%
3000	8.6%	**10.0%**	12.0%	15.0%

Analysis to follow this study would determine the range of flow needed for effective fishway operation. Those flow rates then would assessed in terms of the economic loss of hydropower generation.

The effect of dam operation from converting a spillway bay to non-spill usage is not easily quantified, as compared to the above hydropower flow analysis. The loss of one of the tainter gates generally would merely require that the remaining thirteen gates be opened higher, to maintain the desired spillway discharge. A significant impact from the gate conversion would occur when the gates are near their maximum release rate, such that the original spillway design would depend on all fourteen gates being open. The outflow table in the appendix shows that the 1-percent exceedence rate is 60,000 cfs. For an estimated powerhouse flow of 35,000, this represents a spillway flow of 25,000 cfs. Reducing that flow by 7 percent (1/14), the spillway flow would be 23,250 cfs. However, the outflow table shows that the resulting total flow, 58,250, would be exceeded only about 2 percent of the time. In other words, a 1-percent flow would be affected minimally by the loss of one gate. There apparently wouldn't be any significant loss of spillway function loss for more than 99 percent of the time. Further analysis will be required to assess the risk due to worst-case scenarios.

ADDITIONAL CONSIDERATIONS

Fish passageways other than elevators and locks theoretically can operate with minimal oversight or interference by human observers. This assumes that water levels are optimum at the entrance and exit, and that the appropriate discharge is moving through the fishway. Operation of a counting and sorting station at the upper end of the fishway, however, can yield significant benefits. Such a feature can accurately track the fishway's performance in terms of species composition and long-term effectiveness. This can lead to refinements in the facility design. Another key reason for allocating manpower for sorting the species is to reduce the spread of exotic species up the Missouri River system. Jeff Schuckman of the Nebraska Game and Parks Commission notes that such an exotic species, bighead carp, is now found downstream of Gavins Point Dam. It has feeding behavior almost identical to the paddlefish. Consequently, new competition with paddlefish and other native species from bighead carp above Gavins Point and in the Niobrara River could be forestalled by an effective sorting operation at the Gavins Point fishway.

The fishway probably could be shut down after the early summer, since spawning activity will essentially be finished at that time. This would minimize unnecessary wear, and will ensure that hydropower operation has all inflow at its disposal once the fish have moved past the dam. The upstream closure device probably would include the function of flow regulation. A downstream closure also can be beneficial, to keep backwater from moving debris into the entrance.

SUMMARY OF DESIGN CHARACTERISTICS

The warm water fish species in the Missouri River are not well suited for using some of the fishway types, and Gavins Point Dam presents a formidable obstacle for some of the designs to overcome. Overall, the weir and orifice design probably has the least likelihood of success here. The examination of a mechanical lift mechanism is concentrated on elevators over locks, due to historical performance.

Gavins Point Dam does not present any insurmountable problems for incorporating a fish passage facility. The table on the following page summarizes some specifications and expected effectiveness.

This table shows that an elevator is theoretically most effective for fish targeted for upstream migration past Gavins Point Dam. Its operation is essentially independent of the reservoir pool, and it could be designed to attract and capture the intended species of fish. The main advantage of the elevator over the ladder-type concepts at Gavins Point is the ability to site the facility along the bank where the migrants will be more concentrated. The table shows this for the factor "GP exist. layout". If the chalk island was connected to a downstream bank, the ladder-type facilities would have a high rating for effectiveness.

When considering fishways exclusive of elevators, the vertical slot appears to have the most promise. It is able to function over a wide range of water surface elevations, without major adjustments. The overall height of the climb isn't unreasonable for this design. The lack of a successful working model for warm water species at a high dam like Gavins Point is reasonable cause to question whether a fishway could perform efficiently here. If a fishway was to be installed, and if the fish's reliance on the bank for guidance caused insufficient fishway usage, a channel modification could be considered for the tailrace to guide the fish to the island. One possible design would consist of a weir built diagonally across the tailrace, allowing the fish to follow the weir to the fishway entrance.

The discussion under the Design Concepts section for the pool and weir noted the shortcomings of that design for Missouri River fish at Gavins Point Dam. Of all the fishway concepts, the pool and weir evidently would be the least effective, primarily due to its not meeting the swimming characteristics of the intended species. Including an orifice in the weir design may be adequate to address this shortcoming, but the pool with only weir flow has minimal promise for success here.

CHARACTERISTICS OF FISH PASSAGE DESIGNS AT GAVINS POINT DAM

	POOL AND WEIR	WEIR AND ORIFICE	VERTICAL SLOT	DENIL	ELEVATOR
PRIMARY UNIT					
Number	84	40	93	19	
Height, ft.	6	6	4	5.7	
Width, ft.	6	8	8	3.9	
Length, ft.	8	12	8	23	
Unit drop, ft.	0.67	1.4	0.6	2.94	
Slope	8.3%	11.7%	7.5%	12.8%	
ADDITIONAL FEATURES					
Orifice dia.		24"			
Slot width			18"		
Resting pool:					
Number				18	
Unit length				8'	
TOTAL LENGTH (horiz., ft.)	672	480	744	581	
DISCHARGE, cfs					
Weir/baffle	45	9	--	--	
Slot/orifice	--	18	32	10-15	
Total fishway	45	27	32		
Auxiliary*	55	73	68	90	100
VELOCITY, fps					
Transition	5.7	5.7	5.4	6.3	
Average	1.0	0.4	1.0	1.5	
EFFECTIVENESS					
• Targeted species	Low	Mod-low	Mod-high	Mod-high	High
• Fluctuating pool	Mod-low	Mod-low	High	Mod-low	High
• GP dam height	Mod-high	Mod-high	Mod-high	Mod-low	High
• GP exist. layout	Moderate	Moderate	Moderate	Moderate	High

The actual effectiveness of a fish passageway at Gavins Point Dam may fall short of the theoretical performance described in this report and outlined in the various references. Applying performance data from existing fishways to Gavins Point may not be fully valid due to differences in dam specifications and operation, and in the configuration of the river reach and reservoir pool at the dam. Consequently, testing of a model for the facility would be

* The estimated auxiliary flow is based on a minimum total fishway allocation of 100 cfs. Effective attraction may require more auxiliary flow, as would be determined in the detailed analysis to follow this study.

appropriate. This would confirm the theoretical flow and velocity relative to expected conditions at the dam. The model's hydraulic results, however, still would have to be interpreted in terms of fish usability. In-depth knowledge of how fish would respond to the design being modeled could determine the need for modifying the design. Assuming a design is sound hydraulically and economically, the ultimate decision on final implementation must rely on the judgement of fishery biologists.

Scale models of fishways could verify the project's theoretical hydraulic performance. Similarly, additional testing on key target species could confirm that existing data on swim capabilities are valid for a fish passage design at Gavins Point Dam. The melding of the facility hydraulics with fish behavior appears to be the factor that would benefit most from a physical model. Unfortunately, full scale modeling of a test section of fishway probably is not practical, due to the high discharge required. Possibly the best approach for proving that a proposed facility is practicable for the Missouri River fish at Gavins Point Dam would be to evaluate data from working facilities at lower obstacles that use such a design for those species. Unfortunately, there apparently aren't any existing fishways operating for the fish species targeted for migration at Gavins Point.

ESTIMATED COST

This feasibility study did not develop the detail necessary to reliably estimate costs for any of the potential designs. However, Clay's book includes a method of making rough estimates based on a fishway's volume. A drawback to his general formulas is that the estimate for the powerhouse collection system is higher than all the other features combined. The collection system cost estimate is based on a unit cost applied to the length of the powerhouse. Since the different fishway design's would use the same design for fish collection, the effect of the varying volumes of the designs is lessened in drawing cost comparisons between the designs.

Applying Clay's unit costs to fishway designs at Gavins Point Dam resulted in a project cost of 4 to 6 million, in 1996 dollars. The volumes on which part of the estimates were derived are shown in the following table. Based on the high degree of uncertainty in the estimates, an estimated dollar amount is not assigned to any particular design. Instead, the relative cost between alternative designs is shown in the table, based on the apparent least expensive fishway alternative (Denil).

	Fishway Volume (1000 c.f.)	Relative Capital Cost (to Denil)
Pool & Weir	24.8	+25%
Weir & Orifice	23.6	+25%
Vertical Slot	36.5	+50%
Denil	12.9	--
Elevator	--	-50%

A cost estimate was developed for an elevator design by Clay in his 1961 book. In converting that estimate to 1996 dollars, the margin of error obviously was compounded. The cost comparison table includes the elevator's approximate relative cost, showing it to be about half of that of the Denil.

Operation and maintenance for fishways is in the range of 1 to 2 percent of the capital cost, according to Clay. An elevator design would have O&M costs closer to five percent. As a group, the fishways would have an average annual O&M cost of approximately $70,000. The elevator's estimated O&M would be at least $10,000 higher than that of the fishways. As a conservative estimate, we could assume that the elevator O&M would be up to $25,000 more than for a fishway. If the total project cost is considered as a single present-day amount, that $25,000 difference would add no more than a half-million dollars to the overall cost (for a 25-year project, at 4% interest). So, the elevator still would cost forty percent less than a low-cost fishway ($5M x 50% + 0.5M = $3M). This significant cost advantage of the elevator over fishways is large enough that the elevator probably would maintain its least-cost ranking even for especially high costs of equipment and labor.

CONCLUSIONS

Gavins Point Dam is a logical choice for investigating the potential for a fish passageway. This would extend the migratory range of fish species by nearly 70 miles on the Missouri's mainstem, along with restoring access to tributaries such as the Niobrara River. Four different design concepts are theoretically practical for allowing fish to climb past Gavins Point Dam into the lake. In addition, mechanical methods such as elevators and locks could be employed for carrying the fish up past the dam. This report set dimensions for potential designs of the non-mechanical fishway types. It also drew from various sources in evaluating the practicality of each of these designs at Gavins Point.

All five of the design types listed in the above "Characteristics" table are physically possible at Gavins Point. When assessing each design type for effectiveness with the desired fish species, the pool and weir concept receives a low rating. And although the weir and orifice design should perform better than the pool and weir, it can be rated only low-to-moderate for the targeted species. The vertical slot and denil, on the other hand, have shown greater promise of being effective for the desired Missouri River fish. Since the correlation of fish capabilities to the design is so important, further study should concentrate on the vertical slot or Denil. The pool/weir and weir/orifice design do not appear practical for the target species, and therefore need not be further considered.

