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HIGHWAY RESEARCH REPORT

PASSAGE OF ANADROMOUS FISH THRU HIGHWAY DRAINAGE STRUCTURES

FINAL REPORT

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

DISTRICT 01
HYDRAULICS SECTION

A. R. KAY
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RESEARCH REPORT

629110

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Control of the project has been under the direction of the Hydraulics Engineer, District 01, California Division of Highways. Initiation was handled by Mr. K. W. Kampe, now Senior Highway Engineer-Urban Planning in Sacramento. Principal investigating and reporting has been under the direction of Mr. A. R. Kay, present District 01 Hydraulics Engineer, and Mr. R. B. Lewis, Assistant District Hydraulics Engineer.

Assisting members of the research team were from the District 01 Hydraulics Department and consisted of Messrs. J. E. Murray, E. W. Lamoreaux, and H. N. Lewandowski.

The contributions made by members of the California Department of Fish and Game, both in time and advice, were invaluable in bringing the report to its conclusion. The Fish and Game members involved were:

Mr. Don LaFaunce - Fisheries Biologist
Mr. Keith Anderson - Fisheries Biologist
Mr. Gerald Holman - Fisheries Biologist
Mr. Ted Vande Sande- Hydraulics Engineer

INTRODUCTION

The research project described herein was undertaken to provide a better understanding of the factors that impede passage of anadromous fish and to attempt to establish design criteria for drainage structures required to pass annual runs of anadromous fish.

This research was implemented because of the increasing awareness and concern of the general public about the gradual changing of our ecosystem and over-all loss of natural resources, and because of a general lack of applicable information useful to the engineer in the design of highway drainage facilities requiring the passage of anadromous fish.

THE PROBLEM

To understand the problem relating to fish passage, it is necessary to become partially acquainted with the habits and life cycle of anadromous fish.

The term "anadromous fish" refers in general to all species of fish which hatch from eggs in a stream, migrate to the sea, and then return to fresh water after a period of time to spawn (lay eggs), thus completing the life sustaining cycle. In this report, the term refers specifically to steelhead, silver (coho) salmon and king (chinook) salmon.

The life cycle of these salmonids begins with the hatching of eggs in the streambed gravels. The king salmon begin their migration to the sea within a short time after hatching, but silver salmon and steelhead may remain in the streams for one or more years before migrating to salt water. After a stay in the sea, which varies from one to six years, the salmonids return to the streams to spawn. With few exceptions, the fish return to the streams where they were hatched.

The migration period generally occurs during the period of October through April. Upstream migration of salmon occurs through the fall and winter months while steelhead continue on through early spring. The king salmon varies some in that a few enter the streams in the spring and wait in the deeper pools until the next fall to spawn. The salmon die after spawning while steelhead often survive to return to the ocean and repeat the spawning migration.

In order for a stream to support its potential of anadromous fish, the fish must have free passage up and down the stream. Highway drainage structures designed without knowledge of the physical capabilities of these fish can become impassable barriers and deny the use of the stream above as spawning and nursery habitat.

This research has been undertaken to develop design criteria for drainage facilities which allow the free passage of migrating fish.

INVESTIGATION

The research was carried out in two parts: Field study of existing culverts and formulation of a design procedure which could be verified by the results of the field study.

The general field procedure was to investigate existing culverts, evaluate their fish passage characteristics, compare these with the culvert's hydraulic characteristics and analyze the results.

The field study was performed on existing culverts located in District 01 of the California Division of Highways in northcoastal California. This area is composed of Mendocino, Humboldt, and Del Norte Counties.

A list of 85 study culverts was selected. The criterion for study culverts was that they be located on streams that had a history of supporting populations of anadromous fish. To make sure they met this criterion, the list was sent to the California Department of Fish and Game, Regions I and III, for comments, and they recommended that certain culverts be dropped. This reduced the list to 40 culverts (Table 1). Fish and Game biologists recommended some streams be eliminated from the study because of natural barriers below the culvert sites or the streams were not suitable, for other reasons, for anadromous fish.

The fish passage characteristics were evaluated with the aid of a Smith-Root Mark V "Electrofisher". This is a fish shocking device which stuns fish for a short time, allowing for collection, identification, and counting. The procedure was to sample the fish population in the stream above and below the selected study culverts. The presence of juvenile anadromous fish indicated that some adult fish had at least reached that spot to spawn. If juvenile steelhead, silver salmon, or king salmon were found above the culvert, it was assumed that the adult fish had passed through the structure to spawn. If juvenile fish were found below, but not above, it was assumed that the culvert was a barrier to upstream migration. If no juvenile fish were found on either side, the investigation was rated as inconclusive.

Field sampling with the "Electrofisher" and species identification were conducted under the direct supervision of Department of Fish and Game biologists.

The final fish passage rating for each culvert was based on the fish shocking data, the judgement of the Department of Fish and Game biologists and engineers; and the judgement of the highway research staff.

It is pointed out that the field study did not show that any given percentage of fish attempting to pass through a structure were successful and thus the culvert ratings do not indicate the magnitude of the populations above and below the culvert. It did show that enough fish passed through the culverts to continue an anadromous fish population above.

To develop a fish passage design procedure, it was necessary to determine a discharge to use in the analysis. This discharge must take into consideration that upstream migration takes place within the period October through April. In addition, the fish do not seem to move during times of peak discharge but seek refuge areas until the peak has passed. In view of this, it is not considered necessary or practical to design highway drainage structures to pass fish at peak discharges or 100% of the time. After review and concurrence with representatives of Fish and Game, it was decided a design limitation should be to limit interference to migration to 10%± of the October-April period, or approximately 21 days. Therefore, the discharge for determining the fish passage requirement was selected as that discharge which is equaled or exceeded 10% of the time October through April. Hereafter this discharge will be referred to as Q_f. For a description of how Q_f was estimated for the study area, see Appendix I.

For conditions near Q_f, a change in Q does not materially affect the velocity. To demonstrate this affect, a plot of Q versus velocity was made for culverts A4-Jordan Creek and A41-School Creek. (See Figures 1 and 2). A 50% increase in Q_f produces a change of approximately 12% and 15% for these culverts. Thus, there is a built-in tolerance in that velocity is relatively constant for minor changes in Q.

The resulting normal velocity (V) from a discharge of Q_f was determined through the use of Mannings equation.* (See Table No. 2). A plot was then made of velocity versus culvert length with different symbols indicating the field observed fish passage characteristics. (See Figure No. 3).

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* Reference 12, Pages 287 and 288.

From the plot, it can be seen that there is a limiting value of velocity for each culvert length above which fish cannot negotiate. The data generally defines this limit. A detailed study of each of the culverts near this limit was made.

The curve depicted in Figure 3 is intended as a criteria for fish passage design and reflects what the authors feel represents the defining line between free passage (nearly 100%) and impeded passage. Above this limit, a critical study should be made of each installation on an individual basis to determine requirements for fish passage.

The goal in designing a structure for fish passage should be to maintain the level of migration to a natural state or 100% passage.

Some reasons for non-conformance were that velocities as determined by "Mannings Equation" did not fully represent field conditions due to the presence of natural stream material on the culvert invert or tailwater conditions (Culverts B1, B4, A38 and A39). This results in actual velocities being somewhat less than computed values and the curve was lowered accordingly. Also, Culverts A3 and B5 did not pass fish because of outfall barrier conditions rather than culvert characteristics.

