Design and Operation of Fish Ladders

Dick Quinn
US Fish and Wildlife Service, retired

And in 10 Minutes – usually 8 hours in my training class

Fish Passage Facilities Used in Small Rivers

FISH PASSAGE FACILITIES

CHUTE TYPE FISHWAYS

- Denil Fishways (includes steeppass)

POOL TYPE FISHWAYS

- Vertical Slot Fishways
- Pool and Weir Fishways
- Ice Harbor Fishways

MECHANICAL DEVICES

- Fish Lifts (Elevators) or Fish Locks
- Navigation Locks

BREACHES

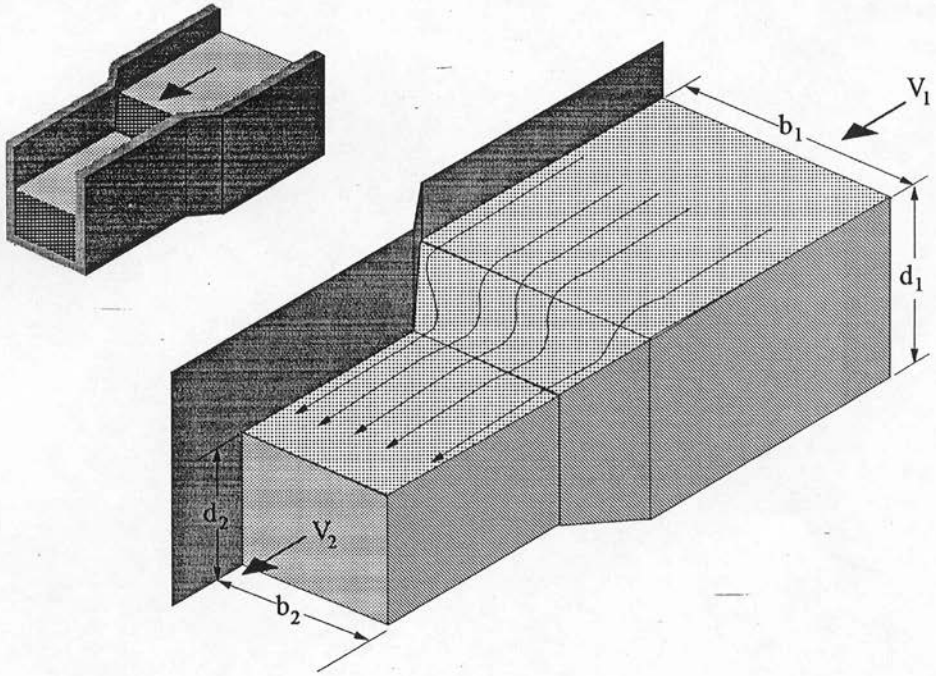
- Notches
- Partial or Complete Breaches

OTHER

Hydrology

Very important
Trust us fishway designers -
Older MA DMF P & W fishways very specific design flows

Conservation of Mass - Continuity



$$Q = V\,A$$

$$\rho\, V_1 A_1 = \rho V_2 A_2$$

where: $A_1 = b_1 d_1$
and $A_2 = b_2 d_2$

b = channel width (m of ft).
d = water depth perpendicular to channel bottom (m or ft).
Q = discharge (m^3/s or ft^3/s).
V = average velocity (m/s or ft/s).
ρ = fluid density (for water 1000 kg/m^3 or 62.4 lbm/ft^3).

NOTE: the rapidly varied part of the flow is caused by the sudden change in the cross-sectional area of the channel.

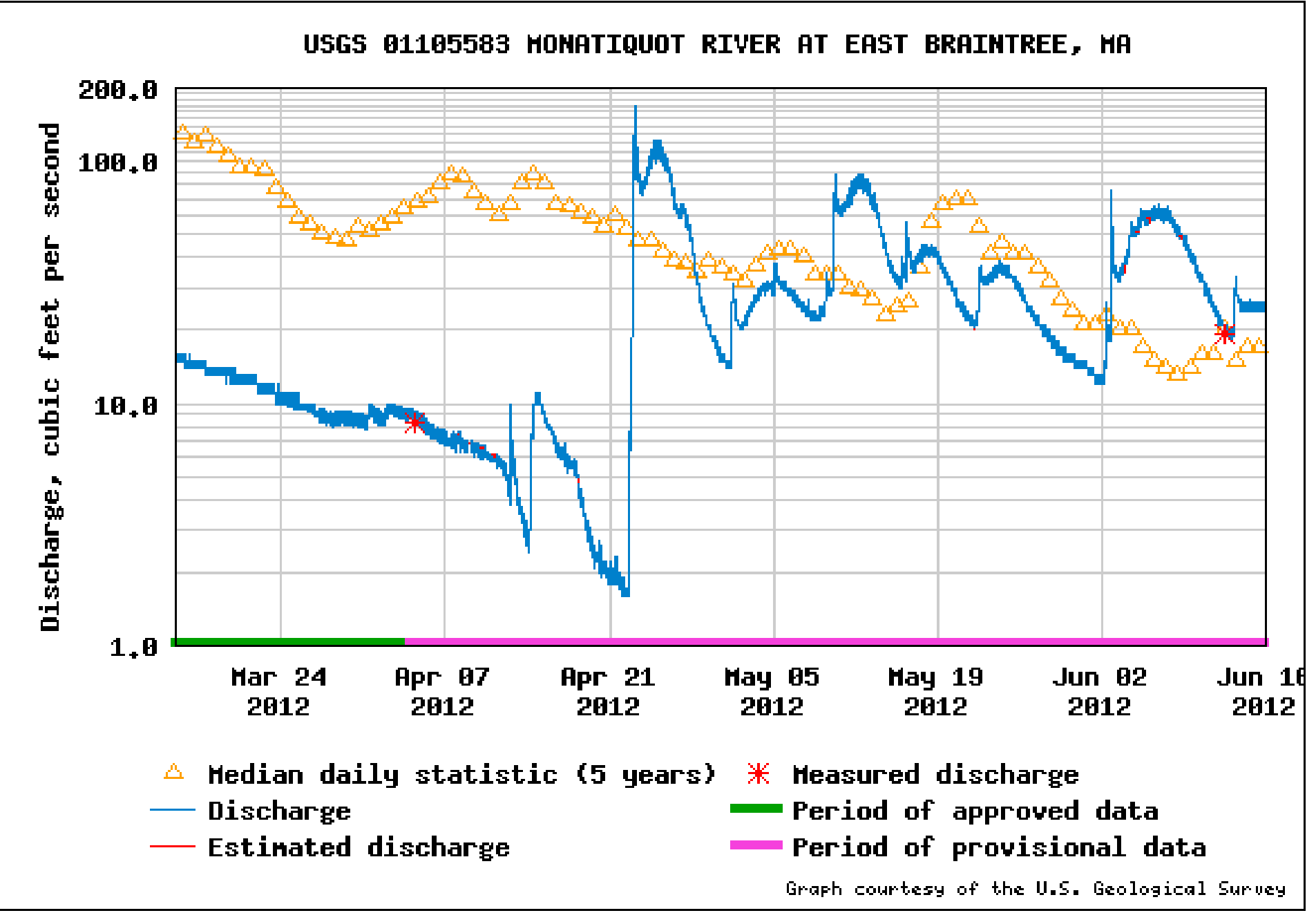
			Stage	Flow	Avg Q
WEYMOUTH BACK RIVER BASIN					
01105600	OLD SWAMP RIVER NEAR SOUTH WEYMOUTH, MA	10/22 19:00 EDT	2.67	3.4	2.80
01105606	WHITMANS POND, WHITMANS POND DAM AT E. WEYMOUTH,MA	10/22 14:15 EDT	72.57	7.2	4.50
01105607	WHITMANS POND FLOOD BY-PASS AT EAST WEYMOUTH, MA	10/22 14:15 EDT	65.33	--	---
01105608	WHITMANS POND FISH LADDER AT EAST WEYMOUTH, MA	10/22 18:15 EDT	31.57	5.7	3.00
SOUTH COASTAL RIVER BASIN					
01105730	INDIAN HEAD RIVER AT HANOVER, MA	10/22 19:30 EDT	1.75	23	23.0
01105870	JONES RIVER AT KINGSTON, MA	10/22 19:15 EDT	3.06	15	17.0
01105876	EEL RIVER AT RT 3A NEAR PLYMOUTH, MA	10/22 19:15 EDT	4.05	14	32.0
CAPE COD RIVER BASIN					
01105880	HERRING RIVER AT NORTH HARWICH, MA	10/22 18:45 EDT	1.90	2.3	6.60
011058837	QUASHNET RIVER AT WAQUOIT VILLAGE, MA	10/22 19:15 EDT	1.95	15	13.0
BUZZARDS BAY RIVER BASIN					
01105933	PASKAMANSET RIVER NEAR SOUTH DARTMOUTH, MA	10/22 16:00 EDT	8.50	4.2	22.0
TAUNTON RIVER BASIN					
01108000	TAUNTON RIVER NEAR BRIDGEWATER, MA	10/22 18:45 EDT	3.57	190	121
01108410	MILL RIVER AT SPRING STREET AT TAUNTON, MA	10/22 19:00 EDT	3.30	13	37.0
01109000	WADING RIVER NEAR NORTON, MA	10/22 19:15 EDT	5.46	20	17.0
01109060	THREEMILE RIVER AT NORTH DIGHTON, MA	10/22 19:15 EDT	2.62	50	48.0