The hydraulic characteristics of the vertical slot are superior to those of the Denil, due to its ability to function effectively over a wide range of pool fluctuation. In addition, the vertical slot design's use of individual baffles as transition points probably affords better protection than the Denil in minimizing the risk of fish "falling back" through fishway segments. In the Denil, a fish might more easily be swept out of the resting pool down the fishway section that had just been ascended. Finally, although the Denil has a good track record for low obstacles, there is minimal documentation of its successful use on higher dams. The fishway design having the most promise in terms of potential effectiveness for the targeted fish species at Gavins Point Dam therefore is the vertical slot.

Economics appear to favor the Denil over the vertical slot, since the vertical slot design would cost approximately fifty percent more than the Denil. Potential effectiveness, however, is especially critical at a high structure such as Gavins Point Dam. One distinguished researcher of fish passageways, Mr. Boyd Kynard, surmises that at present there are no fishways for warm-water fish species installed at a dam with the head differential as great as at Gavins Point Dam. Unless the cost would be well out of line with other potential alternatives, the design with the best hydraulic interaction with the behavior of the target fish should be pursued.

The cost advantage of the Denil over the vertical slot may not be as great as the above rough estimate indicates. Katopodis states that the weir-type fishway is frequently the least expensive, with the Denil often costing less than the vertical slot. The economic comparison table presented above showed the Denil costs less than the weir-type, contrary to the rule-of-thumb offered by Katopodis. If we assume that this conflict is due to a typical cost difference between the Denil and weir types being small, the Denil cost could be considered equivalent in that table (recognizing that Clay's estimation formulas include only the two factors of facility volume and powerhouse length). If the Denil is adjusted in this way, the cost of the vertical slot would be only 25 percent higher than for the Denil.

This analysis has shown the elevator concept to be superior to the standard fishway designs for all significant characteristics, including cost. As actual operation costs are defined, a more accurate cost comparison can be made to the elevator and the fishways. The clear differences in transportation and location between the fishways and the elevator are a good reason to pursue analysis of both. The vertical slot design would allow the fish to move upstream under their own power, thus providing a more natural resolution to the dam's migration interference. On the other hand, the elevator appears to have a greater potential for overall success, probably at a lower cost.

Determining the overall practicality of a fish passageway must consider all ancillary features. These include auxiliary water for attraction, adjustments as necessary at the entrance and exit, and screening/diversion at the exit to keep fish from being swept down the fishway. In addition, a station for counting and sorting the successful migrants should be included. The loss of some hydropower generation as a result of water diverted for fish attraction could significantly effect the analysis of the fish passage project, both in terms of lost revenue and of a potential compromise of the dam project's mission.

While the elevator proposal has the potential for conflicting with a variety of dam facilities and functions (e.g., electrical transmission facilities, vehicle traffic across the dam, necessary modification to the present embankment, etc.), the alignment of a fishway through the dam poses special concerns. A thorough evaluation will be required to ensure that such an alignment will not jeopardize the dam's integrity, either during construction or over the long term.

It is possible that the mission of the Gavins Point Project would not have the latitude to allow the dam facilities to undergo modifications needed for either the elevator or a standard fishway. In that event, it may be possible to construct a bypass channel around the dam. For example, a side channel could be excavated from the north bank of the reservoir, down to Lake Yankton. Such a project would require special attention for regulating flows, and certainly would have a high construction cost. Also, it would still compromise the dam's present potential for full power generation. However, it offers an alternative to fish passage facilities in the vicinity of the powerhouse and spillway. Provided the elevator or vertical slot fishway are considered practicable for further analysis, consideration of a bypass channel is not needed.

Large numbers of fish below the dam indicate that a well-designed fish passageway would receive significant use. The benefits to the game fishery are obvious, and a passageway is a logical response for protecting sturgeon pursuant to the Endangered Species Act. The design's hydraulic performance should be fully evaluated, preferably through model testing. Results of the model test should be analyzed by a fisheries biologist knowledgeable on fish migration. The design should be modified in order to produce favorable hydraulic characteristics and effective fish usage. Performance of the resulting fish passageway should be carefully monitored after it is in full operation, to determine the need for additional modifications, and to document its effectiveness.

APPENDIX A

FIGURES

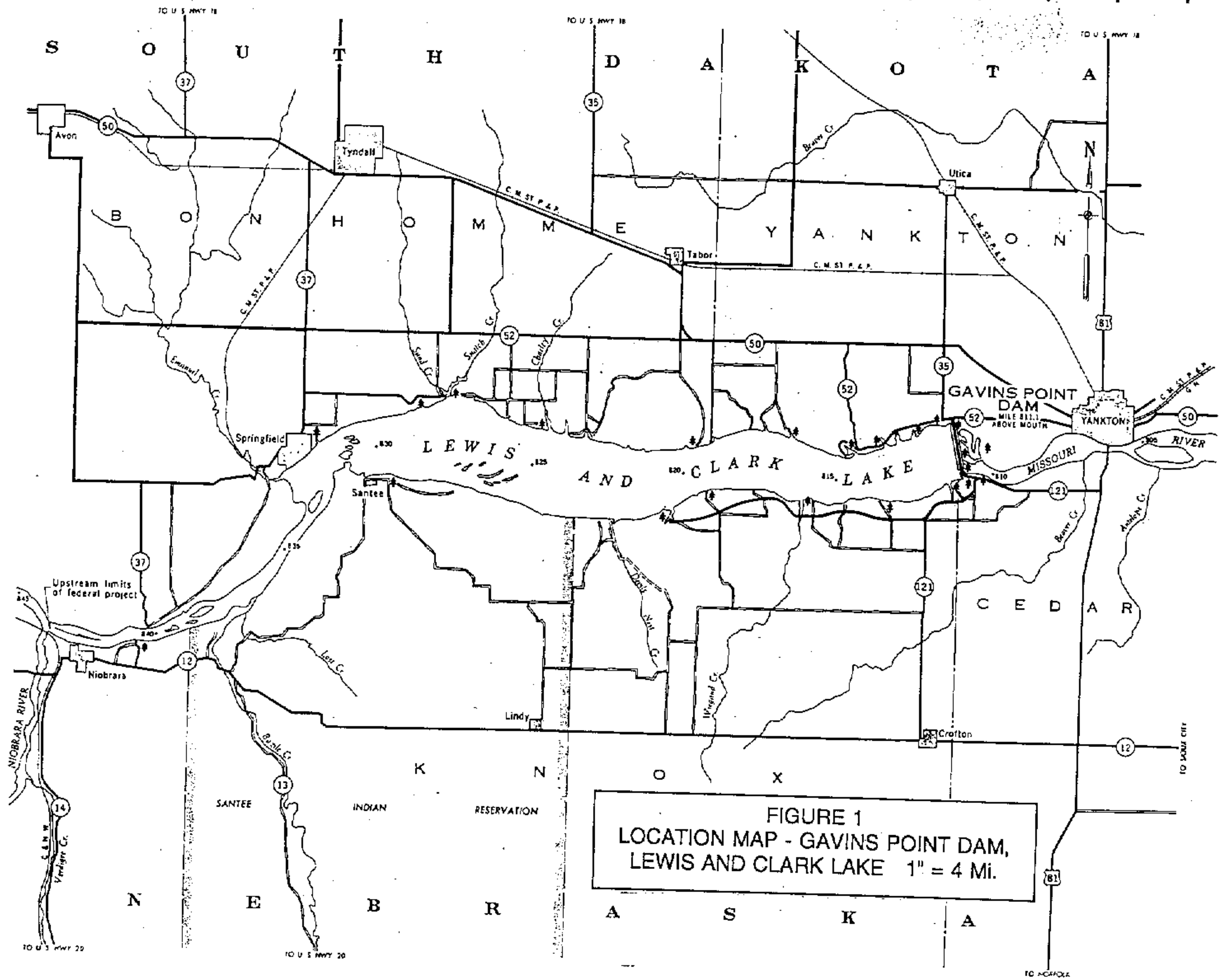


FIGURE 1
LOCATION MAP - GAVINS POINT DAM,
LEWIS AND CLARK LAKE 1" = 4 Mi.