The plot of Figure 3 shows that a design procedure using a relationship between limiting velocity and culvert length is valid. The limit of Figure 3 could be used for design. The data on which it is based does not indicate the percentage of fish passing. It does indicate that fish passed to continue an anadromous fish population above the culvert.

G. L. Ziemer of the Alaska Department of Fish and Game has presented a curve titled, "Swimming Capability of Migrating Salmon in Fresh Water".* The California Department of Fish and Game has verified this curve using data from other sources and has accepted it as allowing 100% passage for migrating salmonids in California. It is the opinion of the research staff that this curve is very conservative especially for steelhead. It appears that a true curve for 100% passage lies somewhere between the two curves and would vary since salmon and steelhead have different swimming abilities.

Figure 4 shows the curve presented by Ziemer (Alaskan curve).

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* Reference 8

PROPOSED DESIGN PROCEDURE

A design procedure to determine if special passage facilities should be considered for a given installation is recommended as follows:

1. Establish that the stream in question does sustain runs of anadromous fish. This is best handled through liaison with representatives of the local Fish and Game region. Knowing the species of anadromous fish could be helpful because of variation in swimming abilities.

2. Estimate Q_f (that discharge equaled or exceeded 10% of the time October through April).

3. Using the physical characteristics of the culvert being reviewed and Q_f estimated in Step 2, determine the resultant velocity.

4. Using the plot of Figure 3, the Alaskan curve or curves developed for other areas, determine if the resultant velocity is above or below the limiting velocity for the culvert length under consideration. If the velocity is below the limiting velocity, the culvert design is satisfactory for fish passage, providing adequate water depth is available throughout the migration period. If the velocity is above the limiting

velocity, revise the culvert design or provide special fish passage facilities (baffles, weirs, fish ladders, etc.).

5. Consider the recommendations given in the following section.

OTHER RECOMMENDATIONS

The following recommendations are based on observations of the research staff as they performed the field work on the 40 study culverts:

1. Some oversizing of culverts is desirable when passage facilities are warranted. This has a resultant effect of reducing velocities and will simplify the subsequent design of the passage devices.

2. Where possible, culvert grade lines should be depressed below normal streambed to encourage gravel deposition and to create a pool at the outlet thus developing a natural streambed fish entrance conditions in the culvert. Some culvert oversizing is desirable for this condition; however, during peak flows, when no migration is occurring, the velocities will usually be high enough to erode to a full culvert size.

3. In those installations where the total grade line cannot be depressed, consideration should be given to the lowering of the outlet flow lines to provide for possible streambed degradation.

4. For a given culvert installation at a specific discharge, the velocity will vary inversely with the roughness

coefficient or "Manning's n", thus selection of a higher "n" value culvert type may reduce velocities below the need for passage devices.

Four of the culverts in the study contained special fish passage devices included in the original culvert design and are working as planned. These installations are between 600 and 750 feet in length. The darkness created by culverts of these lengths seemed to have no effect on fish passage capabilities.

If the above procedure and recommendations are applied to the 40 study culverts, it will correctly predict the marginal and non-passable culverts. In addition, it will indicate that certain marginal culverts that pass fish would require modification or fish passage facilities. This is explained by making one of the following assumptions:

1. There is some characteristic of the culvert or stream, not considered in the velocity calculation, which causes the actual velocity to be less than computed.

2. The culvert passes enough fish to support a population of anadromous fish above the culvert, but does not pass the percentage desired.

CONCLUSIONS

Highway drainage structures can be successfully designed for passage of anadromous fish. Culvert lengths can be 700 feet or greater.

A design procedure utilizing a relationship between stream velocity and culvert length is valid and can be used to indicate when consideration should be given to installation of passage facilities.

A satisfactory limiting discharge for fish passage is one that is equaled or exceeded 10% of the October through April time period.

Design discharge Q_f can be estimated for a watershed either using gages on the stream or gages in close hydrologic proximity.

The design curves listed in Figures 3, 6, and 7, can be successfully used in the determination of passage requirements for the study area.

APPENDIX I

ESTIMATING DESIGN DISCHARGE Q_f FOR FISH PASSAGE

Only a small portion of the streams in the study area have stream flow gages* and generally they are on streams having larger watersheds. An assumption was made that within the study area the flow duration patterns for the smaller watersheds are similar to the patterns for the larger basins. Verification of this assumption was made by comparing flow duration patterns of the small streams having continuous recording gages with the larger streams in close geographic proximity.

Flow duration curves were developed for the period October through April for selected gages within the study area. (See Table 3 and Figure 5.) Streams with smaller drainage basins were chosen for similarity purposes. "When basins differ greatly in size, the runoff from one is a poor indication of the concurrent runoff from the other basin".**

From the flow duration curves, values were picked for the discharge which is equaled or exceeded 10% of the time October through April -- (Q_f).

It was found that within the study area, there is a linear relation between Q_f in CFS/SqMi and Average Annual

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* Ref. 7, Various years 1955 through 1968.

** Ref. 9, Page 70.

Precipitation.

This relationship is shown in Figure 6. The watershed areas of the selected gaged streams vary from 0.9 of a square mile to 50.3 square miles.

Using the relationship shown in Figure 6, it is possible to estimate Q_f for any stream crossing in the study area if the Average Annual Precipitation is known.

Table 3 shows the variation between estimated and actual Q_f in CFS. One of the selected gaged streams (Lopez Creek) is also one of the streams in the culvert study.

Figure 7 shows Average Annual Precipitation contours for the study area. Table 3 shows estimated Q_f for each culvert site in the study.

BIBLIOGRAPHY

1. John E. Fitch, "Offshore Fishes of California", State of California, Department of Fish and Game, Sacramento, 1958.

2. J. H. Wales, "Trout of California", State of California, Department of Fish and Game, Sacramento, 1957.

3. Clarence P. Idyll and Robert F. Sisson, "The Incredible Salmon", National Geographic Vol. 134, No. 2, August 1968, p. 195.

4. Ray K. Linsley and Joseph B. Franzini, "Water Resources Engineering", McGraw-Hill Book Company, New York, 1964.

5. Horace W. King and Ernest F. Brater, "Handbook of Hydraulics", McGraw-Hill Book Company, New York, 1963.

6. Charles R. Weaver, "Influence of Water Velocity Upon Orientation and Performance of Adult Migrating Salmonids", U. S. Fish and Wildlife Service, Fishery Bulletin, Vol. 63, No. 1, p. 97.

7. Water Resources Data for California, Part 1 Surface Water Records", U. S. Geological Survey, Menlo Park, California.

8. G. L. Ziemer, P. E., "Swimming Capability of Migrating Salmon in Fresh Water", State of Alaska, Department of Fish and Game.

9. Searcy, Graphical Correlation of Gaging-Station Records, Geological Survey Water Supply Paper 1541-C.

10. S. E. Rantz, "Average Annual Precipitation and Runoff in Northcoastal California, U. S. Geological Survey Hydrologic Investigations Atlas HA 298, 1968.

11. Howard E. Metsker, "Fish versus Culverts (Some Considerations for Resource Managers)", U. S. Forest Service, Region IV.