15

9.4

2.58

26

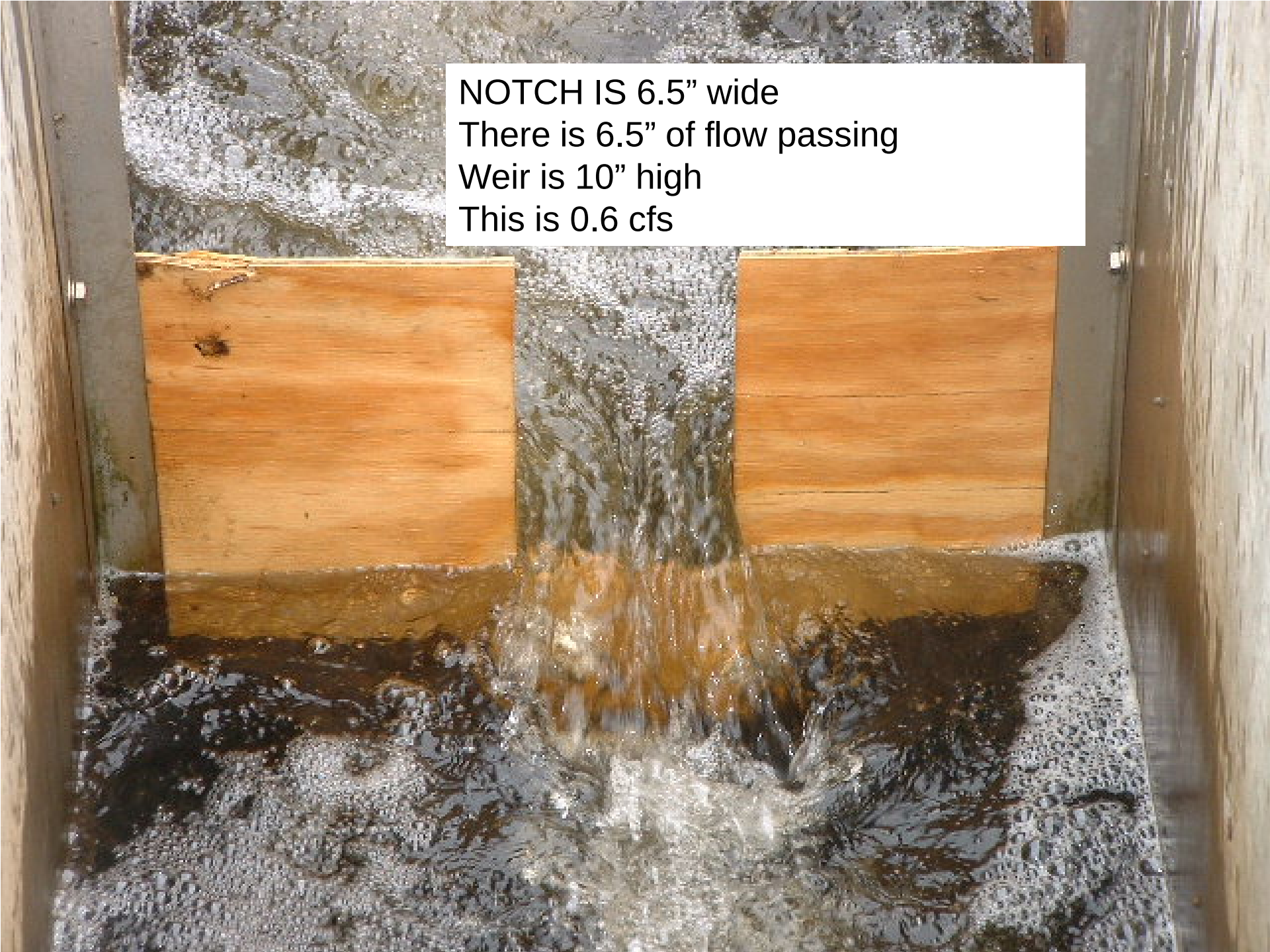

USGS 01105583 MONATIQUOT RIVER AT EAST BRAINTREE, MA
Discharge, cubic feet per second
200.0
100.0
10.0
1.0
Mar 24 2012
Apr 07 2012
Apr 21 2012
May 05 2012
May 19 2012
Jun 02 2012
Median daily statistic (5 years)
Measured discharge
Discharge
Period of approved data
Estimated discharge
Period of provisional data
Graph courtesy of the U.S. Geological Survey

Station: **EAST BRANCH NEPONSET RIVER AT CANTON, MA**
Parameter: STREAM FLOW CFS
Year: 1952-2007
State: MA
County: NORFOLK

ID: 01105500
Statistic: Mean
Latitude: 42:09:16
Longitude: 071:08:47
Elevation: 80.18
Drainage Area: 27.20

Monthly Statistics

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
# Days	1705	1553	1705	1650	1705	1650	1705	1705	1650	1736	1680	1736	20180
Avg Day	68.77	71.16	93.64	90.35	55.90	40.72	19.88	21.24	21.60	31.85	47.41	64.41	52.11
Max Day	641.0	385.0	817.0	516.0	374.0	885.0	368.0	1360	363.0	771.0	486.0	619.0	1360
Min Day	7.20	8.70	17.00	15.00	8.40	2.80	0.600	0.650	0.600	1.70	3.60	5.70	0.600
# Months	55	55	55	55	55	55	55	55	55	56	56	56	55
SDev Month	33.93	28.03	37.12	43.77	27.08	39.46	14.52	28.32	17.34	30.13	29.16	34.96	14.16
Skew Month	0.823	0.307	0.642	0.619	1.11	2.45	1.62	5.21	1.81	2.05	1.38	0.910	-0.302
Min Month	10.62	20.14	40.81	20.73	20.19	8.62	4.46	3.64	4.39	6.42	8.35	9.78	18.65
Max Month	176.6	131.9	176.5	210.0	142.2	185.6	70.48	203.3	76.49	141.8	160.7	159.1	80.99
Exceedences													
1%	275.8	223.0	337.3	311.5	231.9	328.0	113.0	213.6	150.5	223.0	199.8	253.2	250.0
5%	172.0	154.0	204.8	206.0	130.0	122.5	59.00	58.75	77.00	111.4	120.0	156.2	149.0
10%	127.0	126.7	160.0	167.0	101.0	77.00	40.00	35.00	49.00	70.00	94.00	122.0	113.0
20%	95.00	101.0	124.0	128.0	74.00	51.00	26.00	23.00	27.00	39.00	71.00	92.00	80.00
50%	55.00	61.00	77.50	75.00	45.00	24.00	13.00	11.00	12.00	17.00	36.00	51.00	37.00
80%	32.00	36.00	51.00	43.00	28.00	14.00	7.20	5.90	6.70	8.40	17.00	28.00	13.00
90%	26.00	28.00	41.00	32.00	21.00	9.90	5.35	4.65	4.90	6.86	11.00	21.00	8.20
95%	19.00	22.00	35.00	25.50	17.00	7.85	4.40	3.90	3.70	5.60	8.80	14.00	6.10
99%	9.70	16.00	26.00	18.50	13.00	5.50	3.00	2.60	2.60	3.80	6.78	8.70	3.60

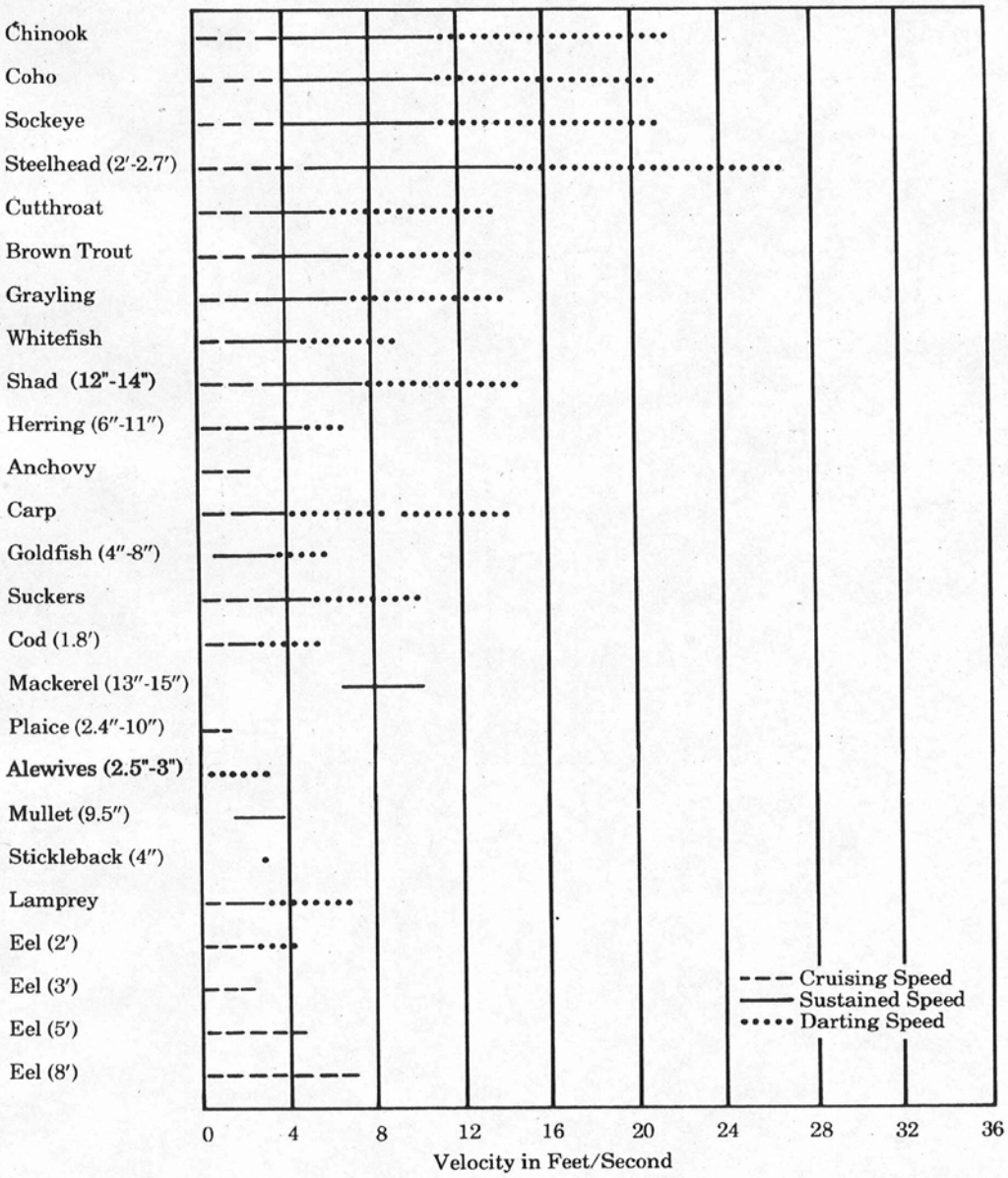

NOTCH IS 6.5” wide
There is 6.5” of flow passing
Weir is 10” high
This is 0.6 cfs