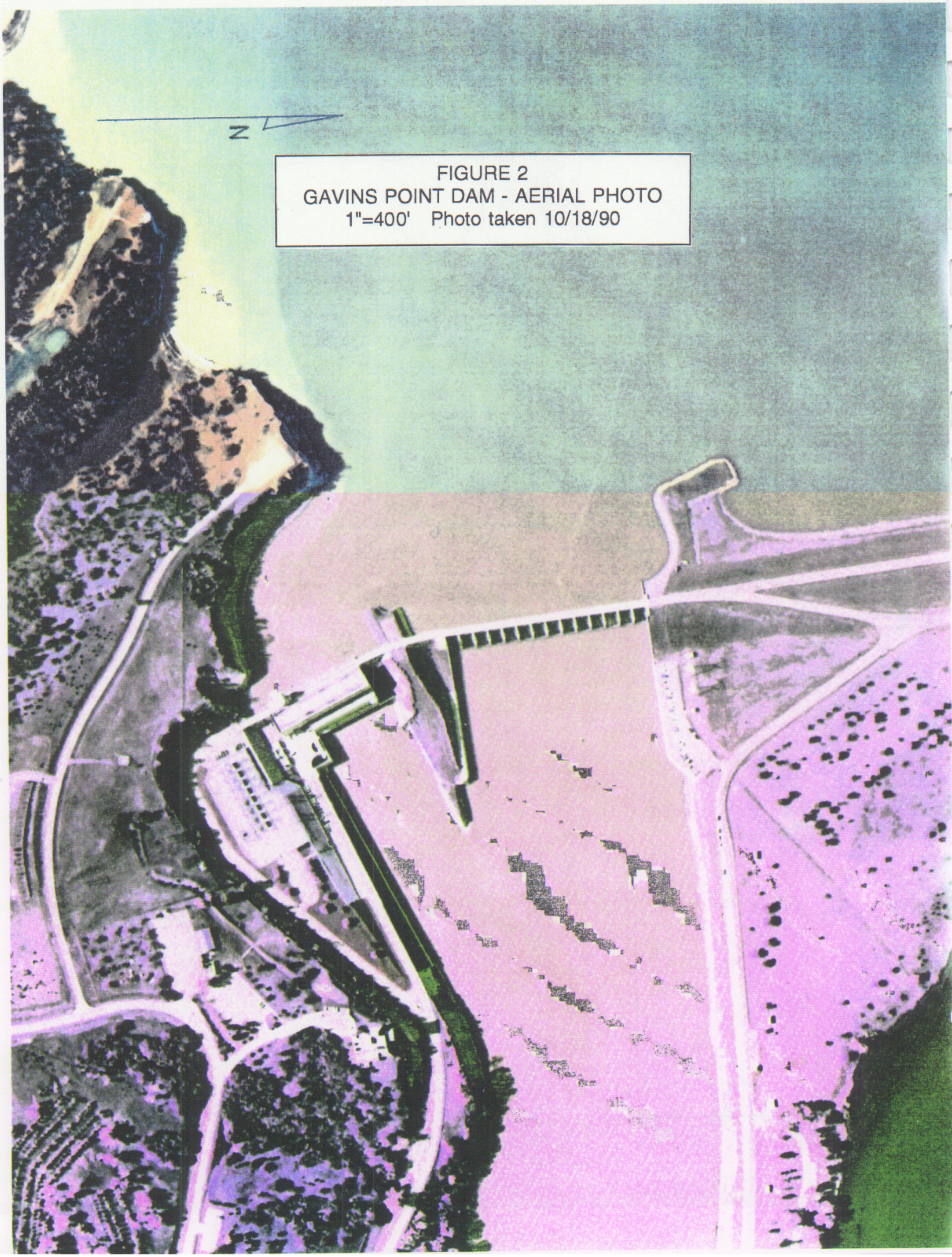


FIGURE 2
GAVINS POINT DAM - AERIAL PHOTO
1"=400' Photo taken 10/18/90

FIGURE 3
DISTRIBUTION OF OUTFLOW, PER MONTH
GAVINS POINT DAM, 29 YEARS OF RECORD, 1967–1995
(All Outflow During December Through March
Has Gone Through the Powerhouse)