12. C. H. Clay, "Design of Fishways and Other Fish Facilities", The Department of Fisheries of Canada, Ottawa, 1961.

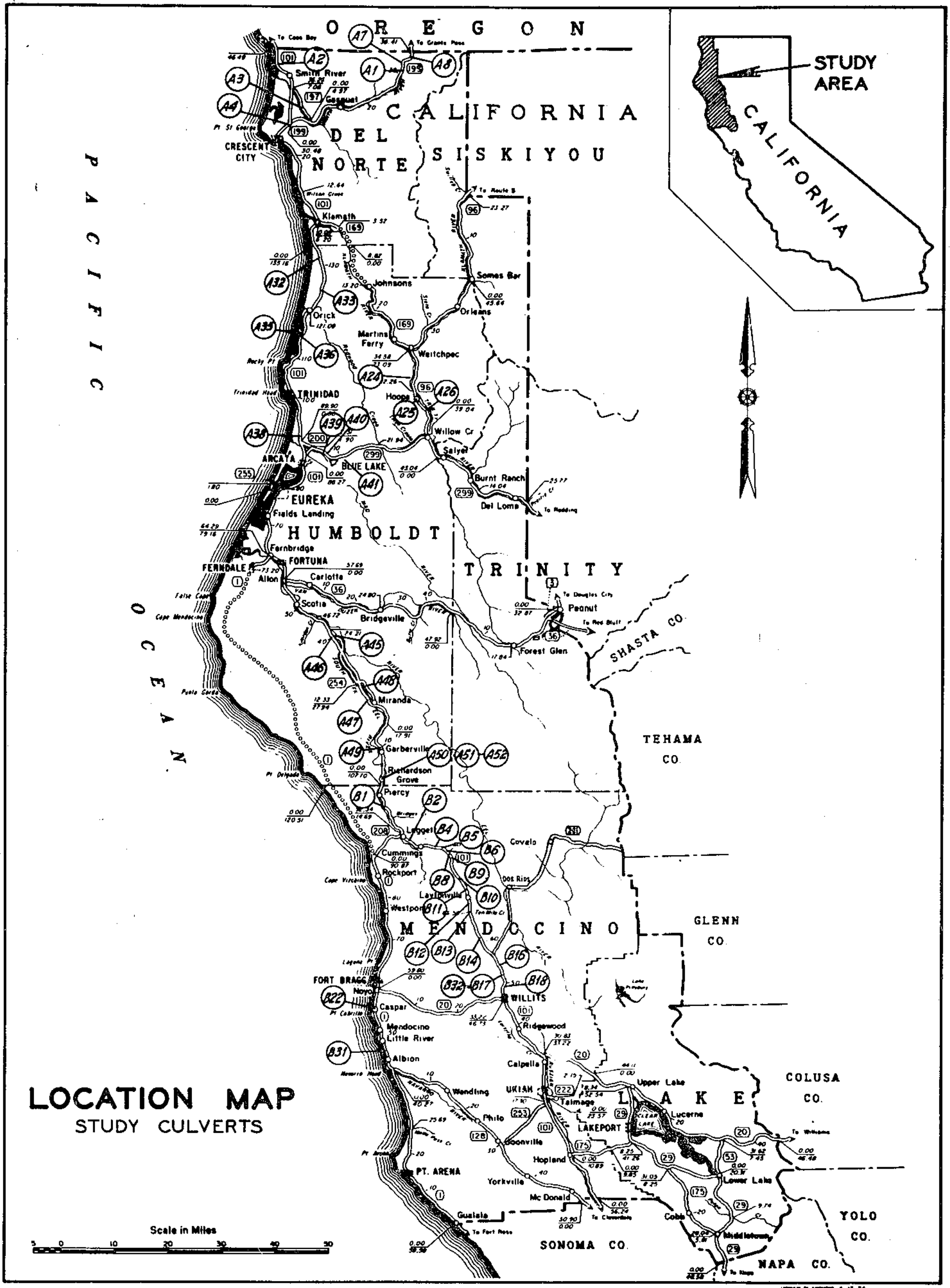

LOCATION MAP
STUDY CULVERTS
OREGON
CALIFORNIA
DEL NORTE
SISKIYOU
HUMBOLDT
TRINITY
MENDOCINO
LAKE
SHASTA CO.
TEHAMA CO.
GLENN CO.
COLUSA CO.
YOLO CO.
NAPA CO.
SONOMA CO.
PACIFIC OCEAN
STUDY AREA
CALIFORNIA
Scale in Miles
5 0 10 20 30 40 50
CRESCENT CITY
Smith River
Gasquet
Klamath
Johnsons
Orick
Somes Bar
Orleans
Martins Ferry
Weitchpec
Hoopa
Willow Cr
Salyer
Burnt Ranch
Del Loma
TRINIDAD
ARCATA
BLUE LAKE
EUREKA
Fields Landing
Fernbridge
FERNDALE
FORTUNA
Alton
Carlotta
Scotia
Bridgeville
Forest Glen
Peanut
Miranda
Garberville
Richardson Grove
Piercy
Leggett
Cummings
Rockport
Covelo
Dos Rios
Laytonville
Westport
FORT BRAGG
Noyo
Caspar
WILLITS
Mendocino
Little River
Albion
Ridgewood
Calpella
UKIAH
Talmage
Upper Lake
Lucerne
LAKEPORT
Wendling
Philo
Boonville
Hopland
Yorkville
Mc Donald
PT. ARENA
Gualala
Lower Lake
Cobb
Middletown
A1 A2 A3 A4 A7 A8
A24 A25 A26 A32 A33 A35 A36 A38 A39 A40 A41
A45 A46 A47 A48 A49 A50 A51 A52
B1 B2 B4 B5 B6 B8 B9 B10 B11 B12 B13 B14 B16 B17 B18 B22 B31 B32
101 199 197 169 96 200 299 255 36 254 208 20 128 253 222 175 29 53 1 3