Basic (ENG) Biology

OUR FISH DON’T JUMP

SWIMMING SPEEDS OF ADULT AND JUVENILE FISH

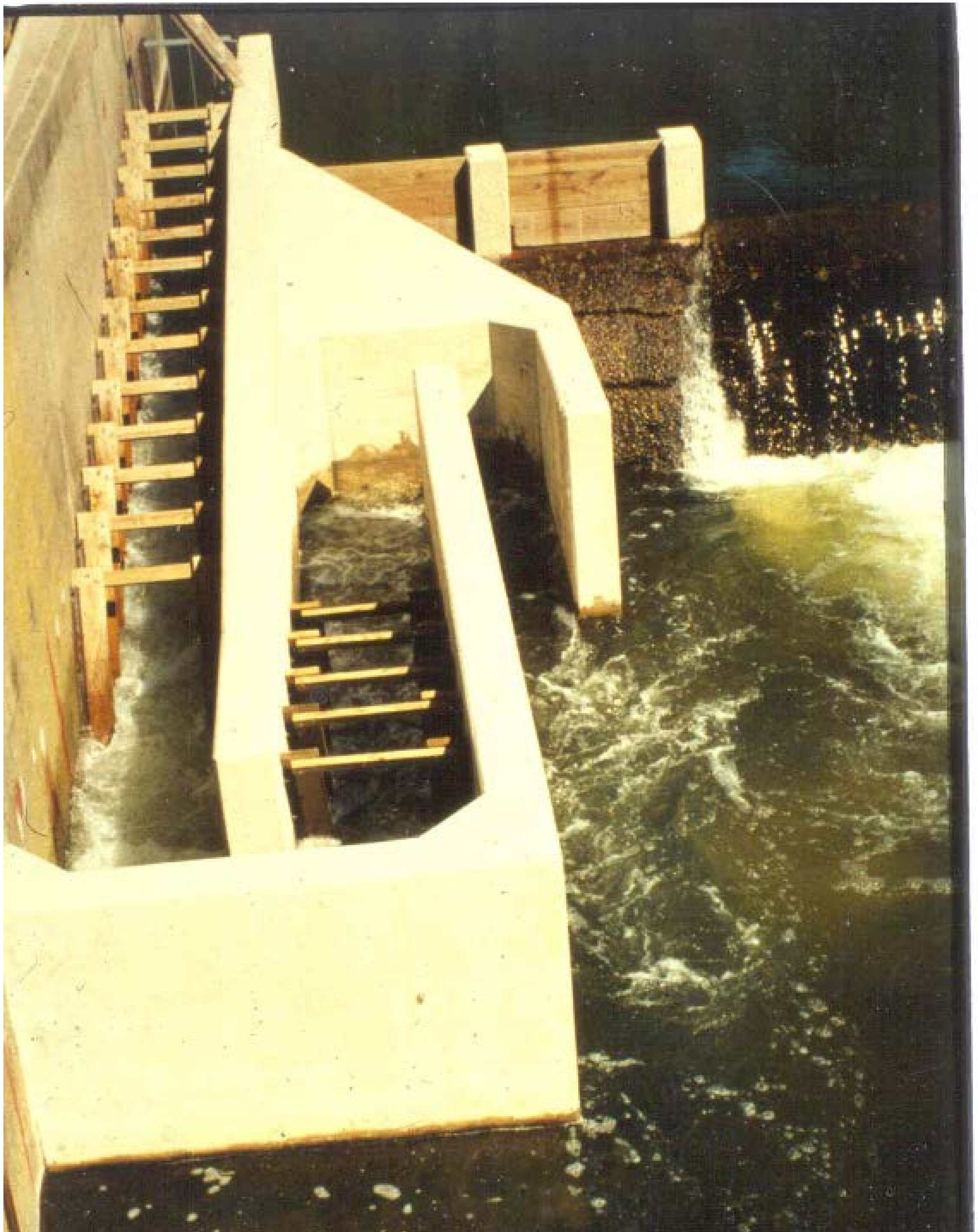
A
Relative Swimming Speeds of Adult Fish



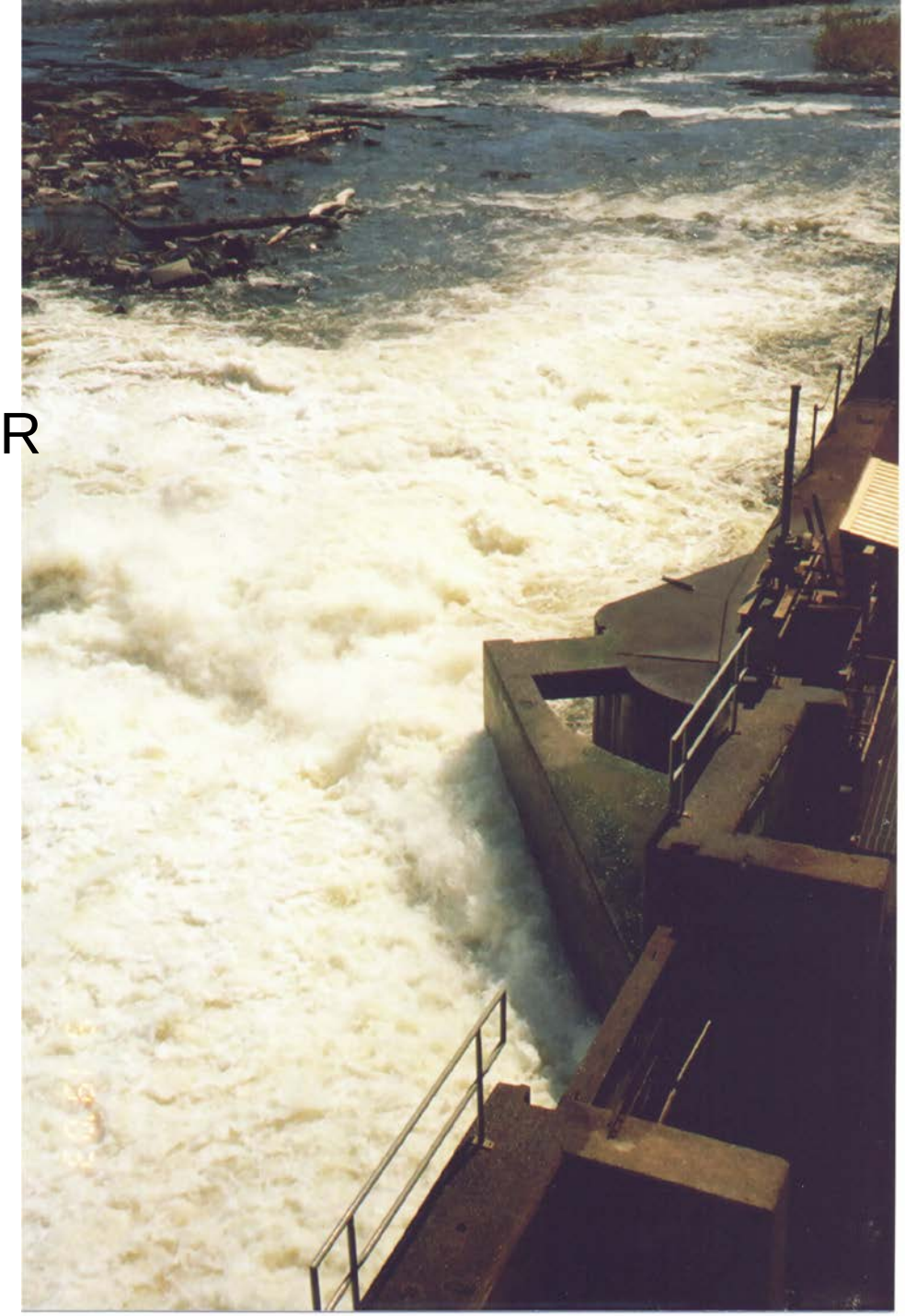
CHUTE TYPE FISHWAYS

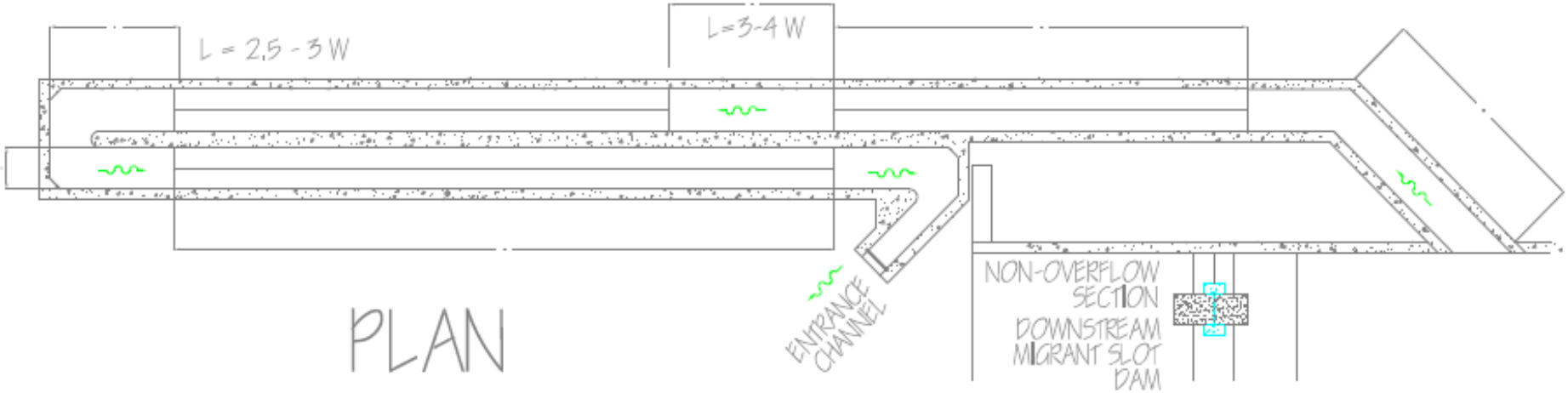
Denil Fishways

(includes Alaskan Steeppasses)

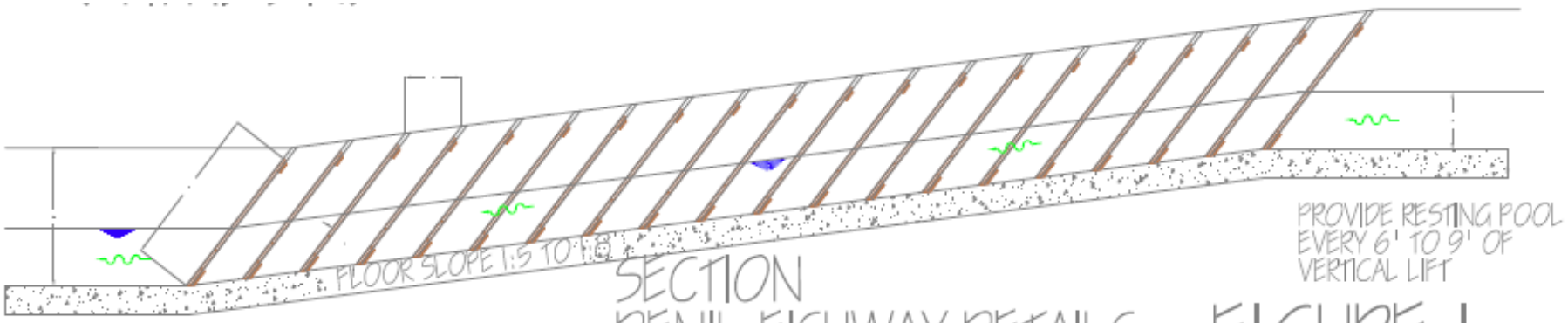


POTTER HILL
PAWCATUCK R
RI



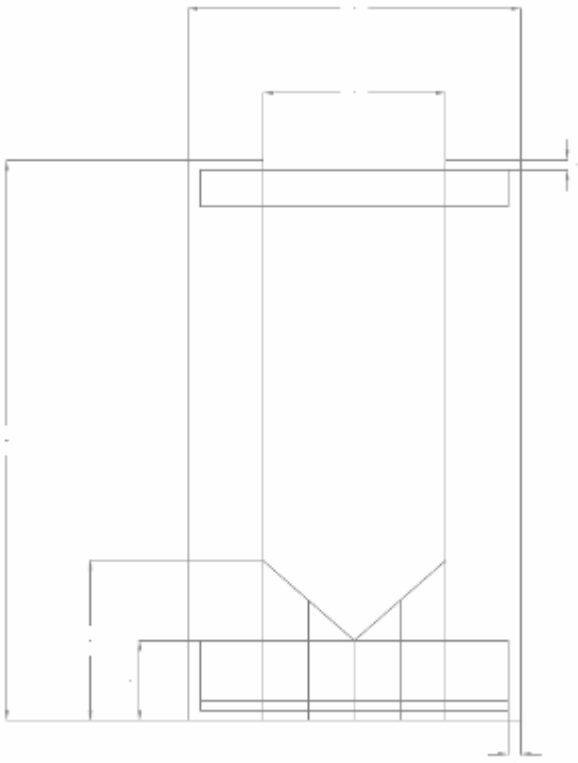


PLAN



SECTION

DENIL FISHWAY DETAILS FIGURE 1



FISHWAY WIDTH = W
(B = 7/12 W) (S = 2/3 W)