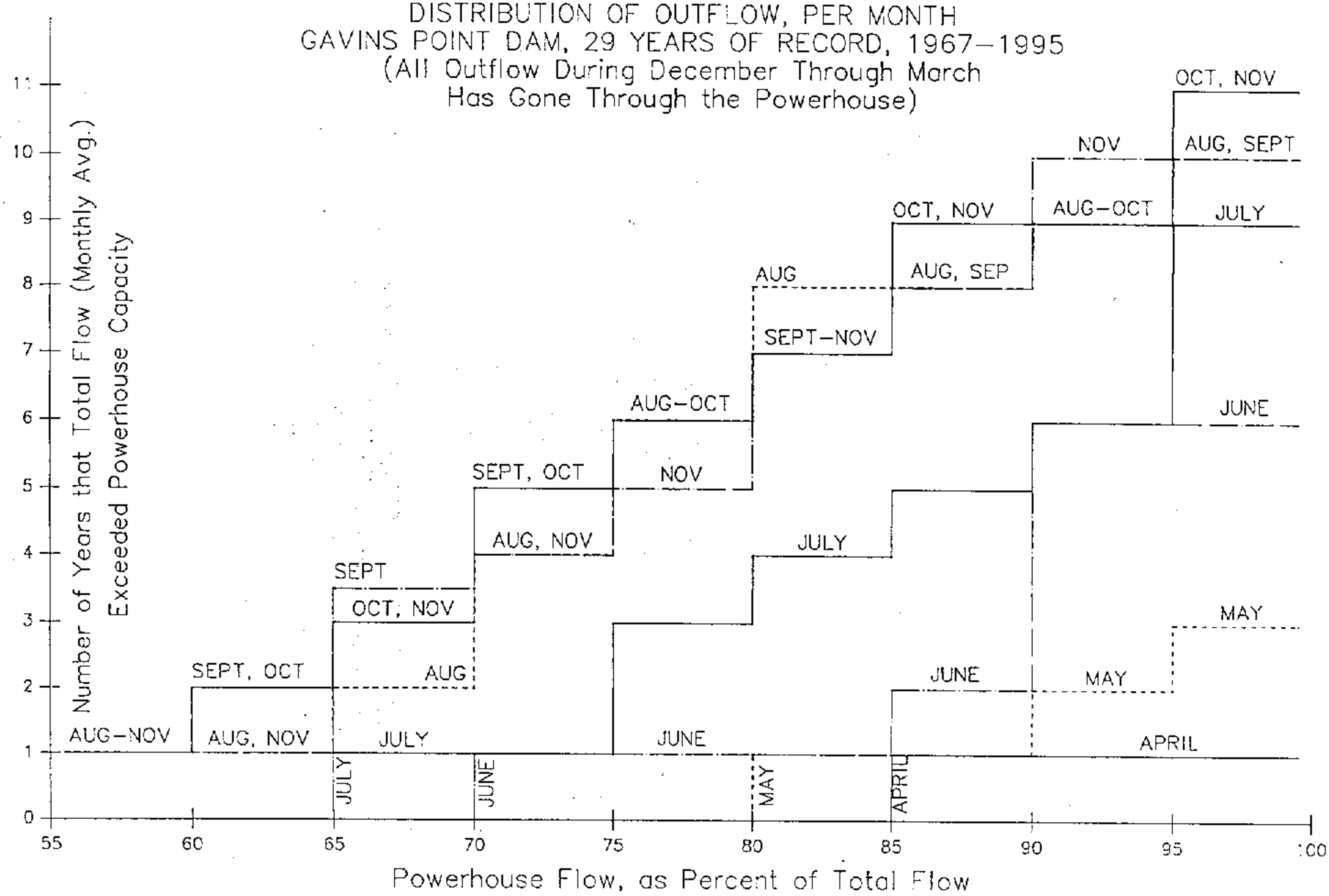


FIGURE 4
CRITICAL VELOCITIES MEASURED BY TUNINK, 1977

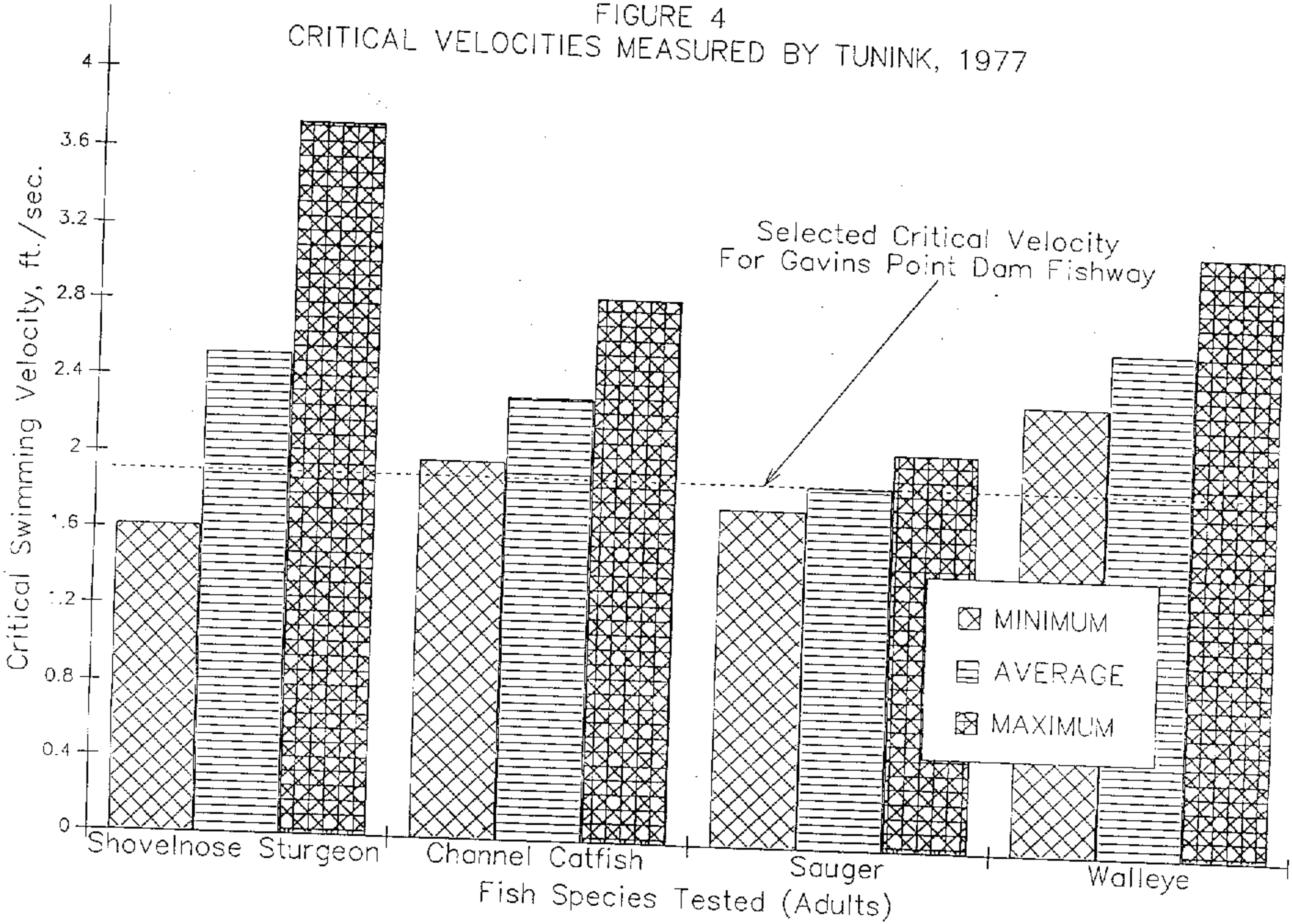
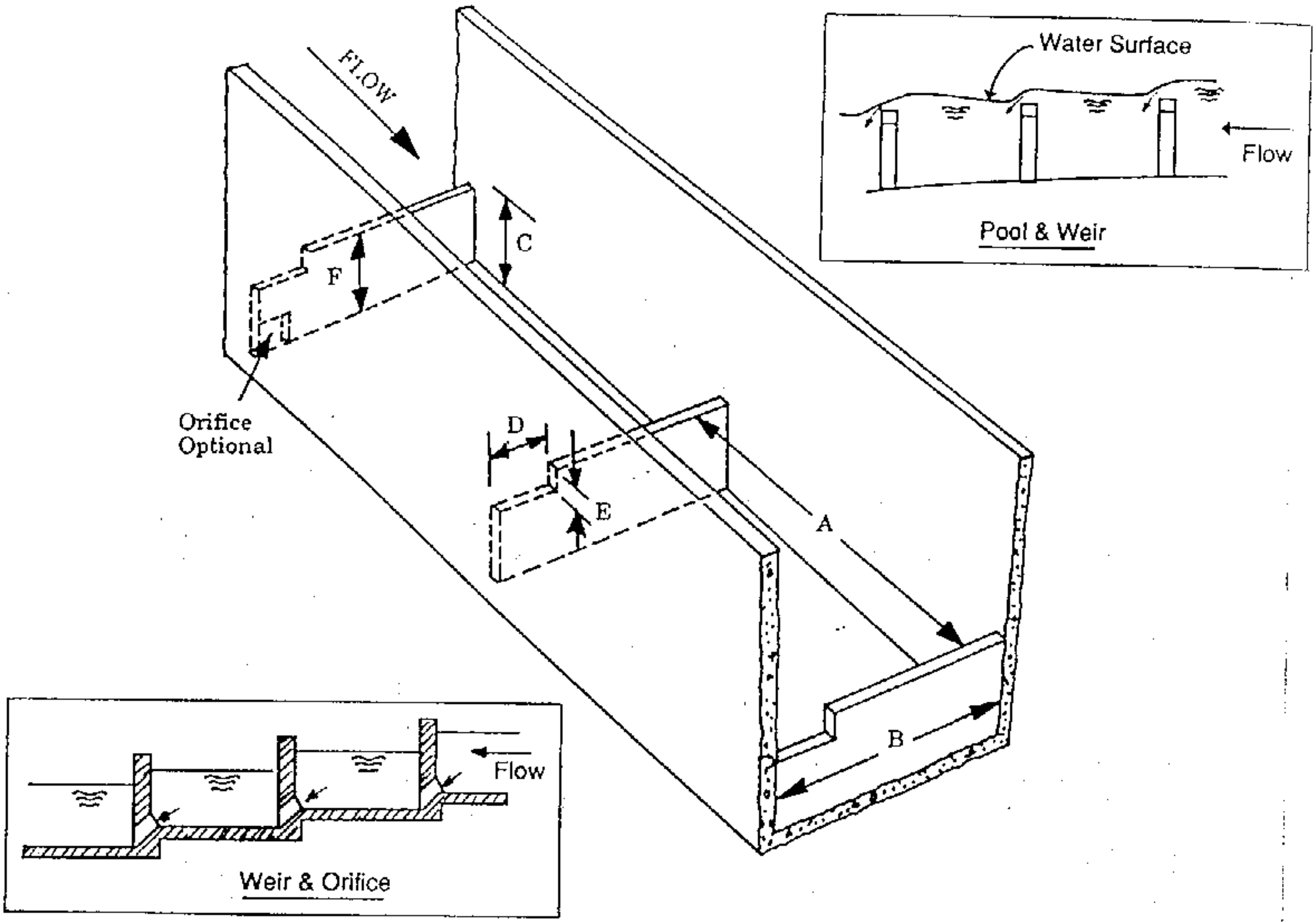
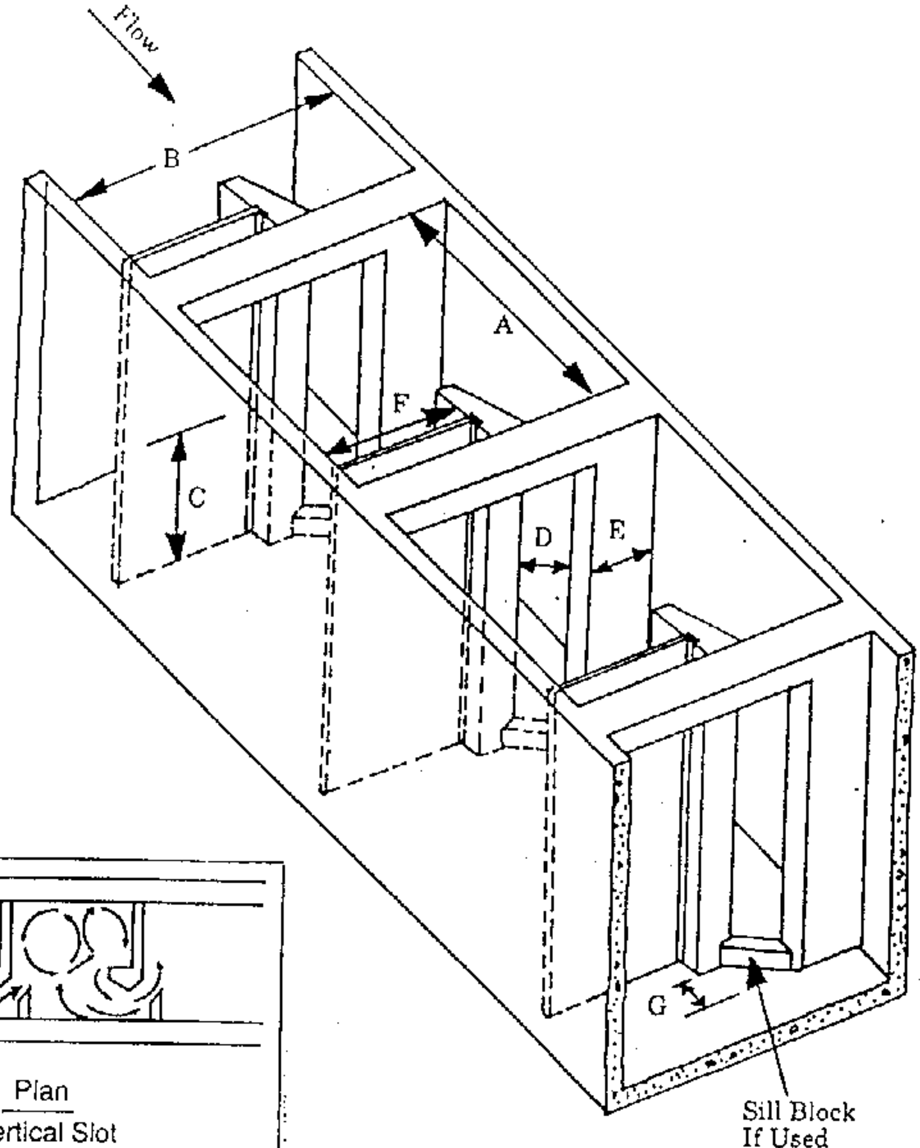


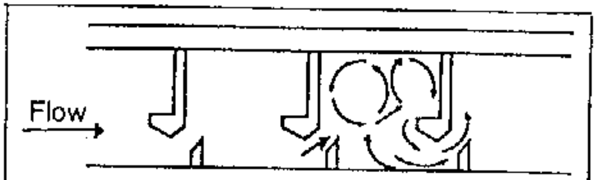
FIGURE 5
POOL AND WEIR FISHWAY
Source: Bell Fisheries Handbook, 1991;
C. H. Clay, 1995



A	Pool Length	6′	8′	10′
B	Pool Width	4′	6′	8′
C	Water Depth	3′	4′	6′
D	Slot Width	.5′	.5′	.5′
E	Slot Depth	.5′	.5′	.5′
F	Baffle Height	2.5′	3.5′	5.25′
	Water Depth in Notch	12″	12″	15″
	Discharge in CFS Min	1.65	4.0	4.0
	Normal	5.0	12.3	25.0
	Max.	24.0	36.0	48.0
	Drop Per Pool	1′	1′	1′

FIGURE 6
VERTICAL SLOT FISHWAY
Source: Bell Fisheries Handbook, 1991;
C. H. Clay, 1995