TABLE 1 : CULVERT TYPES

NO.	STREAM	CULVERT TYPE	DRAINAGE AREA SQ. MI.
A1	Griffin Cr.	150" SPP	3.8
A2	Lopez Cr.	8'x6' RCB	0.9
A3	Peacock Cr.	90" CMP	2.0
A4	Jordan Cr.	8'x5' RCB	2.2
A7	Griffin Cr. #2	Dbl. 5'x5' RCB	1.3
A8	Broken Kettle Cr.	132" SPP	2.1
A24	Beaver Cr.	144" SPP Paved	3.3
A25	Hospital Cr.	6'x6' RCB	2.3
A26	Campbell Cr.	10'x10' RCB	6.8
A32	Prairie Cr.	5'x5' RCB	0.3
A33	Little Lost Man	Dbl. 8'x8' RCB	3.8
A35	McDonald Cr. #2	6'x3' RCB	2.0
A36	McDonald Cr. #1	Dbl. 5'x3' RCB	3.2
A38	Mill Cr. (101)	96" CMP	3.5
A39	Mill Cr. (299)	90" CMP	3.1
A40	Noisy Cr.	Dbl. 48" RCP	2.2
A41	School Cr.	120" SPP	2.4
A45	Chadd Cr. #2	108" SPP	3.4
A46	Chadd Cr. #1	114" SPP	2.0
A47	Bear Buttes Cr.	144" SPP	4.6
A48	Fish Cr.	6'x6' RCB	4.5
A49	Bear Gulch Cr.	13' RC Arch	3.5
A50	Durphy Cr. #1	114" SPP	2.5
A51	Durphy Cr. #2	12'x7.5' RCB	2.5
A52	Durphy Cr. #3	114" SPP	2.5
B1	Red Mtn. Cr.	300 Sq. Ft. Arch	12.3
B2	Cedar Cr.	363 Sq. Ft. Arch	14.7
B4	Rattlesnake #3	Dbl. 18' RC Arch	34.4
B5	Elk Cr.	138" SPP	4.0
B6*	Rattlesnake #2	26' RC Arch	
B8*	Twin Rocks Cr.	8'x12' SPA & RCB	
B9*	Rattlesnake #1	144" SPP & 8' RCB	
B10	Steep Gulch Cr.	120" SPP	2.8
B11	Lewis Cr.	96" CMP	1.3
B12	Wilson Cr.	102" SPP	1.7
B13	Ten Mile Cr.	Dbl. 10'x7' RCB	4.1
B14	Long Valley Cr.	228" SPP	12.6
B16	Reeves Cr.	Dbl. 8'x5.5' RCB	1.9
B17	Ryan Cr. #1	60" CMP	1.2
B18	Upp Cr.	Dbl. 10'x5.5' RCB	1.6
B22	Doyle Cr.	84" SPP	1.3
B31	Mallo Pass Cr.	14' Span Arch	4.1
B32	Ryan Cr. #2	10'x6' RCB	1.2

LEGEND:

RCB Reinforced Concrete Box
CMP Corrugated Metal Pipe
SPP Structural Plate Pipe
SPA Structural Plate Arch

* Eliminated from Study

STUDY CULVERT CHARACTERISTICS

NO.	STREAM	Qf C.F.S.	SLOPE FT/FT	n	V F.P.S.	DEPTH	LENGTH	FISH PASSAGE?	REMARKS
A1	Griffin Cr.	90	.005	.030	4.8	2.6	406	Inconclusive	
A2	Lopez Cr.	20	.025	.015	7.8	0.3	79	Inconclusive	
A3	Peacock Cr.	40	.022	.024	7.9	1.3	54	No	Excessive jump at outlet
A4	Jordan Cr.	40	.004	.015	5.2	1.0	92	Yes	
A7	Griffin Cr. #2	30	.020	.015	7.5	0.4	32	Inconclusive	
A8	Broken Kettle Cr.	50	.008	.031	4.6	1.9	436	Yes	
A24	Beaver Cr.	40	.053	.015	14.6	0.7	126	No	Conc. Paved Invert
A25	Hospital Cr.	25	.040	.015	9.9	0.4	40	Marginal	
A26	Campbell Cr.	75	.054	.015	15.0	0.5	150	No	
A32	Prairie Cr.	5	.034	.015	5.6	0.2	56	Yes	
A33	Little Lost Man	60	.006	.015	5.9	0.6	35	Yes	
A35	McDonald Cr. #2	30	.025	.015	9.3	0.5	47	Yes	
A36	McDonald Cr. #1	50	.012	.015	7.7	0.7	35	Yes	
A38	Mill Cr. (101)	35	.010	.021	6.1	1.4	156	Yes	Tailwater-All Stages
A39	Mill Cr. (299)	35	.029	.024	8.4	1.1	41	Yes	Tailwater
A40	Noisy Cr.	25	.006	.012	6.3	0.9	45	Yes	
A41	School Cr.	35	.004	.031	3.4	1.9	60	Yes	
A45	Chadd Cr. #2	45	.020	.031	6.2	1.5	92	Yes	

TABLE 2

STUDY CULVERT CHARACTERISTICS - Cont'd.

NO.	STREAM	Q_f C.F.S	SLOPE FT/FT	n	V F.P.S.	DEPTH	LENGTH	FISH PASSAGE?	REMARKS
A46	Chadd Cr. #1	25	.038	.031	6.8	1.0	598	Yes	Wooden Weirs
A47	Bear Buttes Cr.	65	.016	.030	5.1	2.0	272	Yes	
A48	Fish Cr.	50	.109	.015	17.4	0.5	103	No	
A49	Bear Gulch	40	.013	.015	7.0	0.8	603	Yes	Concrete Weirs
A50	Durphy Cr. #1	30	.009	.031	4.1	1.5	70	Yes	
A51	Durphy Cr. #2	30	.029	.015	8.3	0.3	92	Marginal	
A52	Durphy Cr. #3	30	.014	.031	5.0	1.3	50	Yes	
B1	Red Mtn. Cr.	190	.005	.015	7.5	1.3	304	Yes	Gravel Covers Invert
B2	Cedar Cr.	250	.012	.015	12.0	1.4	750	Yes	Conc. Weirs and Denil Fish Ladder
B4	Rattlesnake #3	590	.0056	.015	9.6	2.2	245	Yes	Gravel Covers Invert
B5	Elk Cr.	70	.010	.030	5.5	2.1	258	No	Bad Fish Ladder
B10	Steep Gulch Cr.	40	.032	.031	7.5	1.2	155	Yes	
B11	Lewis Cr.	20	.020	.024	5.9	1.0	65	Yes	
B12	Wilson Cr.	25	.006	.032	3.5	1.6	182	Yes	
B13	Ten Mile Cr.	60	.003	.015	4.3	0.7	70	Yes	
B14	Long Valley Cr.	175	.007	.030	6.0	3.0	452	Yes	
B16	Reeves Cr.	20	.012	.015	3.9	0.3	75	Yes	
B17	Ryan Cr.	15	.026	.024	7.0	0.9	120	Yes	

STUDY CULVERT CHARACTERISTICS - Cont'd.

NO.	STREAM	Qf C.F.S.	SLOPE FT/FT	n	V F.P.S.	DEPTH	LENGTH	FISH PASSAGE?	REMARKS
B18	Upp Cr.		.020	.015			74	Inconclusive	No Water at Study Time
B22	Doyle Cr.	6	.026	.032	3.8	0.6	726	No	
B31	Mallo Pass Cr.	20	.028	.015	5.4	0.3	649	Yes	Conc. Weirs
B32	Ryan Cr. #2	15	.026	.015	6.0	0.3	83	Yes	

TABLE 2

STREAM GAGING STATIONS

GAGE NO. USGS	STREAM NAME	DRAINAGE AREA SQ. MILE	AVE. ANNUAL PRECIP. IN. PER YR.	ACTUAL Q_f C.F.S.	ESTIMATED Q_f C.F.S.	PERCENT ERROR
11-4627	Feliz Cr. near Hopland	31.1	45	165	180	+ 9%
11-4680.7	So. Fork Big River near Comptche	36.2	50	177	268	+51%
11-4685.4	Pudding Cr. near Fort Bragg	12.5	52	85	100	+18%
11-4686	Middle Fork Ten Mile River	32.9	58	283	328	+16%
11-4731	Williams Cr. near Covelo	30.4	50	268	225	-16%
11-4736	Short Cr. near Covelo	15.2	50	120	112	- 7%
11-4755	So. Fork Eel River near Branscomb	43.9	79	694	733	+ 6%
11-4757	Ten Mile Cr. near Laytonville	50.3	66	604	630	+ 4%
11-4766	Bull Cr. near Weott	28.1	80	483	478	- 1%
11-4777	So. Fork Van Duzen River	36.2	75	326	557	+71%
11-4797	Elk River near Falk	44.2	55	486	398	-18%
11-4800	Jacoby Cr. near Freshwater	6.1	50	60	45	-25%
11-4808	No. Fork Mad River near Korbel	40.5	70	486	559	+15%
11-4812	Little River at Crannel	44.4	65	471	542	+15%
11-5327	Rowdy Cr. at Smith River	33.6	85	672	625	- 7%
11-5330	Lopez Cr. near Smith River	0.9	90	19	18	- 5%

TABLE 3

VELOCITY VS. DISCHARGE RELATIONSHIP

CULVERT A4 JORDAN CREEK
8' SPAN x 5' HIGH REINFORCED CONCRETE BOX CULVERT SLOPE = .004 FT/FT

A 50% INCREASE IN DISCHARGE FROM 40 TO 60 C.F.S.
PRODUCES A 15% VELOCITY INCREASE.