FISHWAY WIDTH W	A	B	C	D	BAFFLE SPACING S
4'-0"	4'-3"	2'-4"	2'-0"	1'-0"	2'-6"
3'-6"	3'-9"	2'-0"	1'-9"	10.5"	2'-4"
3'-0"	3'-3"	1'-9"	1'-6"	9"	2'-0"
2'-6"	2'-9"	1'-5.5"	1'-3"	7.5"	1'-8"
2'-0"	2'-3"	1'-2"	1'-0"	6"	1'-4"
1'-6"	1'-9"	10"	1'-0"	6"	1'-0"

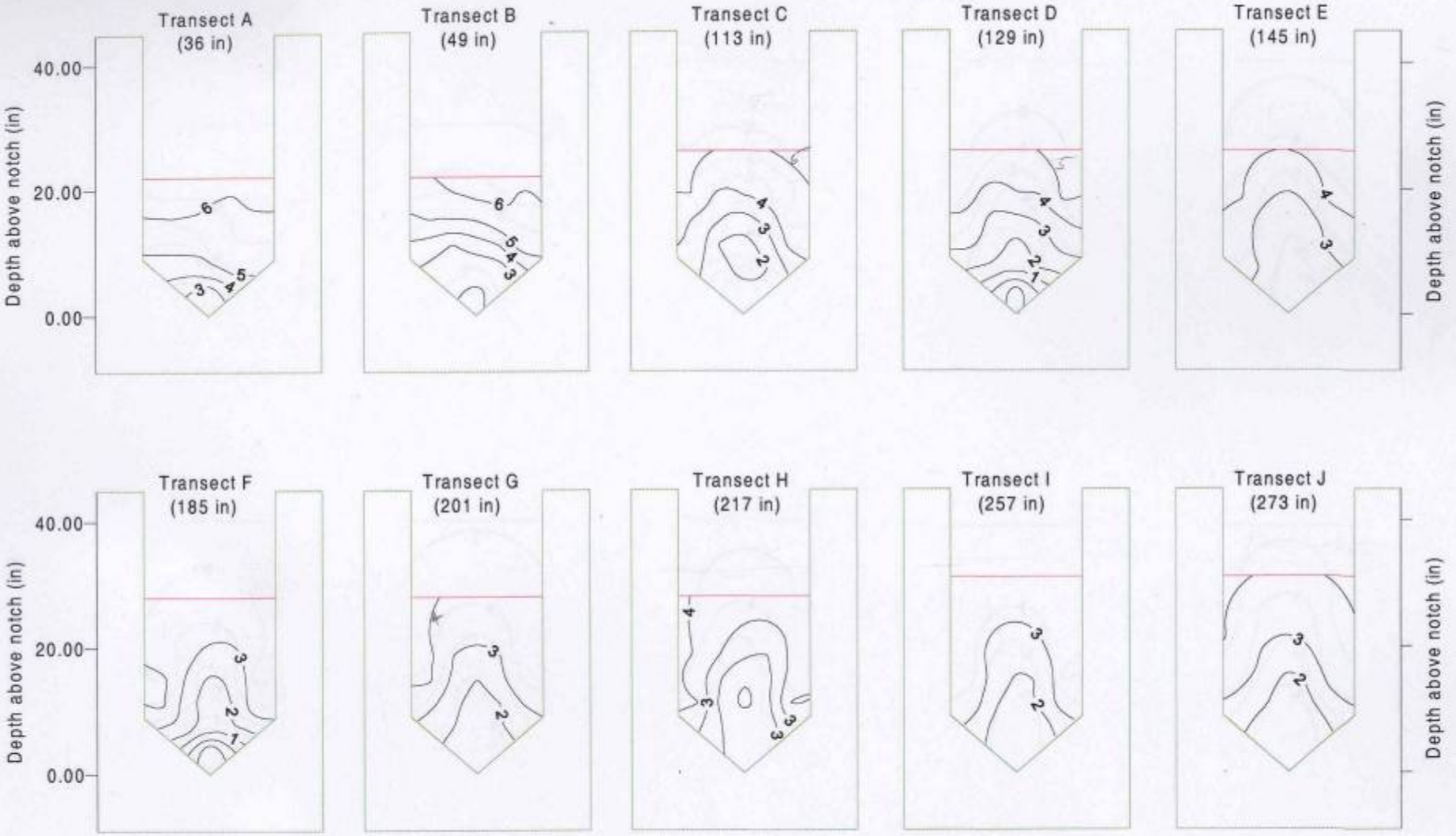
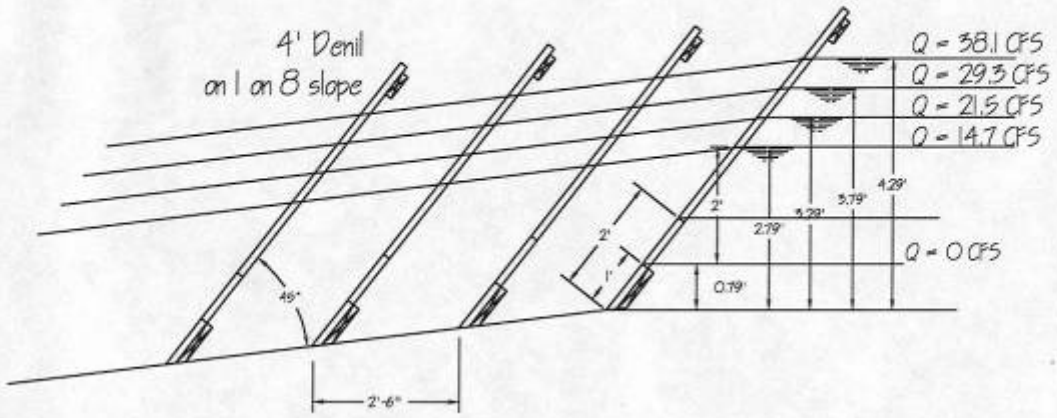
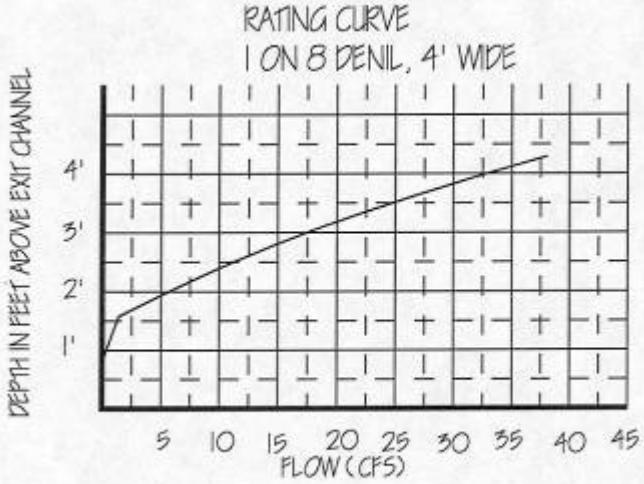
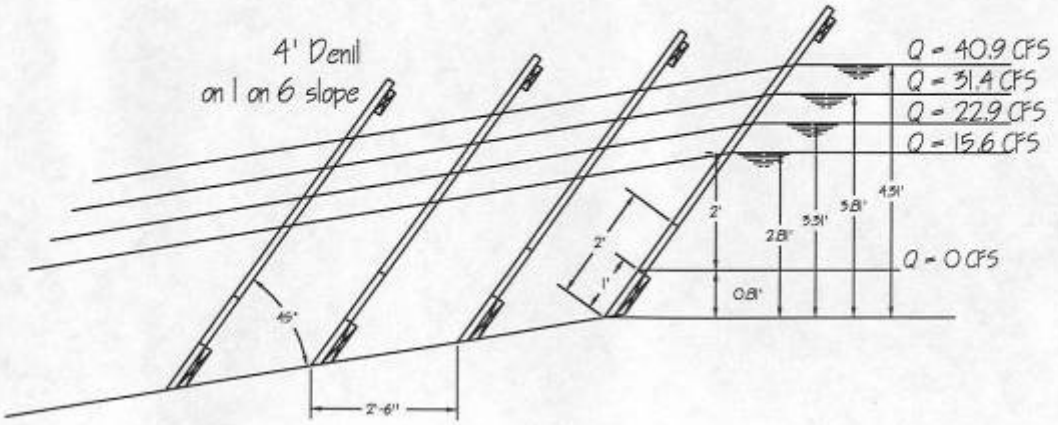
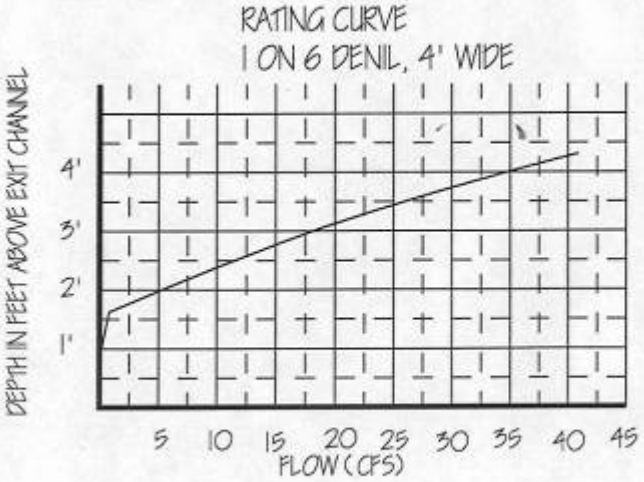


Figure C-3. Velocity profiles at 1 : 8 slope, low headpond (32 in)


4' Denil
on 1 on 8 slope
Q = 38.1 CFS
Q = 29.3 CFS
Q = 21.5 CFS
Q = 14.7 CFS
Q = 0 CFS
2'
2'
1'
2.79'
3.29'
3.79'
4.29'
0.79'
45°
2'-6"


RATING CURVE
1 ON 8 DENIL, 4' WIDE
DEPTH IN FEET ABOVE EXIT CHANNEL
4'
3'
2'
1'
5 10 15 20 25 30 35 40 45
FLOW (CFS)


4' Denil
on 1 on 6 slope
Q = 40.9 CFS
Q = 31.4 CFS
Q = 22.9 CFS
Q = 15.6 CFS
Q = 0 CFS
2'
2'
1'
2.81'
3.31'
3.81'
4.31'
0.81'
45°
2'-6"