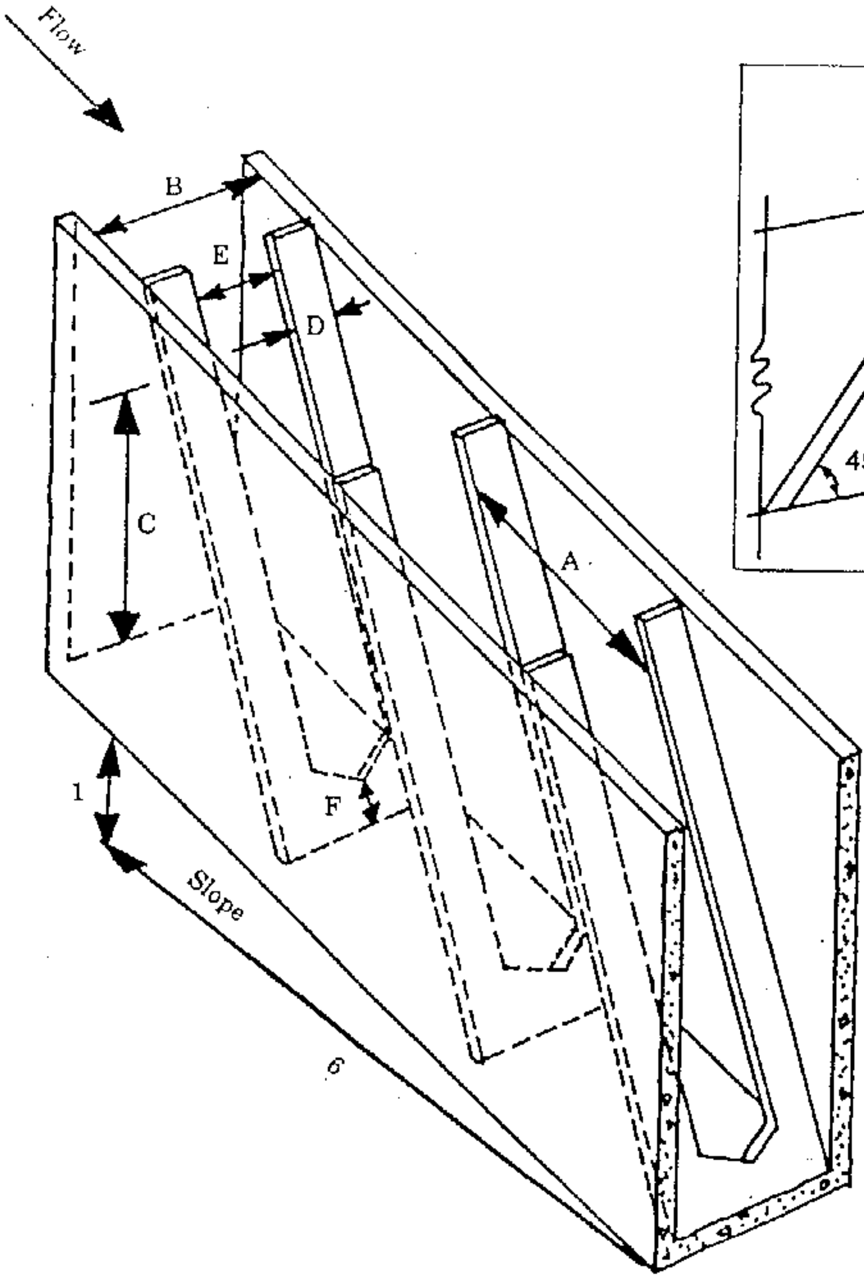


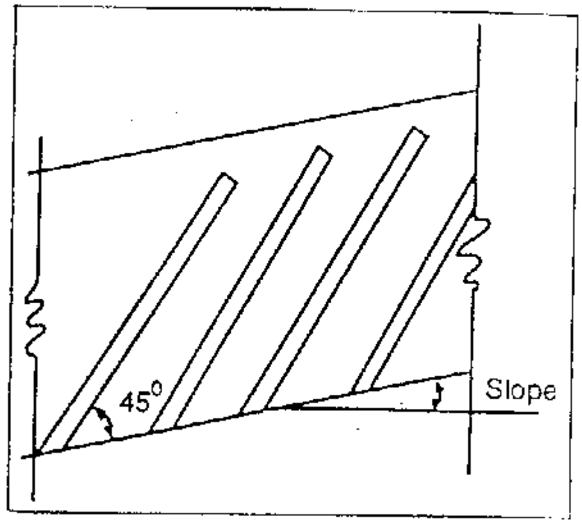
Plan
Vertical Slot

A	Pool Length	6'	8'	10'
B	Pool Width	4'	6'	8'
C	Water depth (Min)	2'	3'	3'
D	Slot Width	.5*	.75*	1.0*
E	Wing Baffle Length	9"	1'-3⅝"	1'-3⅝"
F	Wing Baffle Distance	2'	3'-1"	3'-7"
G	Displacement of Baffle	4'	5'-½"	5'-½"
Discharge Per Foot of Depth Above Block in CFS		3.2	4.8	6.4
Drop Per Pool		1'	1'	1'

*Sill Block in Place

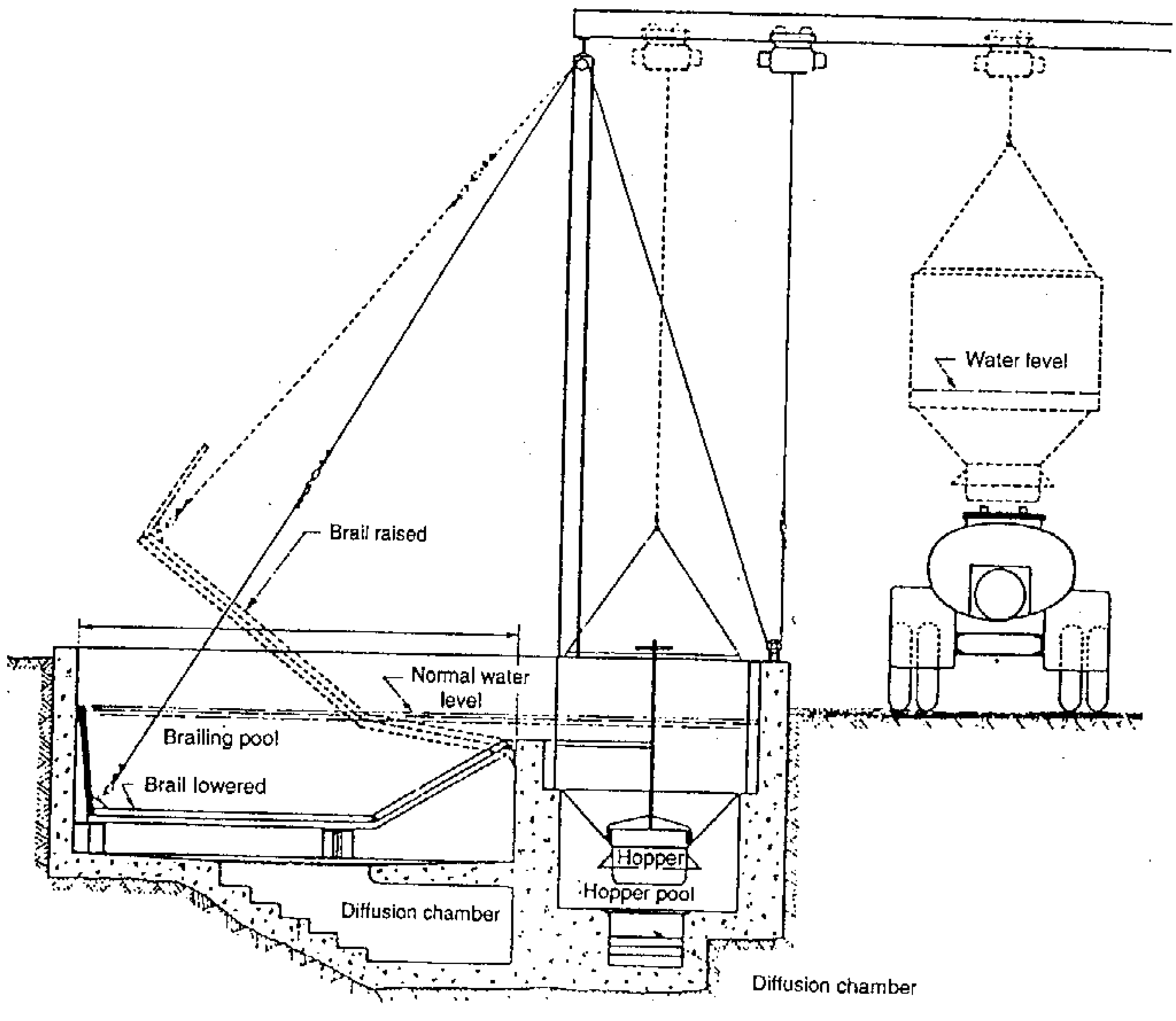
FIGURE 7
DENIL FISHWAY
Source: Bell Fisheries Handbook, 1991;
C. H. Clay, 1995





A	Pool Length	2′
B	Pool Width	3′
C	Water Depth	3′
D	Baffle Width	7.5″
E	Slot Width	1.75′
F	Bottom Baffle Notch Ht.	7″
Discharge Variable CFS --		21
Av. Vel. 4 FPS		

FIGURE 8
TYPICAL FISH ELEVATOR
Source: C. H. Clay, 1995



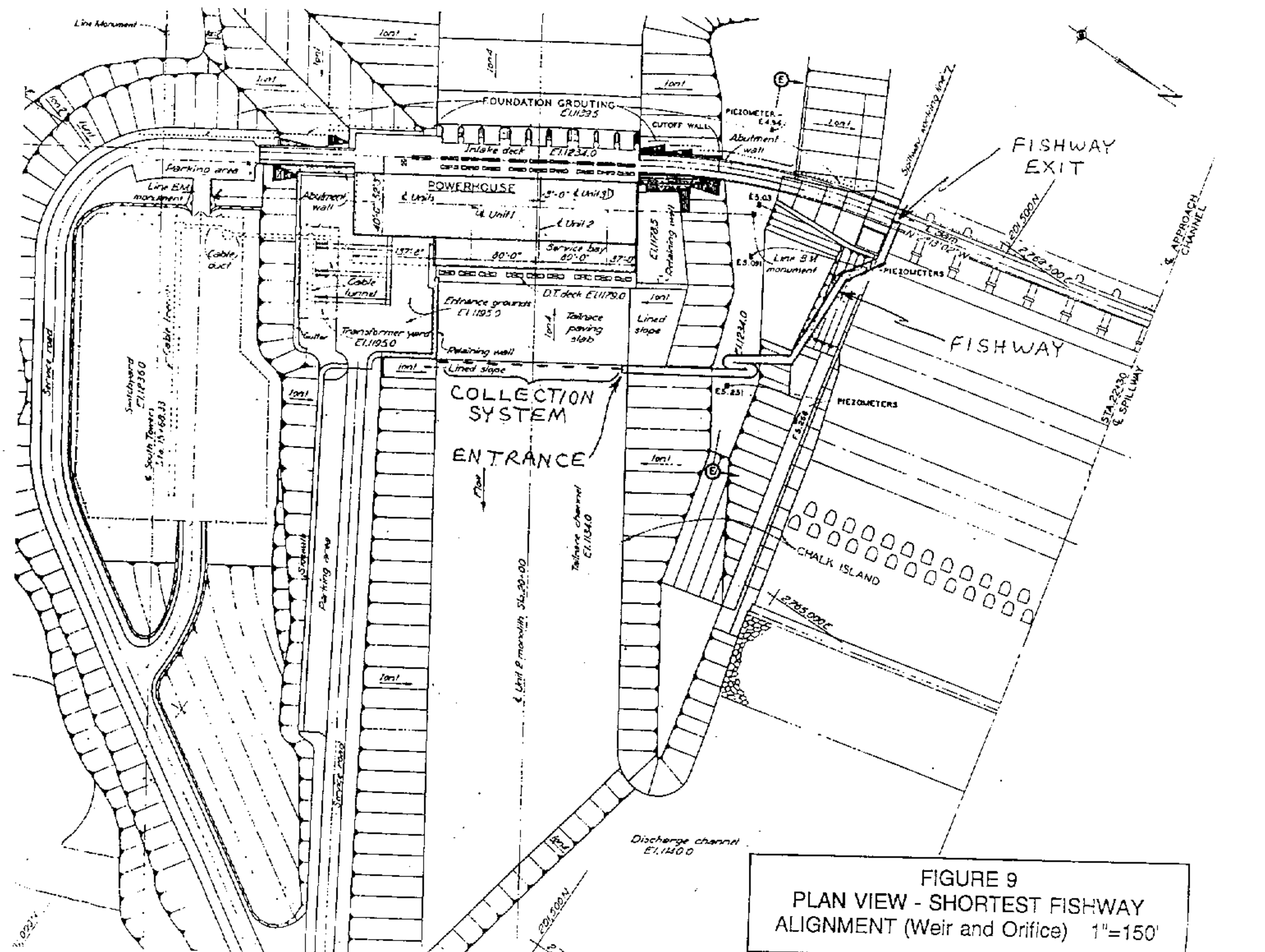


FIGURE 9
PLAN VIEW - SHORTEST FISHWAY
ALIGNMENT (Weir and Orifice) 1"=150'