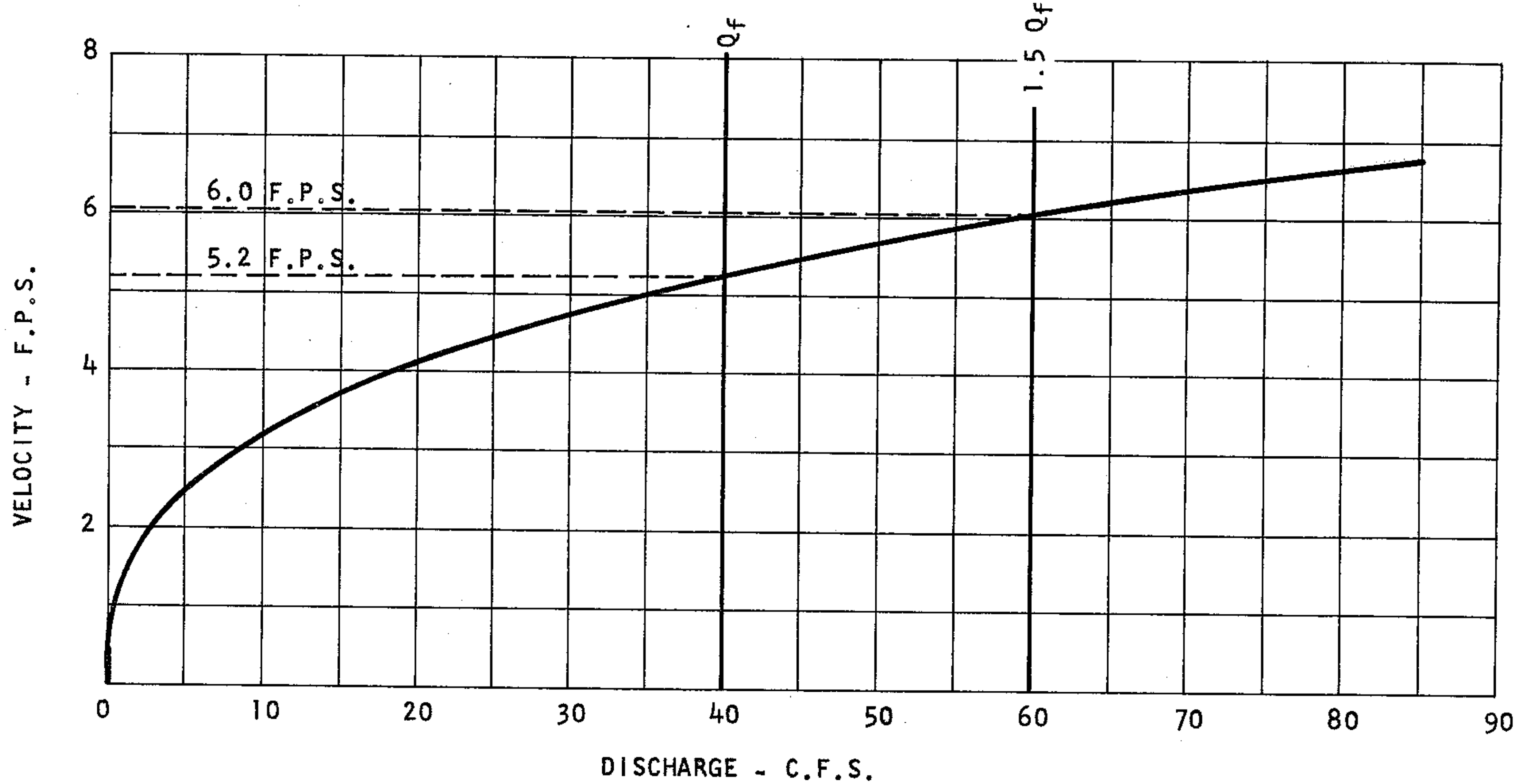


FIGURE 1

VELOCITY VS. DISCHARGE RELATIONSHIP

CULVERT A41 SCHOOL CREEK
120" STRUCTURAL PLATE PIPE   SLOPE = .004 FT/FT