RATING CURVE
1 ON 6 DENIL, 4' WIDE
DEPTH IN FEET ABOVE EXIT CHANNEL
4'
3'
2'
1'
5 10 15 20 25 30 35 40 45
FLOW (CFS)

ENTRANCE JET FOR [redacted] FISHWAY

Velocity in Entrance Turn Pool is 1 fps
Normal Depth is 30"
Fishway is 4' wide

To get our 5 fps attraction jet, we need to add boards to the entrance channel stop log slots

We are in a reduced width section - only 30" wide

Using Continuity Equation

$V^{\text{TURN POOL}} \times A^{\text{TURN POOL}} = V^{\text{ENTRANCE}} \times A^{\text{ENTRANCE}}$

1 fps x 4' wide x 30" deep = 5 fps x 30" wide x depth $^{\text{ENTRANCE}}$

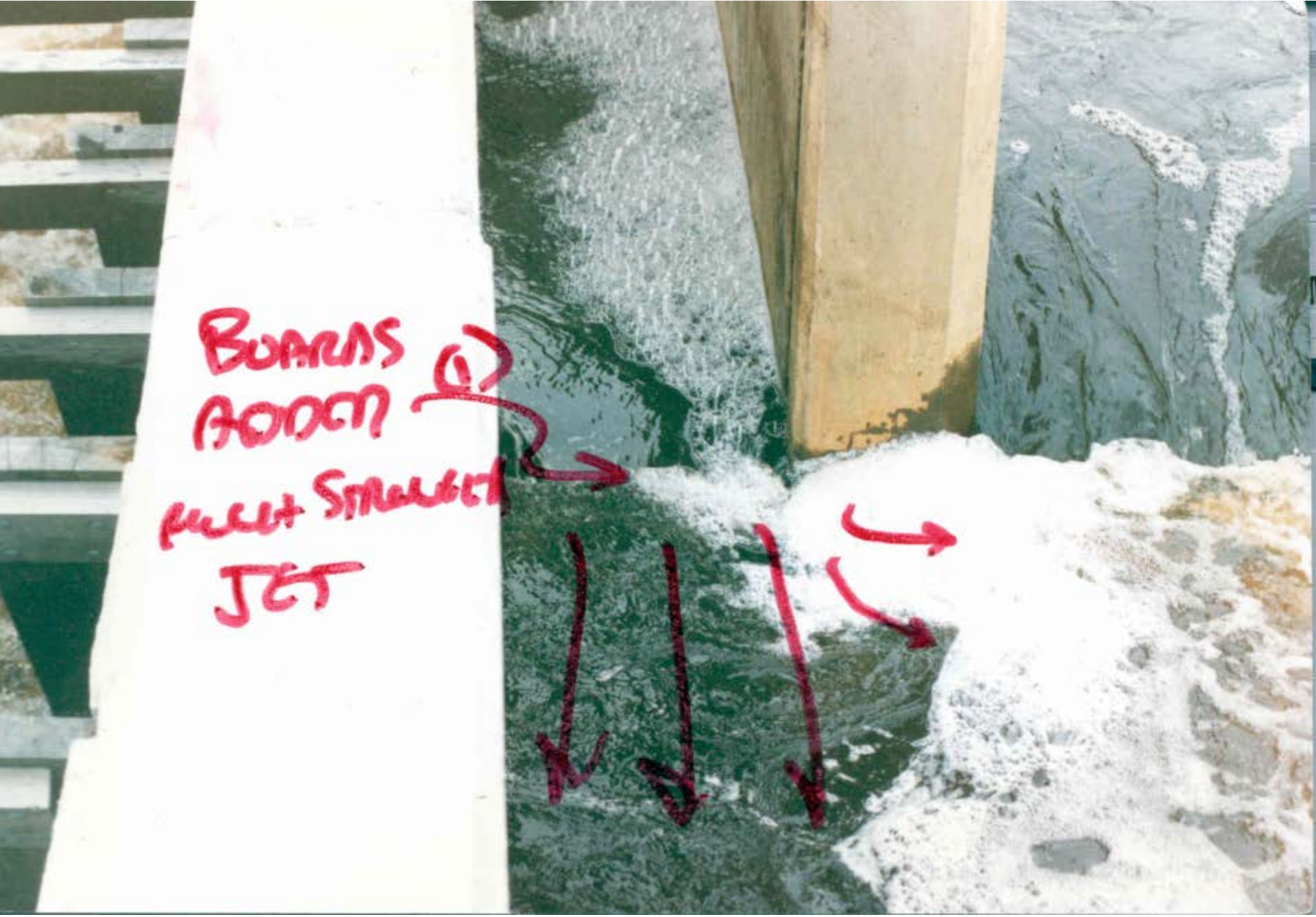
0.8' = depth $^{\text{ENTRANCE}}$

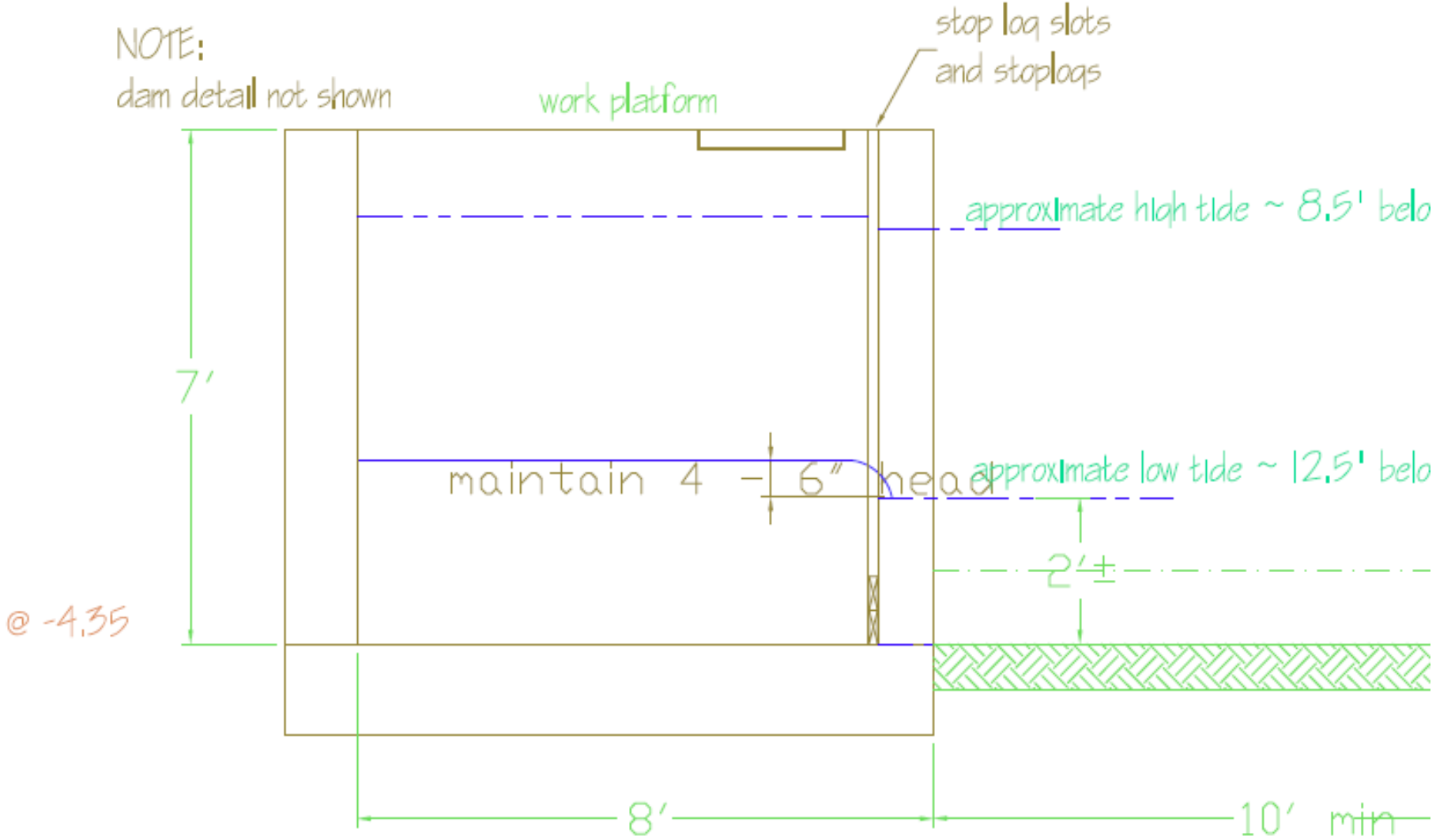
What this says is that we must add enough boards to the entrance channel stop log slots so that there is 0.8' of water passing over the top of the boards, or that theoretically there is at a minimum 20" of boards in the entrance channel stop log slots.

Because we are increasing our velocity to 5 foot per second, we are also introducing a lot of additional head losses. Head losses from a 5 foot per second velocity jet is about 0.4'. Additional head losses are incurred from the entrance channel structure itself.

Obviously, no one wants to calculate out the theoretical water surface elevations for every flow condition that is experienced at the fishway entrance channel. Hence, to simplify operations, we recommend that the difference in water surface elevations between the water surface in the entrance channel and tailwater be between 4" & 6" at low to normal flows.


LO BANOS
OR HERE


BOARDS
ROOM
JET


NOTE:
dam detail not shown
work platform
stop log slots
and stoplogs
approximate high tide ~ 8.5' belo
7'
maintain 4 - 6" head
approximate low tide ~ 12.5' belo
2'±
@ -4.35
8'
10' min

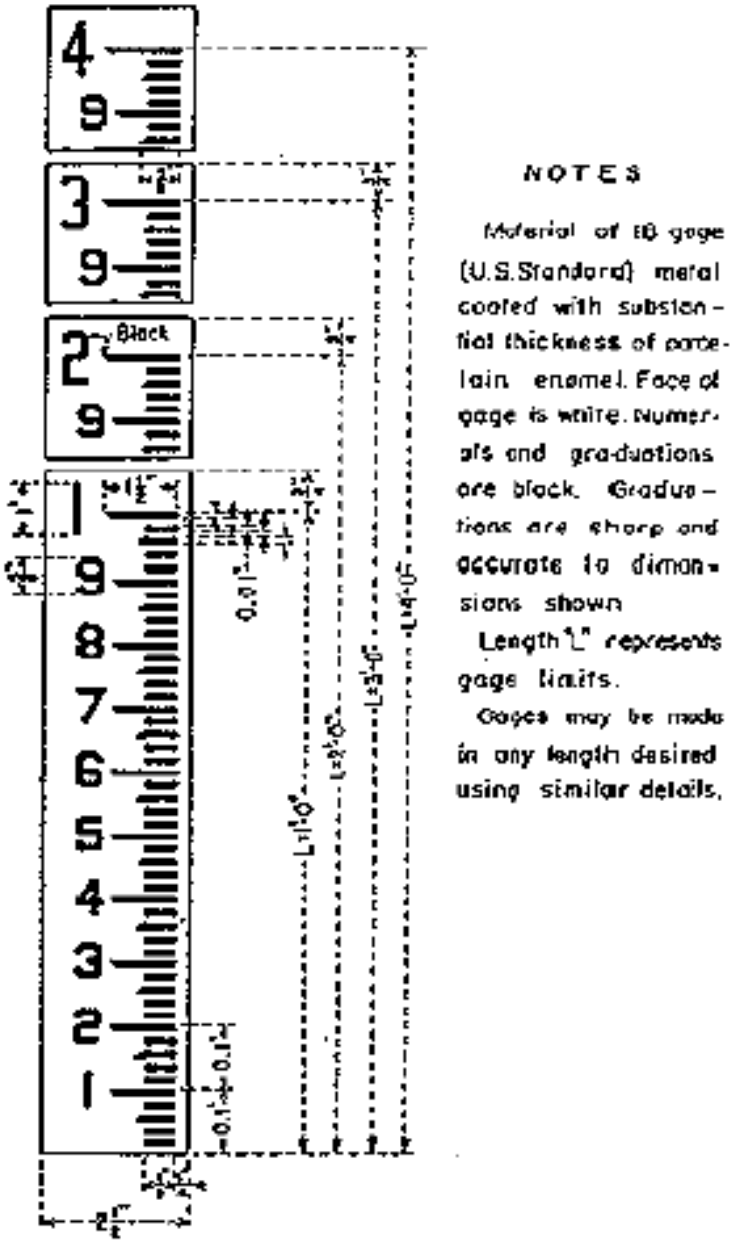


Figure 8-4 -- Typical staff gage for measuring head or water stage.