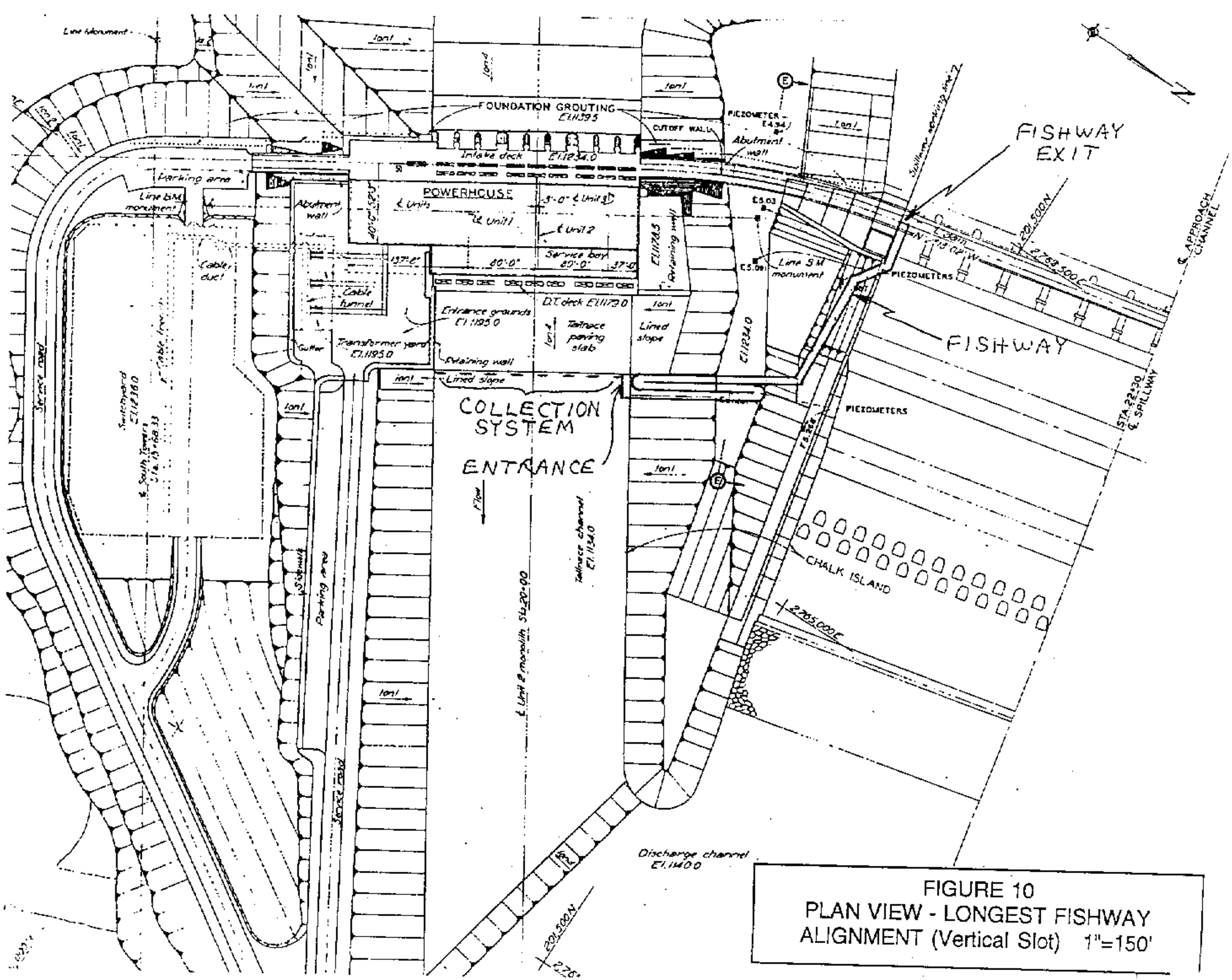


FIGURE 10
PLAN VIEW - LONGEST FISHWAY
ALIGNMENT (Vertical Slot) 1"=150'

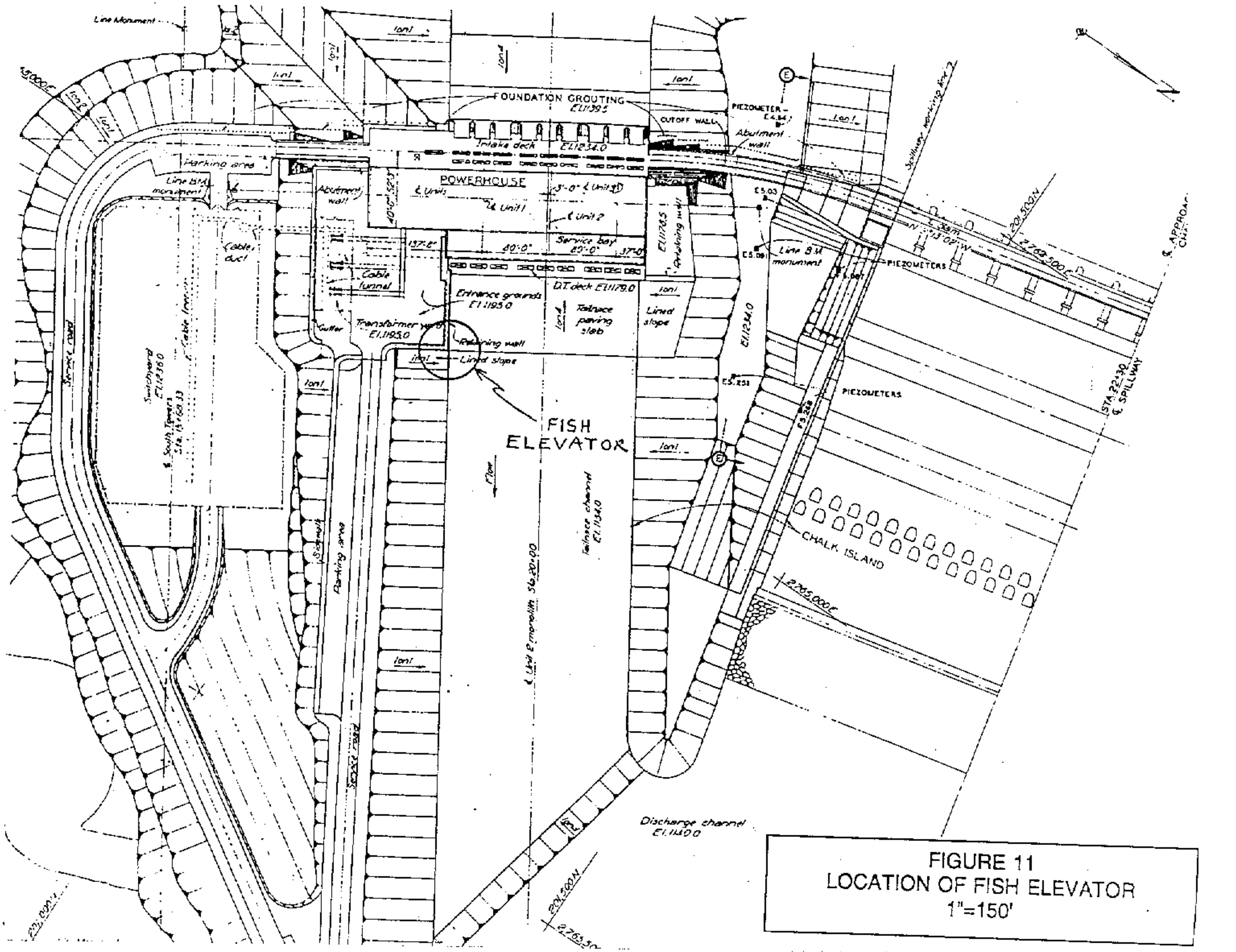
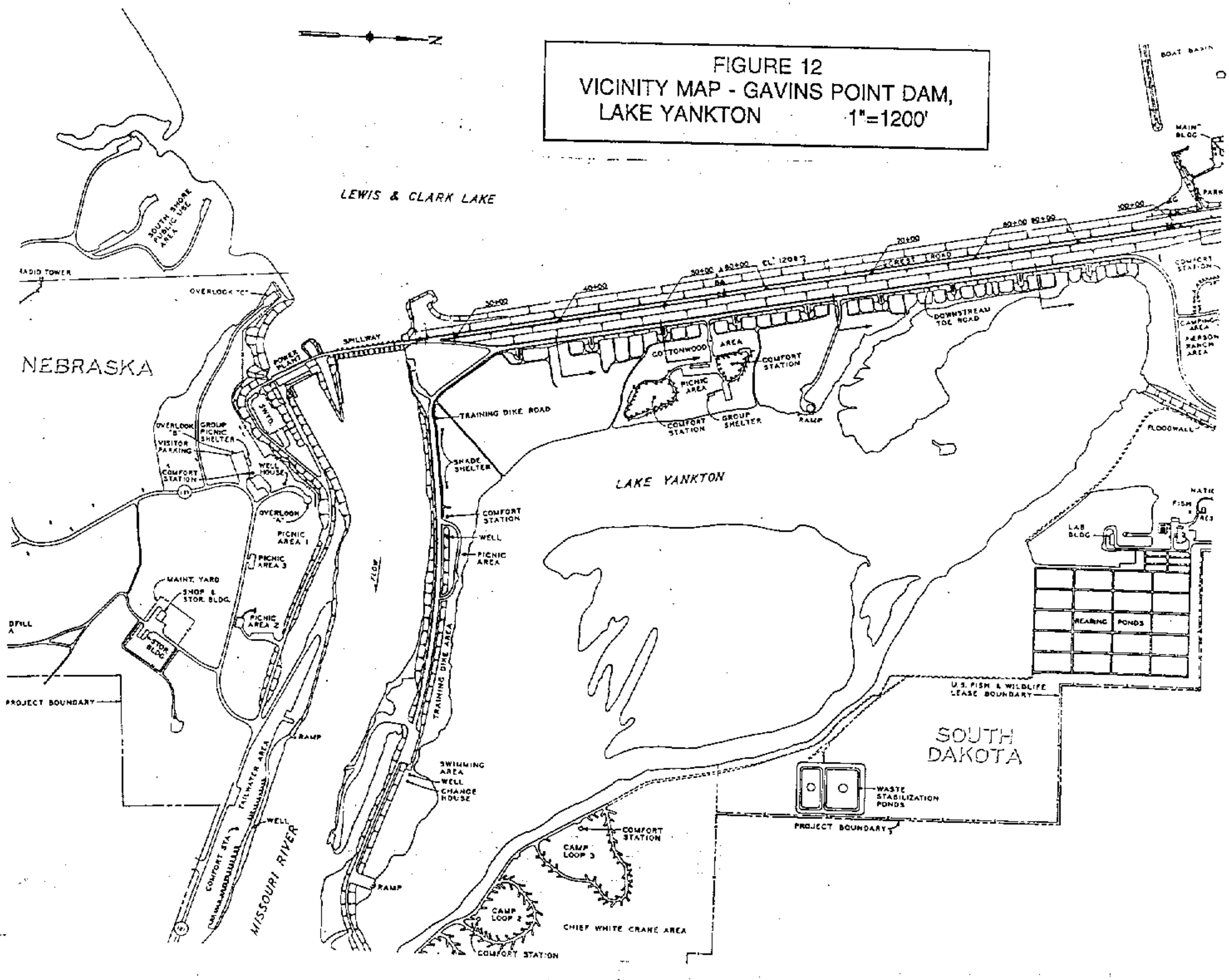