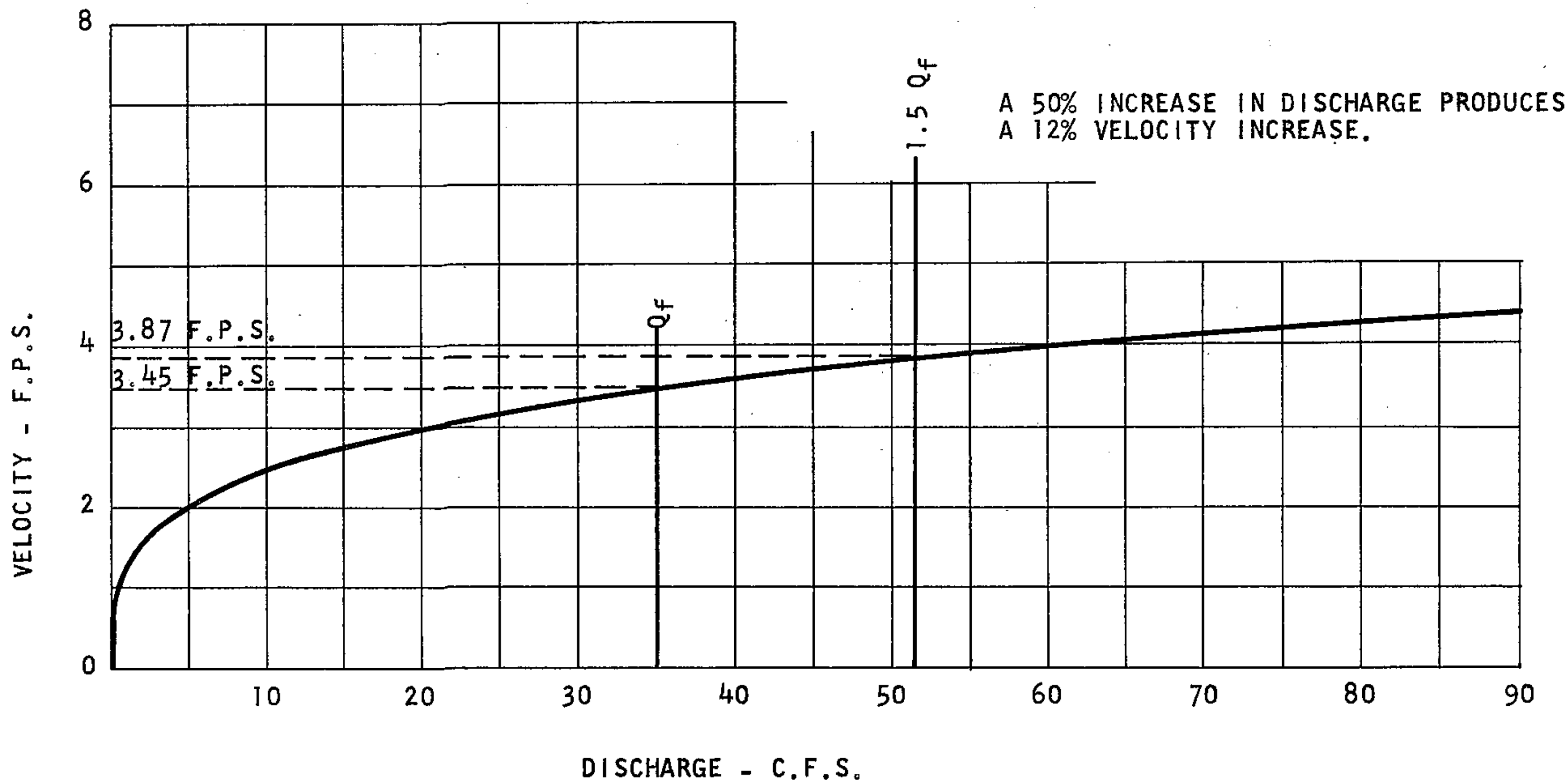


FIGURE 2

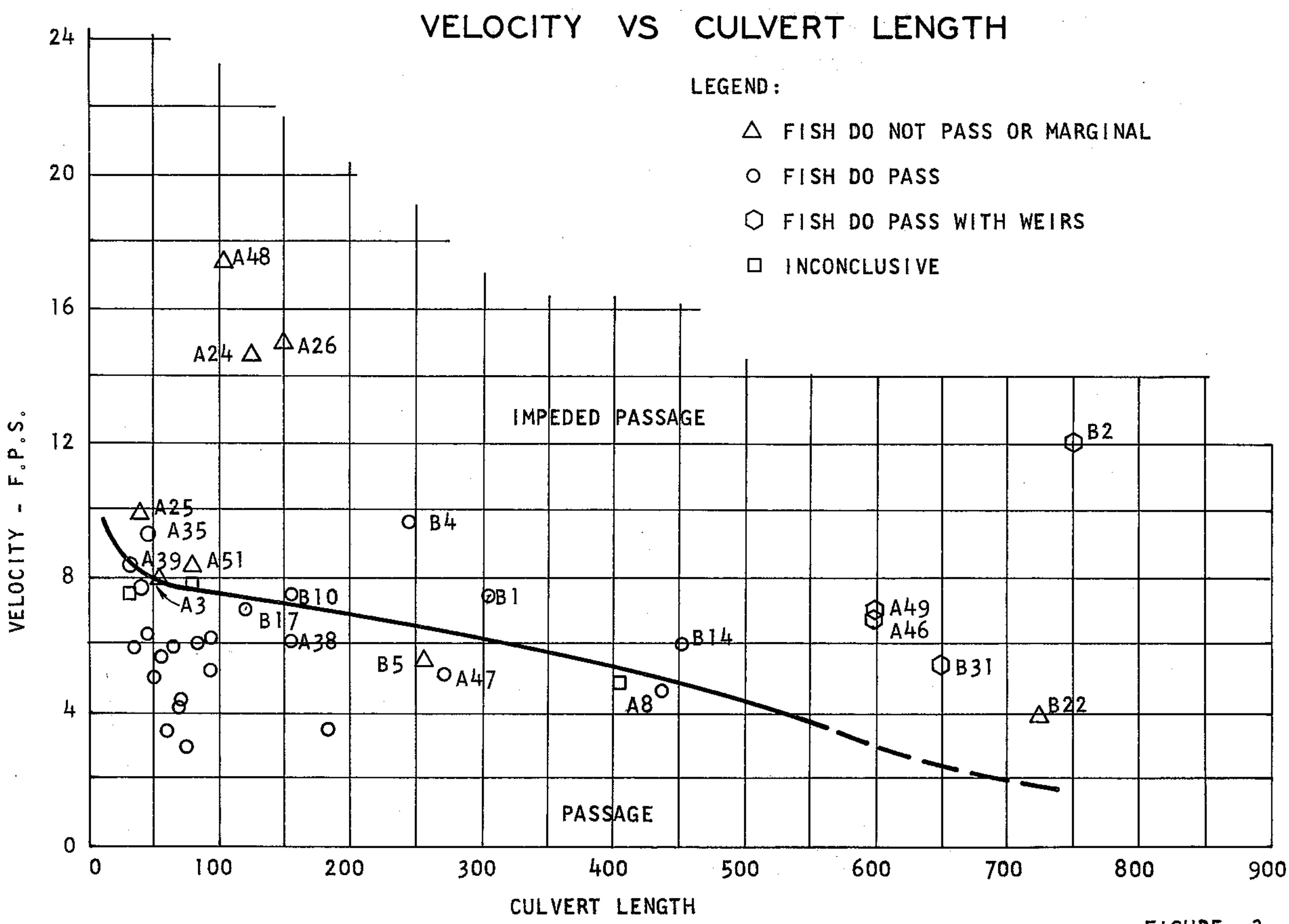
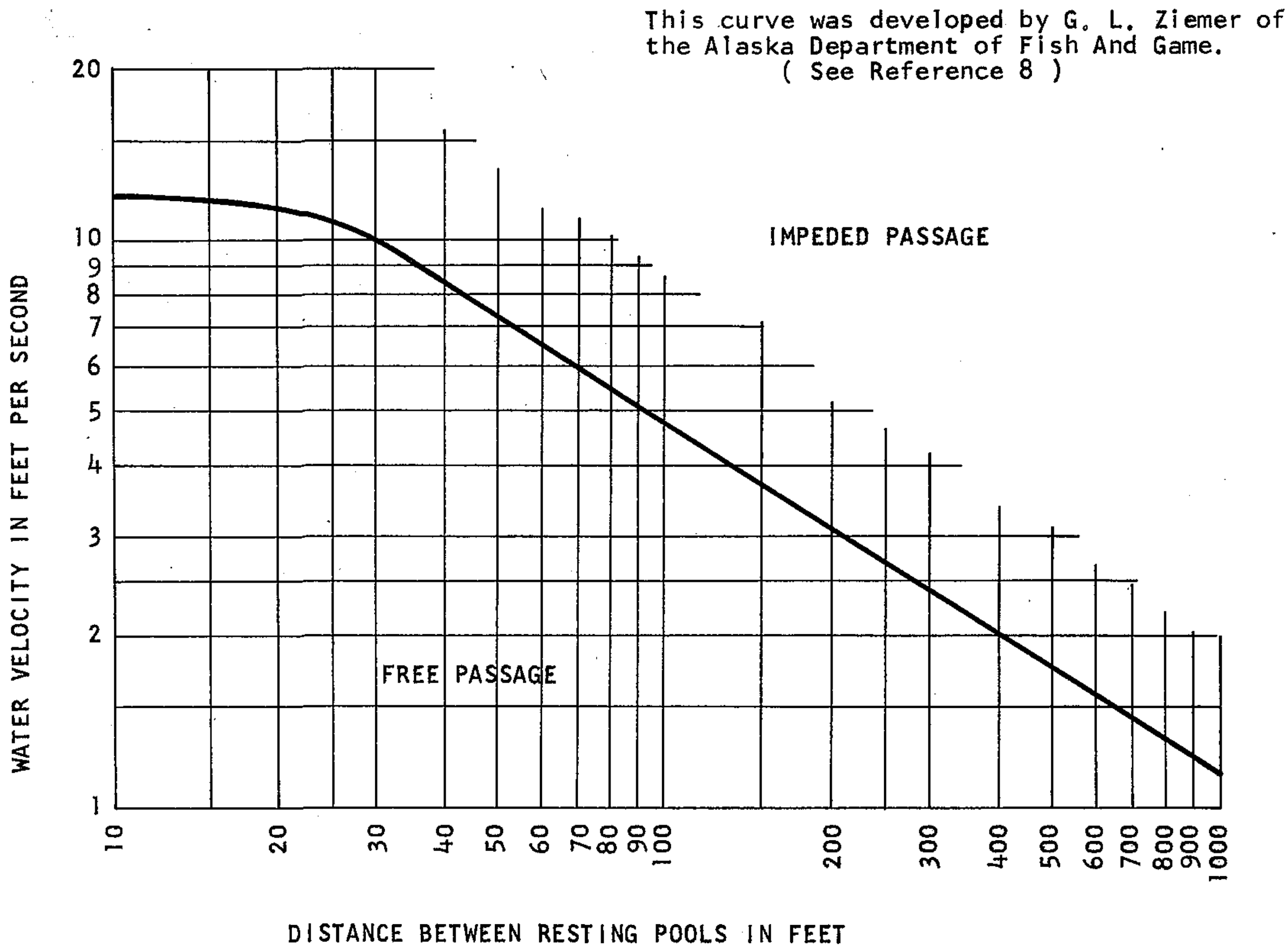