4


105
104
103
'01 12 7

How Important is the fishway entrance??

Fishway Entrance

The fishway entrance, the critical link to fishway effectiveness, must be designed to attract fish in a timely manner: "No fish in = No fish out" (13,14,132). Adequate attraction flow is the most important element of a successful passage system because it provides the means of getting fish to the entrance and providing them access to the fishway.

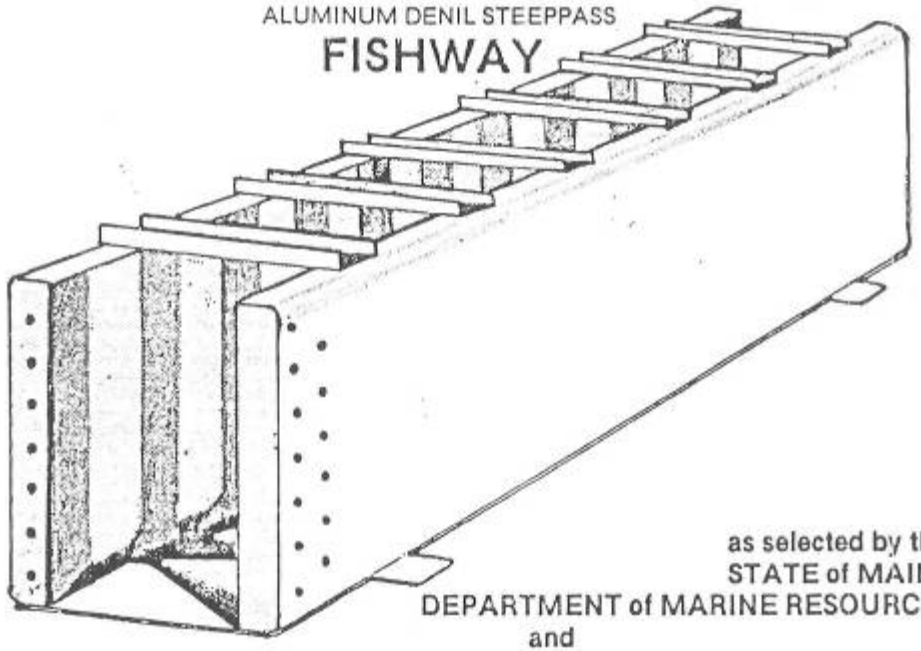
Ken Bates -

Sheepscot

Sheepscot Machine Works
P. O. Box 406
Boothbay, Maine 04537
207-633-2219

ALUMINUM DENIL STEEPPASS

FISHWAY



as selected by the
STATE of MAINE
DEPARTMENT of MARINE RESOURCES
and
DEPARTMENT OF INLAND FISHERIES AND WILDLIFE

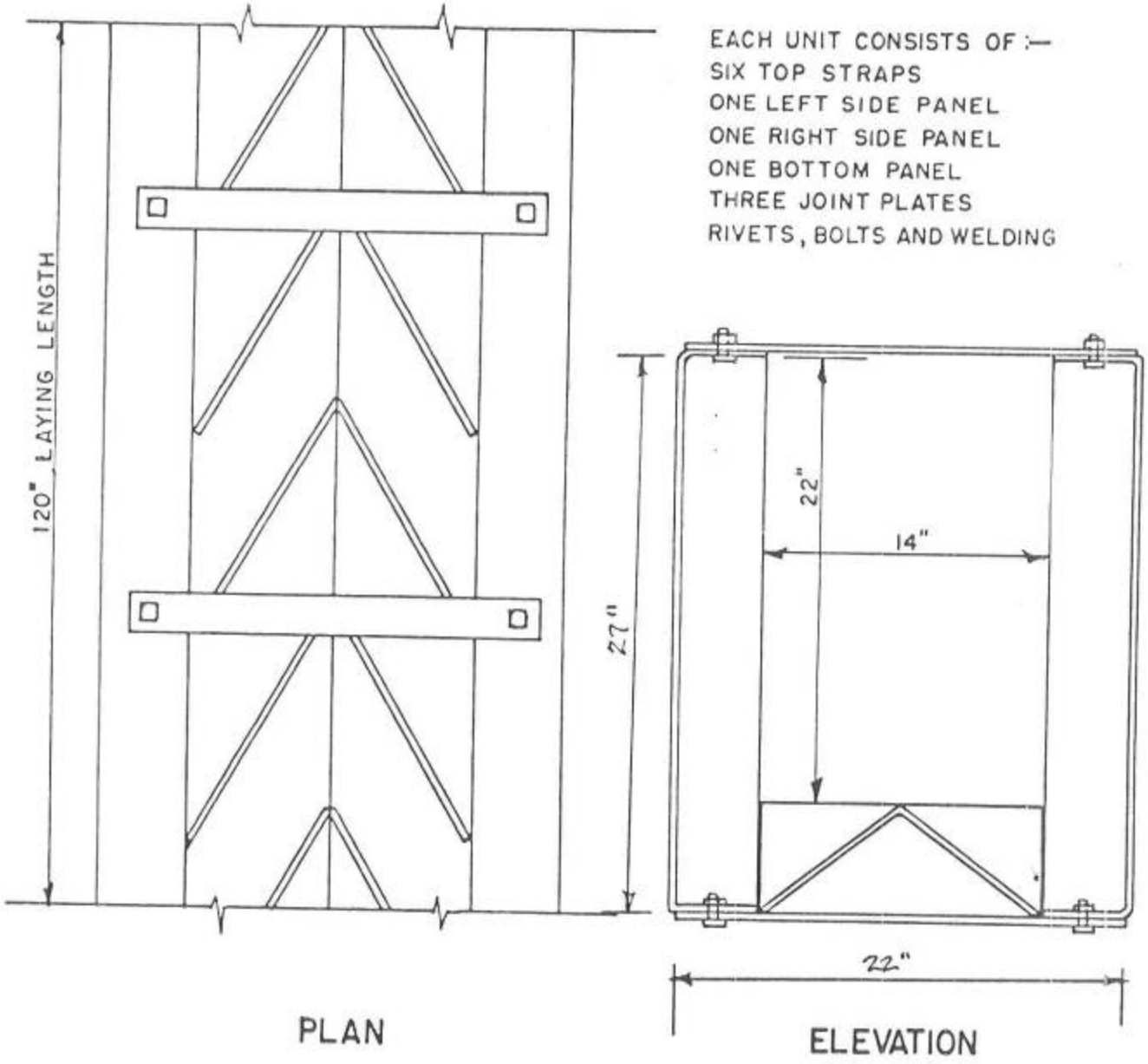
PROVEN ALASKAN DESIGN:

- —SLOWS WATER PASSAGE, ENABLING MORE SPECIES OF FISH TO PASS MORE EASILY. — RECOMMENDED BY FIELD BIOLOGISTS.
- —HAS COMPACT EFFICIENCY (Maine's first installed 10' x 2' unit has replaced 28' x 4' wooden denil fishway.)
- —INCLUDES PROVISIONS FOR BASE MOUNTING AND FOR FOUR-MAN CARRY TO REMOTE LOCATIONS.
- —BOLT-ON, MULTIPLE UNIT JOINING PLATES INCLUDED.

MODULAR CONSTRUCTION OF ALUMINUM PLATE, SUPERIOR IN:

- —COST — estimated 38 - 50% the cost of wood and 17 - 19% the cost of concrete fishways.
- —EASE OF INSTALLATION — Saves time and labor.
- —LONG LASTING DURABILITY.
- —MAINTENANCE FREE.