FIGURE 11
LOCATION OF FISH ELEVATOR
1"=150'

FIGURE 12
VICINITY MAP - GAVINS POINT DAM,
LAKE YANKTON 1"=1200'



APPENDIX B

GAVINS POINT DAM - POOL/FLOW DURATION

- Duration Curves Overview
- Table of Pool Durations
- Table of Tailwater Durations
- Table of Outflow Durations
- Pool Duration Curves
- Tailwater Elevation Duration Curves
- Reservoir Outflow Duration Curves

Duration Curves

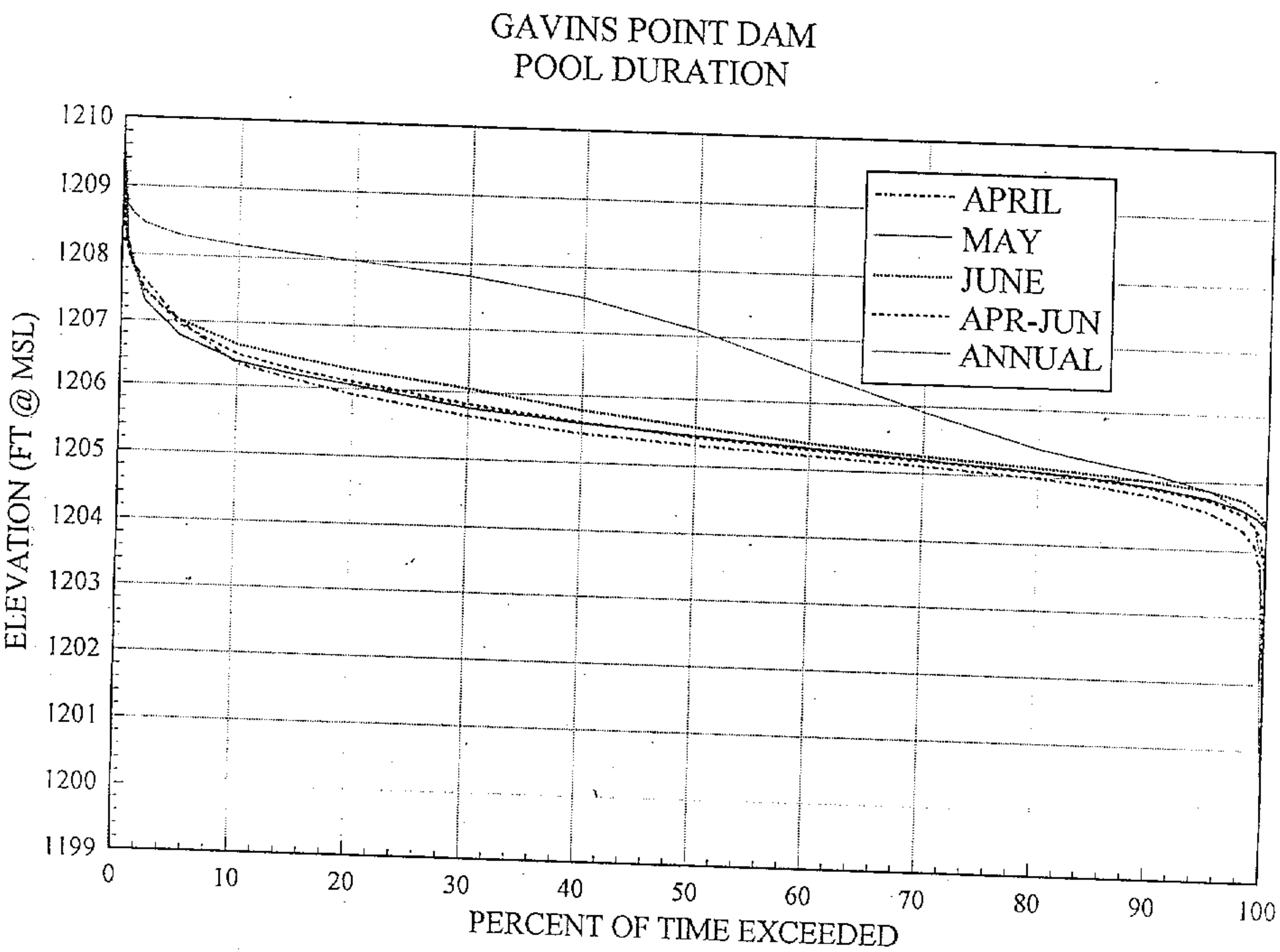
The purpose of this analysis was to derive monthly, seasonal and annual flow duration and stage duration curves for pool elevation, tailwater elevation and reservoir outflow based on average daily values for the period of record for Gavins Point Dam. This data was used to assess the potential of fish passage success and optimize fish passage inlet and outlet location and elevation.

Flow and stage duration curves were derived using the Hydrologic Engineering Center's (HEC) statistical program STATS. The period of record used was from 1967 through 1995 which is the period at which the Missouri River mainstem reservoir system was considered fully operational with all reservoirs up to their normal operating pools. Duration curves were derived separately for the months of April, May, and June, seasonal curves for April through June combined, and annual curves using data for all twelve months of the year. Due to the degradation that has occured on the Missouri River downstream of Gavins Point Dam, the tailwater elevations for the period of record could not be used. To derive the tailwater elevations for existing conditions, the most recent tailwater rating curve developed in 1995 was applied to Gavins Point Dam outflows for the period of record. The final duration curves for pool elevation, tailwater elevation and reservoir outflow are shown in Tables 1 through 3 and Figures 1 through 3, respectively.

GAVINS POINT DAM POOL DURATIONS					
PERCENT OF TIME	**APRIL**	**MAY**	**JUNE**	**APR-JUN**	**ANNUAL**
EXCEEDED	ELEV	ELEV	ELEV	ELEV	ELEV
0.01	1208.23	1209.48	1208.80	1209.48	1209.39
0.05	1208.23	1209.48	1208.80	1209.32	1209.08
0.10	1208.23	1209.48	1208.80	1208.78	1208.95
0.20	1208.21	1209.25	1208.50	1208.46	1208.85
0.50	1208.08	1208.24	1208.08	1208.11	1208.71
1.00	1207.85	1207.91	1207.83	1207.86	1208.60
2.00	1207.65	1207.31	1207.46	1207.50	1208.47
5.00	1207.01	1206.79	1207.02	1206.95	1208.30
10.00	1206.34	1206.38	1206.65	1206.50	1208.17
15.00	1206.12	1206.20	1206.47	1206.28	1208.08
20.00	1205.92	1206.06	1206.30	1206.12	1208.00
30.00	1205.65	1205.77	1206.06	1205.82	1207.82
40.00	1205.44	1205.59	1205.79	1205.60	1207.55
50.00	1205.31	1205.45	1205.59	1205.43	1207.09
60.00	1205.22	1205.33	1205.40	1205.30	1206.48
70.00	1205.11	1205.20	1205.26	1205.19	1205.92
80.00	1204.99	1205.08	1205.14	1205.07	1205.42
85.00	1204.90	1205.01	1205.07	1205.00	1205.25
90.00	1204.77	1204.90	1204.99	1204.89	1205.10
95.00	1204.56	1204.76	1204.88	1204.73	1204.88
98.00	1204.29	1204.59	1204.74	1204.53	1204.59
99.00	1204.09	1204.50	1204.62	1204.37	1204.35
99.50	1203.71	1204.43	1204.52	1204.21	1203.97
99.80	1202.81	1204.38	1204.42	1203.85	1201.01
99.90	1201.98	1204.35	1204.40	1203.27	1200.51
99.95	1201.88	1204.32	1204.39	1202.30	1200.20
99.99	1201.72	1204.28	1204.37	1201.80	1199.96