VELOCITY VS CULVERT LENGTH
LEGEND:
FISH DO NOT PASS OR MARGINAL
FISH DO PASS
FISH DO PASS WITH WEIRS
INCONCLUSIVE
IMPEDED PASSAGE
PASSAGE
VELOCITY - F.P.S.
CULVERT LENGTH
0
4
8
12
16
20
24
0
100
200
300
400
500
600
700
800
900
A48
A24
A26
A25
A35
A39
A51
A3
B10
B17
A38
B4
B5
A47
B1
B14
A8
A49
A46
B31
B2
B22

FIGURE 3

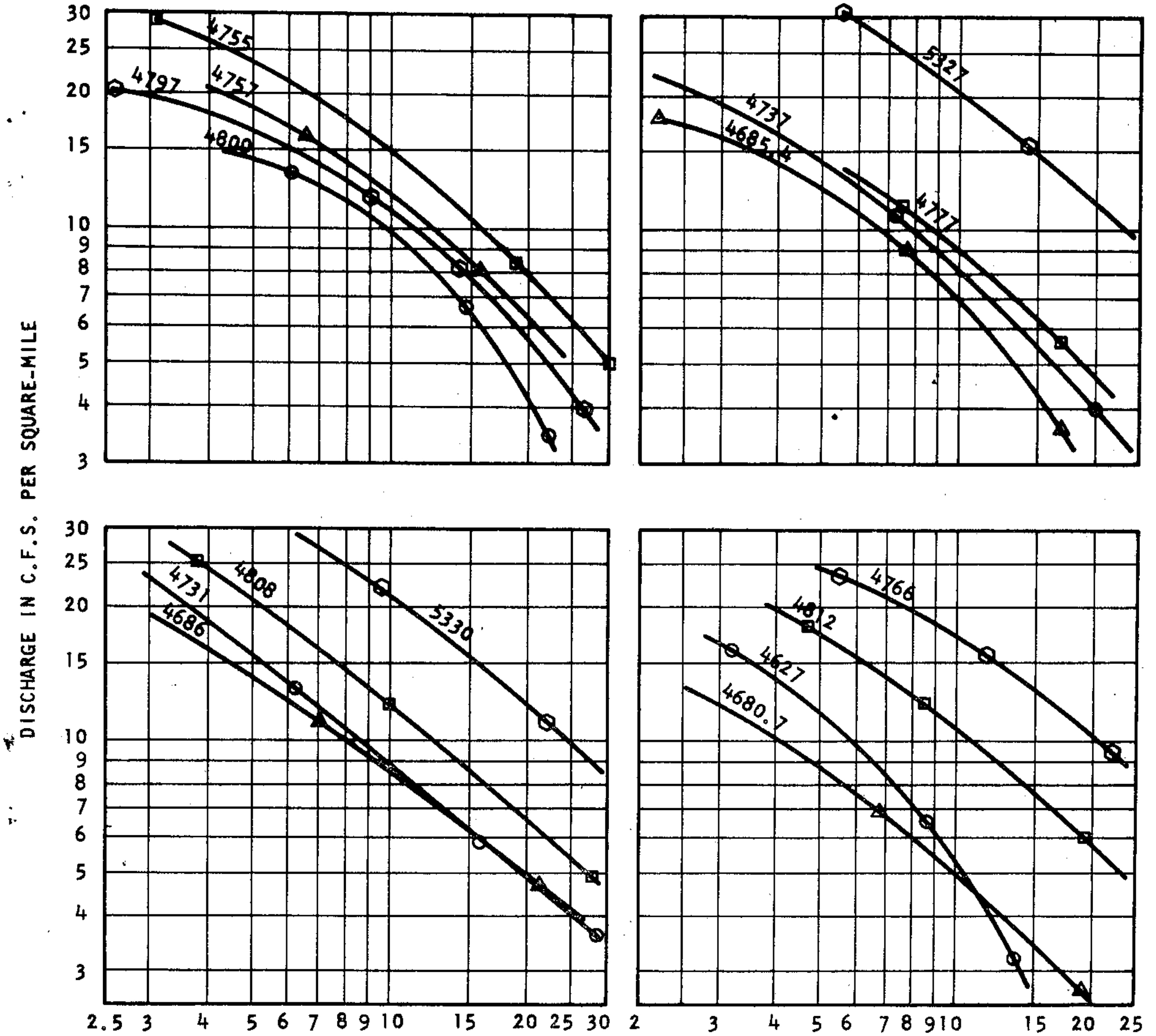


SWIMMING CAPABILITY OF MIGRATING SALMON

(ALASKAN CURVE)