17



STEEPPASS MODEL A

FIGURE 6

Table 1. Steeppass Model "A" Fishway - Hydraulic Data

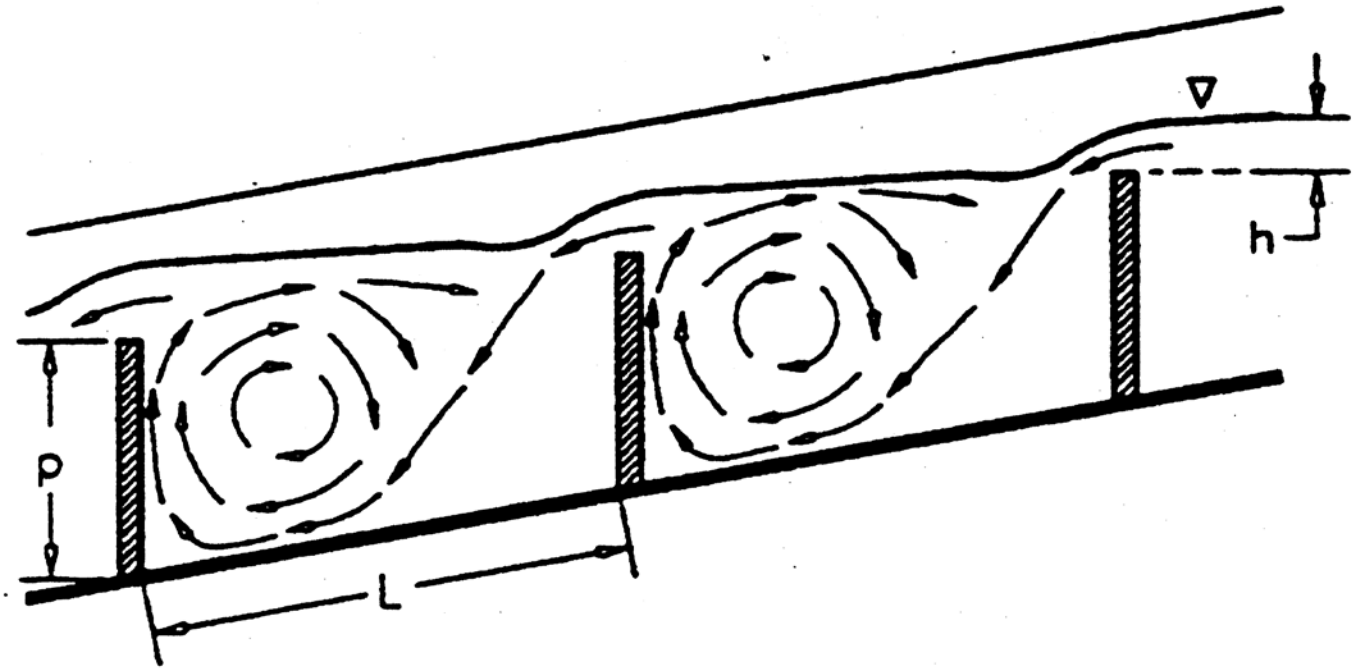
Run No. and Slope	h. Feet	d. Feet	Q. c.f.s.	A. sq. ft.	$\bar{V}$ F.S.	C. (chezy)
1960-1	0.13	0.16	0.66	0.19	3.47	5.0
	0.35	0.76	2.88	0.89	3.23	9.1
0.379 1 on 2.64	0.47	1.07	4.47	1.25	3.57	9.4
1960-2	0.13	0.18	0.66	0.21	3.14	4.5
	0.35	0.81	2.88	0.95	3.03	8.7
0.355	0.41	1.01	3.64	1.18	3.08	8.5
1960-3	0.26	0.54	1.85	0.63	2.94	9.7
	0.35	0.83	2.88	0.97	2.97	8.8
0.329	0.42	1.05	3.78	1.23	3.07	8.7
	0.47	1.17	4.47	1.37	3.26	9.1
1960-4	0.26	0.60	1.85	0.70	2.64	8.8
	0.35	0.87	2.88	1.02	2.82	8.6
0.306 1 on 3.26	0.42	1.05	3.78	1.23	3.07	9.0
	0.47	1.17	4.47	1.37	3.26	9.4
1960-5	0.26	0.59	1.85	0.69	2.68	9.3
	0.35	0.85	2.88	0.99	2.91	9.3
0.283	0.41	1.03	3.64	1.21	3.01	9.2
	0.47	1.18	4.47	1.38	3.24	9.7
1960-6	0.25	0.57	1.74	0.67	2.60	9.4
	0.35	0.86	2.88	1.01	2.85	9.4
0.261	0.41	1.02	3.64	1.19	3.06	9.8
	0.47	1.19	4.47	1.39	3.21	10.0
1960-7	0.26	0.61	1.85	0.71	2.60	9.5
	0.35	0.89	2.88	1.04	2.77	9.3
0.250 1 on 4	0.41	1.08	3.64	1.26	3.89	9.4
	0.47	1.22	4.47	1.43	3.12	9.9
1960-8	0.26	0.61	1.85	0.71	2.60	9.7
	0.35	0.90	2.88	1.05	2.74	9.4
	0.41	1.07	3.64	1.25	2.91	9.6
0.239	0.47	1.36	4.47	1.59	2.81	9.0
1960-9	0.26	0.63	1.85	0.74	2.50	9.7
	0.34	0.94	2.76	1.10	2.50	8.9
0.217 1 on 4.60	0.41	1.11	3.64	1.30	2.80	9.7
	0.47	1.26	4.47	1.47	3.04	10.2

GILBERT STUART

POOL TYPE FISHWAYS

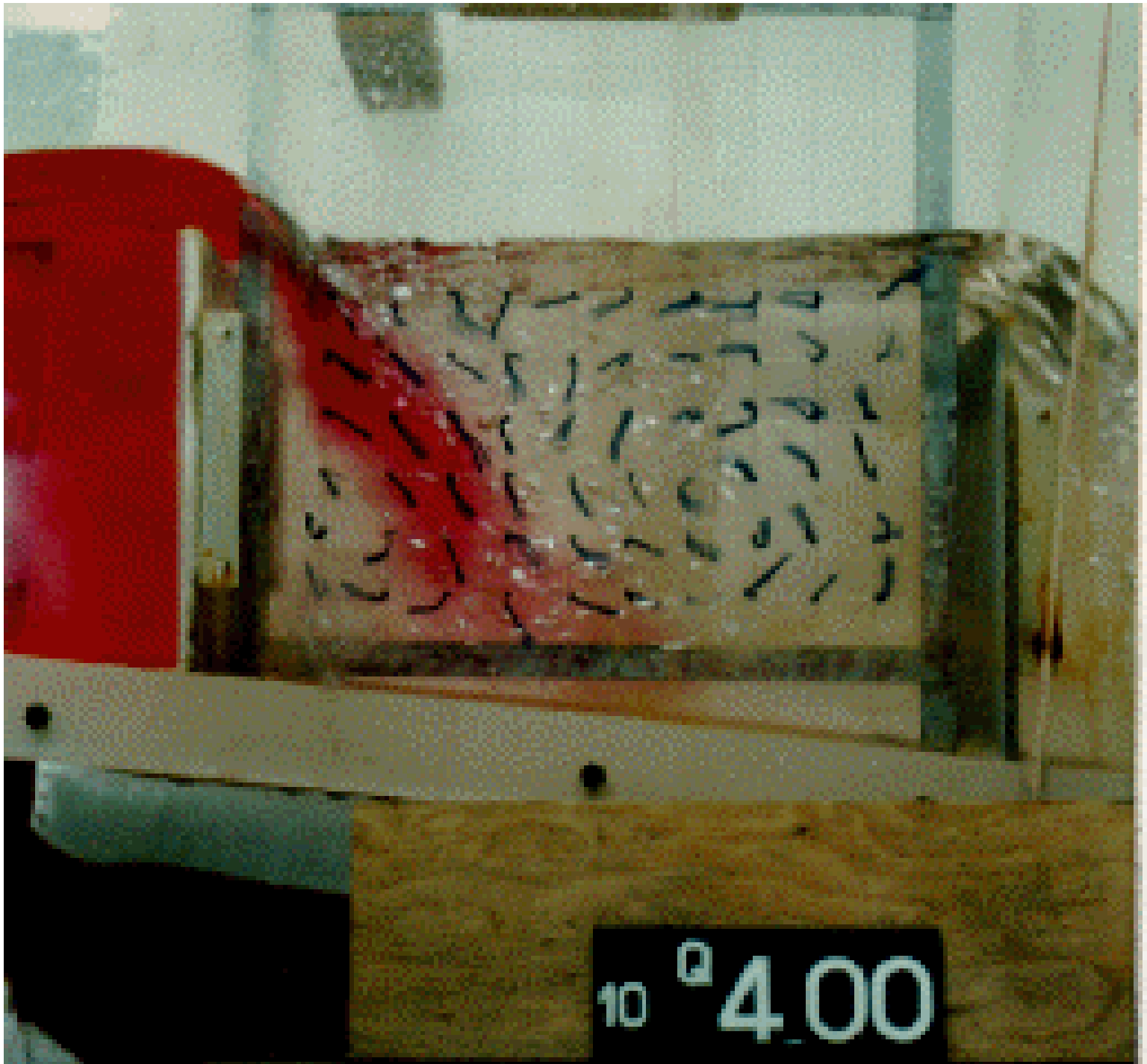
- Ice Harbor Fishways
- Pool & Weir Fishways
- Vertical Slot Fishways