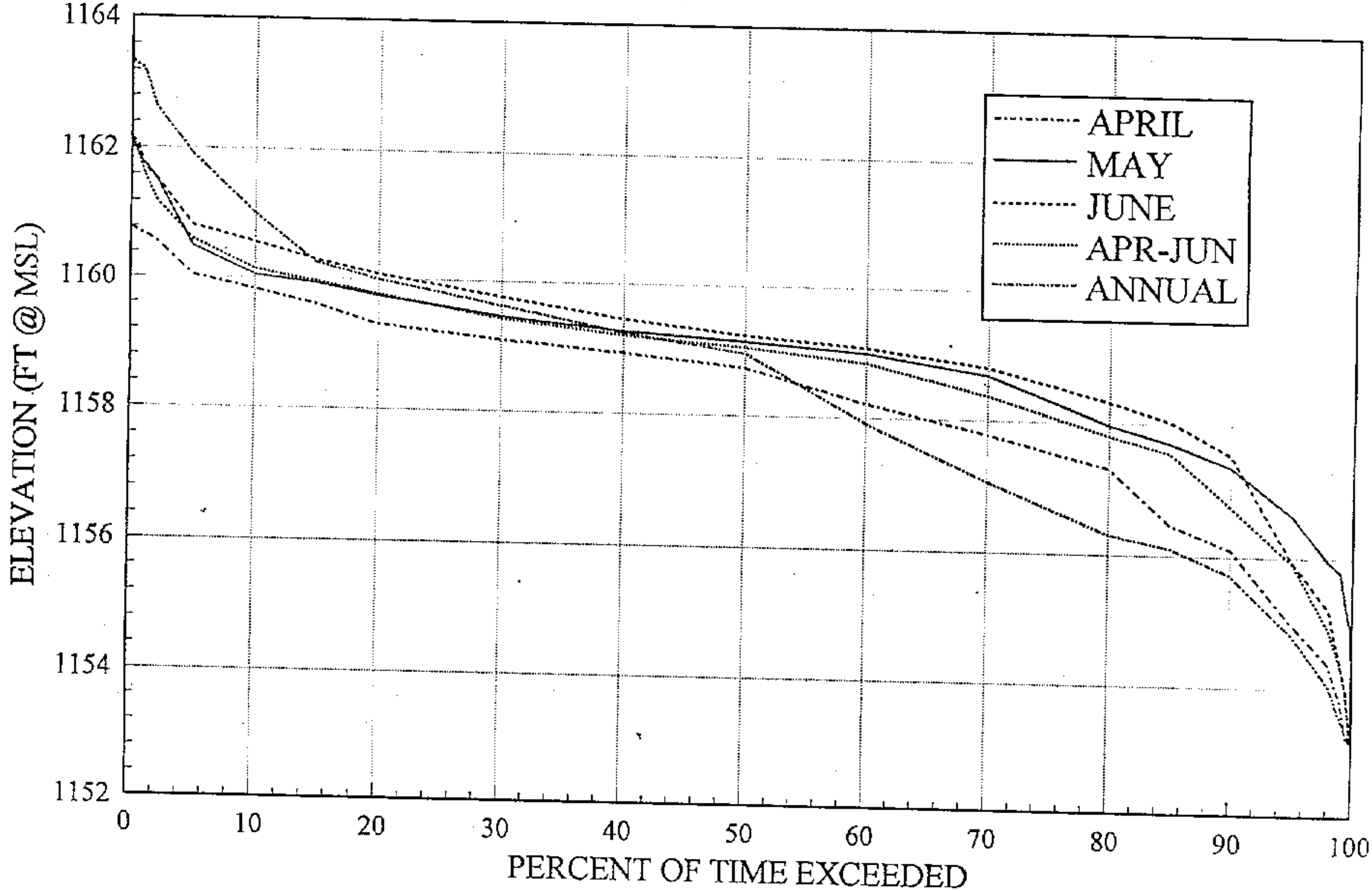
GAVINS POINT DAM TAILWATER DURATIONS					
PERCENT TIME EXCEEDED	APRIL ELEV	MAY ELEV	JUNE ELEV	APR-JUN ELEV	ANNUAL ELEV
0.01	1160.78	1162.13	1162.13	1162.13	1163.39
0.05	1160.78	1162.13	1162.13	1162.13	1163.37
0.10	1160.78	1162.13	1162.13	1162.11	1163.36
0.20	1160.78	1162.08	1162.12	1162.06	1163.33
0.50	1160.74	1161.93	1162.06	1161.91	1163.28
1.00	1160.68	1161.76	1161.73	1161.62	1163.22
2.00	1160.59	1161.54	1161.55	1161.22	1162.63
5.00	1160.05	1160.50	1160.83	1160.61	1161.91
10.00	1159.83	1160.06	1160.58	1160.14	1161.03
15.00	1159.60	1159.93	1160.32	1159.96	1160.27
20.00	1159.30	1159.75	1160.09	1159.78	1160.01
30.00	1159.09	1159.45	1159.76	1159.42	1159.62
40.00	1158.93	1159.26	1159.45	1159.20	1159.24
50.00	1158.74	1159.14	1159.23	1159.05	1158.96
60.00	1158.23	1158.99	1159.07	1158.85	1157.92
70.00	1157.79	1158.69	1158.82	1158.39	1157.07
80.00	1157.30	1157.96	1158.32	1157.81	1156.31
85.00	1156.48	1157.70	1158.04	1157.56	1156.11
90.00	1156.10	1157.35	1157.53	1156.76	1155.72
95.00	1154.99	1156.65	1155.95	1155.93	1154.83
98.00	1154.39	1155.94	1155.24	1154.92	1154.07
99.00	1153.84	1155.78	1154.39	1154.38	1153.56
99.50	1153.26	1155.24	1154.00	1153.93	1153.31
99.80	1153.20	1154.94	1153.29	1153.25	1153.24
99.90	1153.16	1154.49	1153.24	1153.21	1153.20
99.95	1153.13	1154.46	1153.19	1153.17	1153.16
99.99	1153.09	1154.41	1153.12	1153.10	1153.11

GAVINS POINT DAM RESERVOIR OUTFLOW DURATIONS					
PERCENT OF TIME EXCEEDED	APRIL OUTFLOW	MAY OUTFLOW	JUNE OUTFLOW	APR-JUN OUTFLOW	ANNUAL OUTFLOW
0.01	40100	50000	50000	50000	61100
0.05	40100	50000	50000	50000	61002
0.10	40100	50000	50000	50000	60893
0.20	40098	50000	50000	50000	60733
0.50	40084	48195	50000	47942	60428
1.00	40063	47002	46885	46555	60108
2.00	40029	45838	46420	42221	54177
5.00	35091	38724	41022	40186	48399
10.00	34000	35097	40000	35712	42210
15.00	32864	34415	36873	34687	36866
20.00	31869	33750	35452	33938	35105
30.00	30091	32426	34099	32320	33245
40.00	29103	31466	32523	31095	31278
50.00	28158	30693	31264	29975	29380
60.00	26123	29688	30137	28746	24151
70.00	23369	27942	28587	26625	20993
80.00	21347	24142	25879	23484	17490
85.00	18449	22889	24693	22264	16537
90.00	16529	21221	22156	19438	14879
95.00	12789	18775	15722	15579	12050
98.00	11177	15683	13736	12484	9473
99.00	8783	14700	11182	11116	7789
99.50	6865	13856	9327	9103	7028
99.80	6660	12541	6959	6847	6795
99.90	6542	11943	6783	6686	6661
99.95	6447	11609	6640	6558	6550
99.99	6286	11018	6398	6346	6353



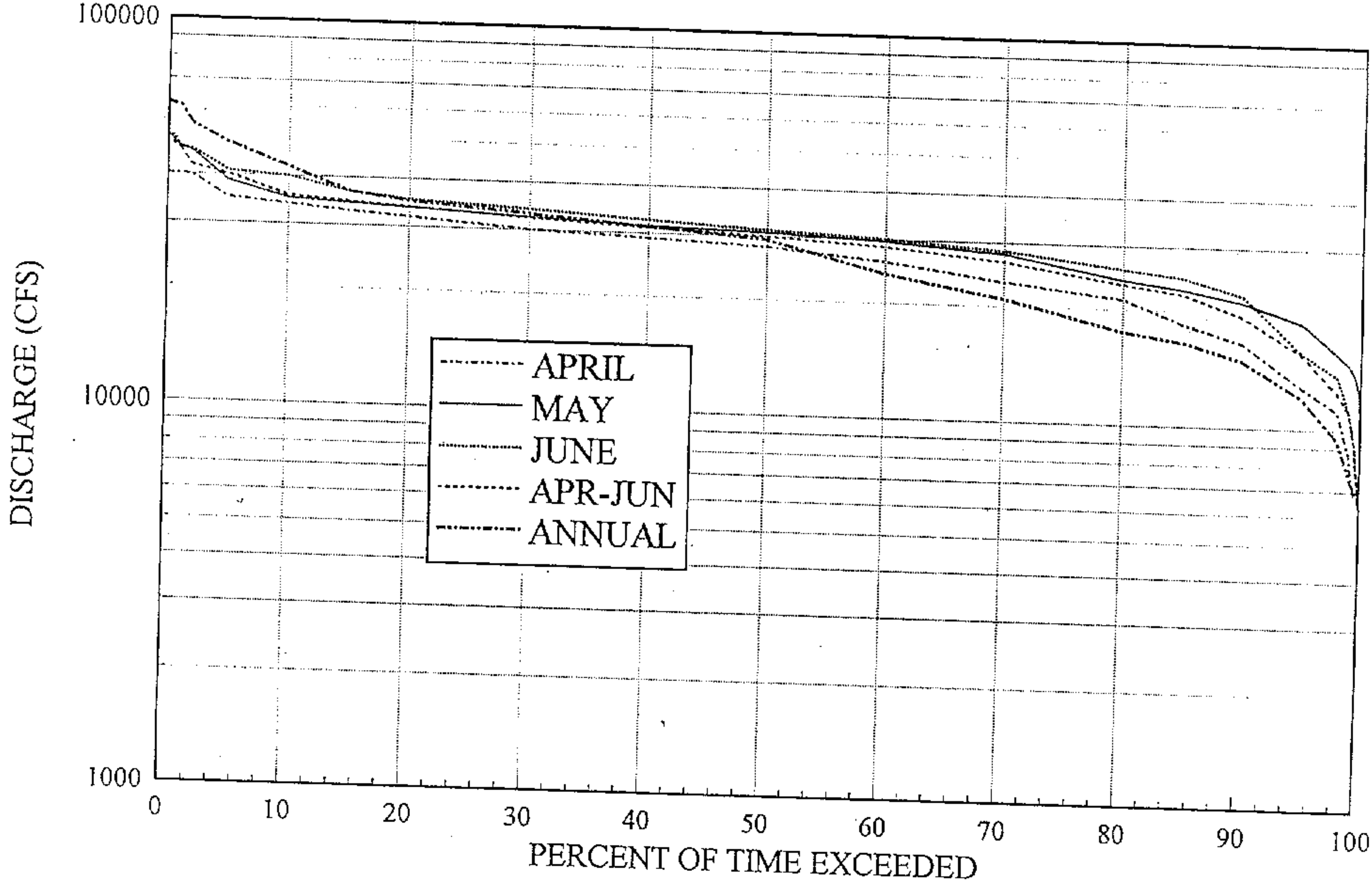
PERIOD OF RECORD: 1967-1995

GAVINS POINT DAM
TAILWATER ELEVATION DURATION



PERIOD OF RECORD: 1967-1995
ELEVATIONS DERIVED FROM 1995 RATING CURVE

GAVINS POINT DAM
RESERVOIR OUTFLOW DURATION



PERIOD OF RECORD: 1967-1995

FISH PASSAGE STUDY - GAVINS POINT DAM
TABLE OF REFERENCES

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Corps Program Aids Migratory Fish	Dawn M. Edwards	Portland Dist.	Sep 92		salmon	Columbia River	PD

DOCUMENT	AUTHOR, CONTACT PERSON	AGENCY, PUBLICATION	DATE	FACILITY TYPE	FISH SPECIES, etc.	PROJECT/STREAM	REFERENCE LOCATION
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