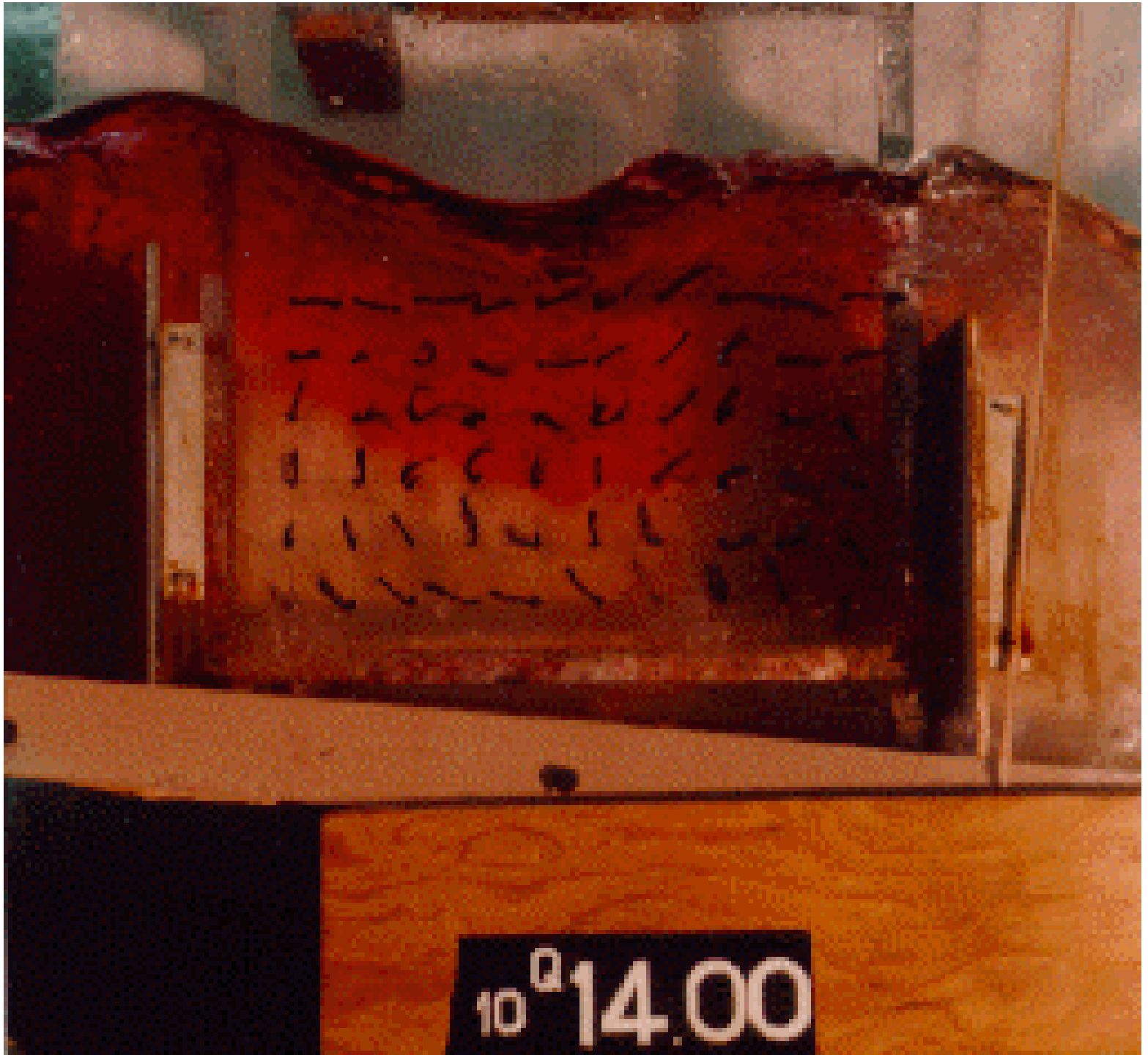
Plunging - Weir Flow



$$Q_p = \frac{Q_w}{Bh^{1.5}\sqrt{g}} = 0.61$$

$$u_m = \sqrt{2gh}$$


10 D 4.00


10 Q 14.00

Plunging Flow; h = 10” +/-

Streaming Flow; h = 14” +/-

Sample Fishway Sizing Computations – FWS Methods

1. Size Fishway Pools to Accommodate Maximum Rate of Fish Traffic Which Occurs During Peak Day

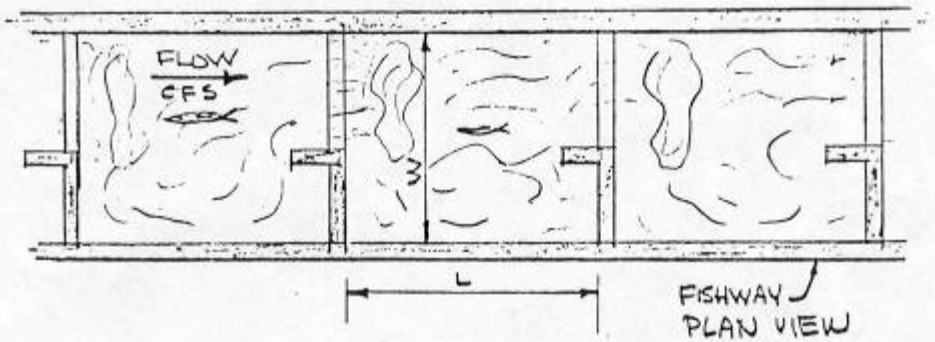
2. Peak Hour/Peak Day Normally Produced by Fisheries Agencies

Approximate Value for Peak Day = Total Run x 10%
Range is 5 to 15%

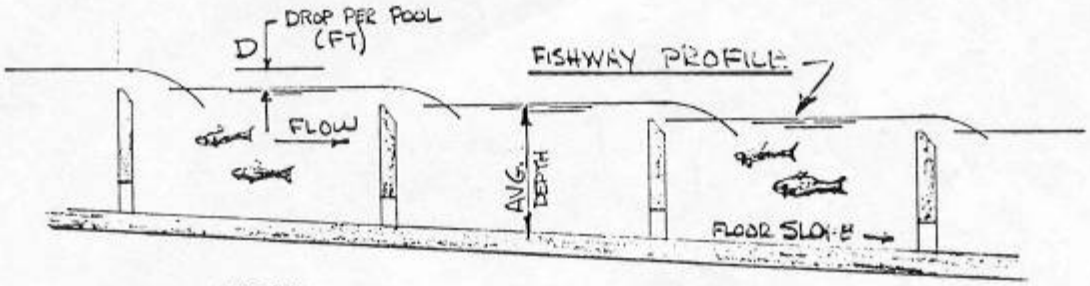
Approximate Value for Peak Hour = Peak Day x 15%

ENERGY DISSIPATION FACTOR

SHOULD NOT EXCEED 4.0 FT. LBS/SECOND PER UNIT POOL VOLUME



FISHWAY PLAN VIEW



E.D.F ?

ENERGY DISSIPATION FACTOR (AKA) POWER DISSIPATION FACTOR → PROVIDES MEASURE OF AVERAGE POOL TURBULENCE

E.D.F = ENERGY DISSIPATION / UNIT POOL VOLUME

= FT-LBS / SECOND PER CUBIC FOOT OF POOL

$$= \frac{\text{FLOW RATE} \times \text{WEIGHT} \times \text{DROP PER POOL}}{\text{POOL VOLUME}}$$

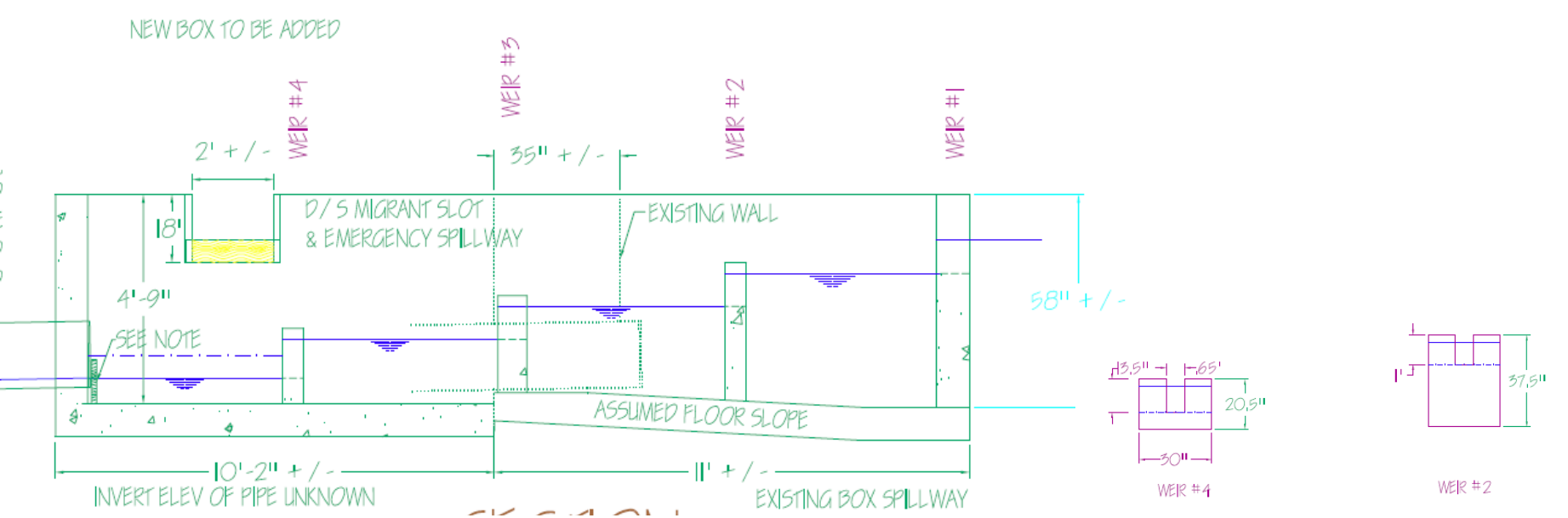
Example: Fishway Flow = 35 CFS

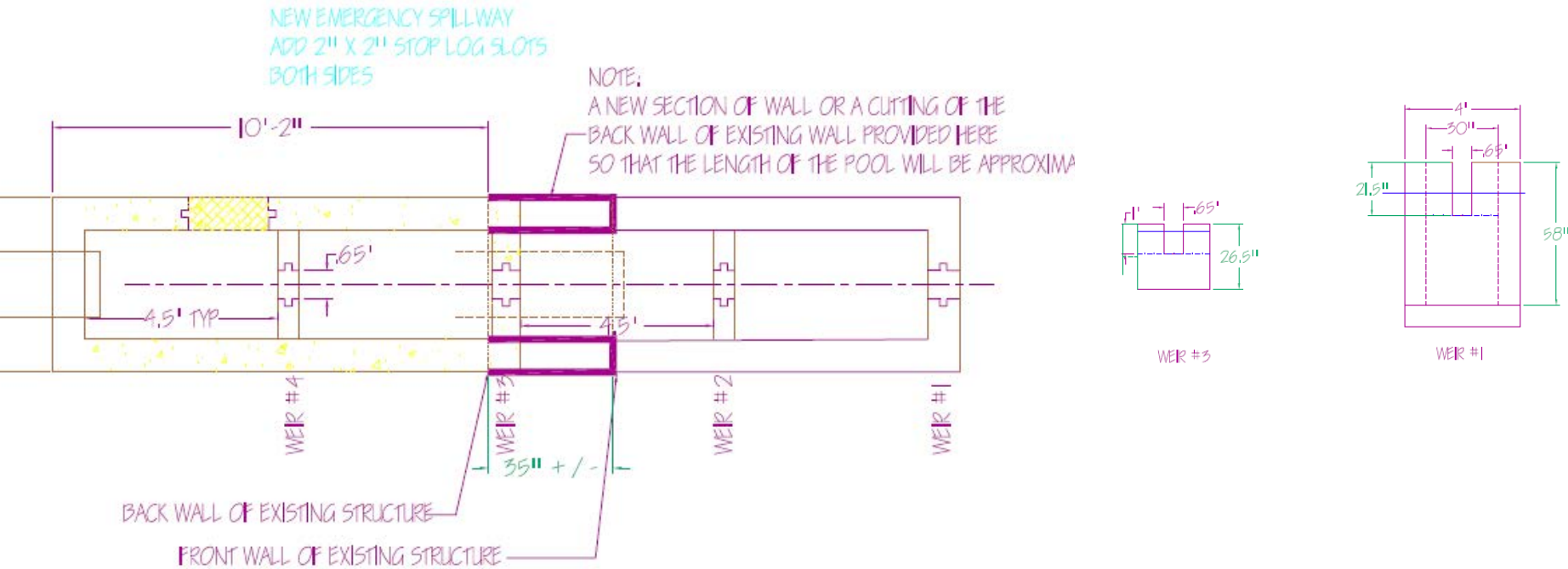
Drop per Pool = 0.75 FT.

Pool Volume = 8' Wide x 9.33' long x 6.5' Avg Depth

$$E.D.F. = \frac{Q \times W \times D}{VOL} = \frac{35\ cfs \times 62.4\ lbs/ft^3 \times 0.75\ ft}{8' \times 9.33' \times 6.5'} = \frac{1638\ FT\text{-}LB./SEC}{485.2\ FT^3} = 3.38$$

OK


NEW BOX TO BE ADDED
WEIR #4
WEIR #3
WEIR #2
WEIR #1
2' + / -
35" + / -
18"
D/S MIGRANT SLOT
& EMERGENCY SPILLWAY
EXISTING WALL
4'-9"
SEE NOTE
58" + / -
ASSUMED FLOOR SLOPE
10'-2" + / -
INVERT ELEV OF PIPE UNKNOWN
11' + / -
EXISTING BOX SPILLWAY
13.5"
.65'
20.5"
30"
WEIR #4
1'
37.5"
WEIR #2


NEW EMERGENCY SPILLWAY
ADD 2" X 2" STOP LOG SLOTS
BOTH SIDES
NOTE:
A NEW SECTION OF WALL OR A CUTTING OF THE
BACK WALL OF EXISTING WALL PROVIDED HERE
SO THAT THE LENGTH OF THE POOL WILL BE APPROXIMA
10'-2"
.65'
4.5' TYP
4.5'
WEIR #4
WEIR #3
WEIR #2
WEIR #1
35" + / -
BACK WALL OF EXISTING STRUCTURE
FRONT WALL OF EXISTING STRUCTURE
1'
.65'
26.5"
WEIR #3
4'
30"
.65'
21.5"
58"
WEIR #1

PLAN