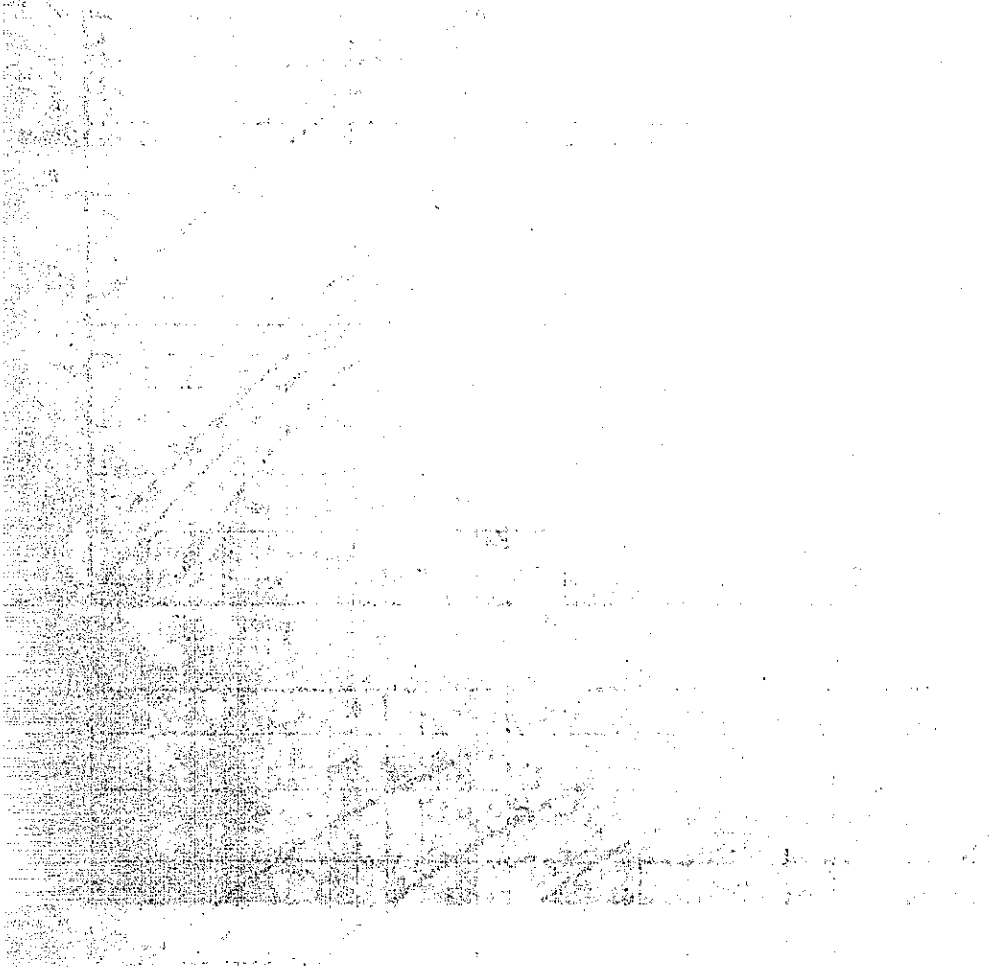
FIGURE 4

FLOW DURATION CURVES



% OF TIME DISCHARGE IS EXCEEDED OCTOBER THRU APRIL

THE ABOVE CURVES REPRESENT THE AVERAGE FOR THE ANALYSIS PERIOD. THE ANALYSIS PERIOD VARIES FROM GAGE TO GAGE ACCORDING TO THE RECORD AVAILABLE BUT IN NO CASE IS LESS THAN 5 YEARS.



GAGE NO.	AVE. ANNUAL PRECIP.	C.F.S.*
4680.7	50	5.0
4685.4	52	6.3
4686	58	8.9
4812	65	10.5
4757	66	11.6
4755	79	15.0
4766	80	17.0
5330	90	20.0
4797	55	10.9
4627	45	5.2
4800	50	9.4
5327	85	18.6
4736	50	8.2
4731	50	9.0
4777	75	19.5
4808	70	12.0

CORRELATION COEFFICIENT-r= .937
EST. REGRESSION LINE- C.F.S.* = .321P-8.66
Q_f = (.321P-8.66)A

P = AVE. ANNUAL PRECIPITATION - In./Yr.
A = DRAINAGE AREA - SQ. MI.

Q_f

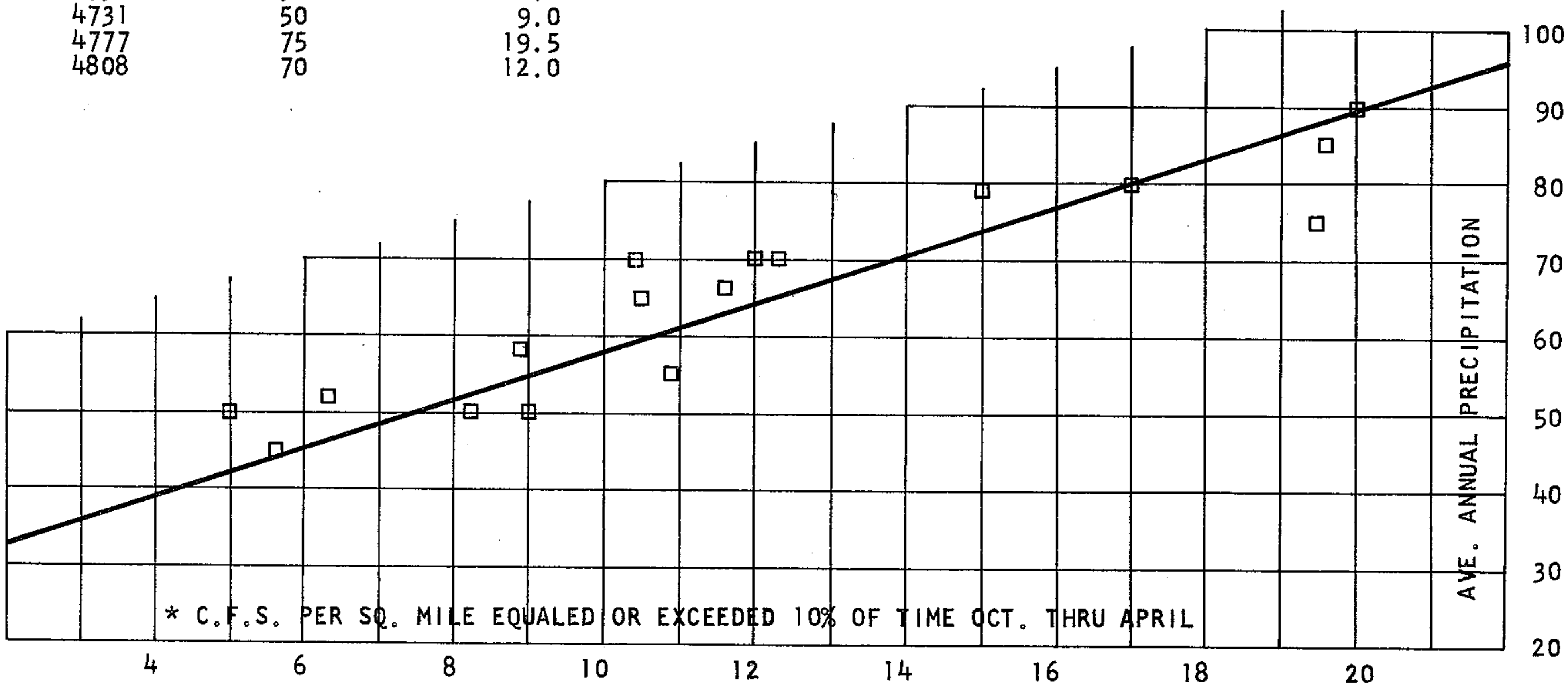
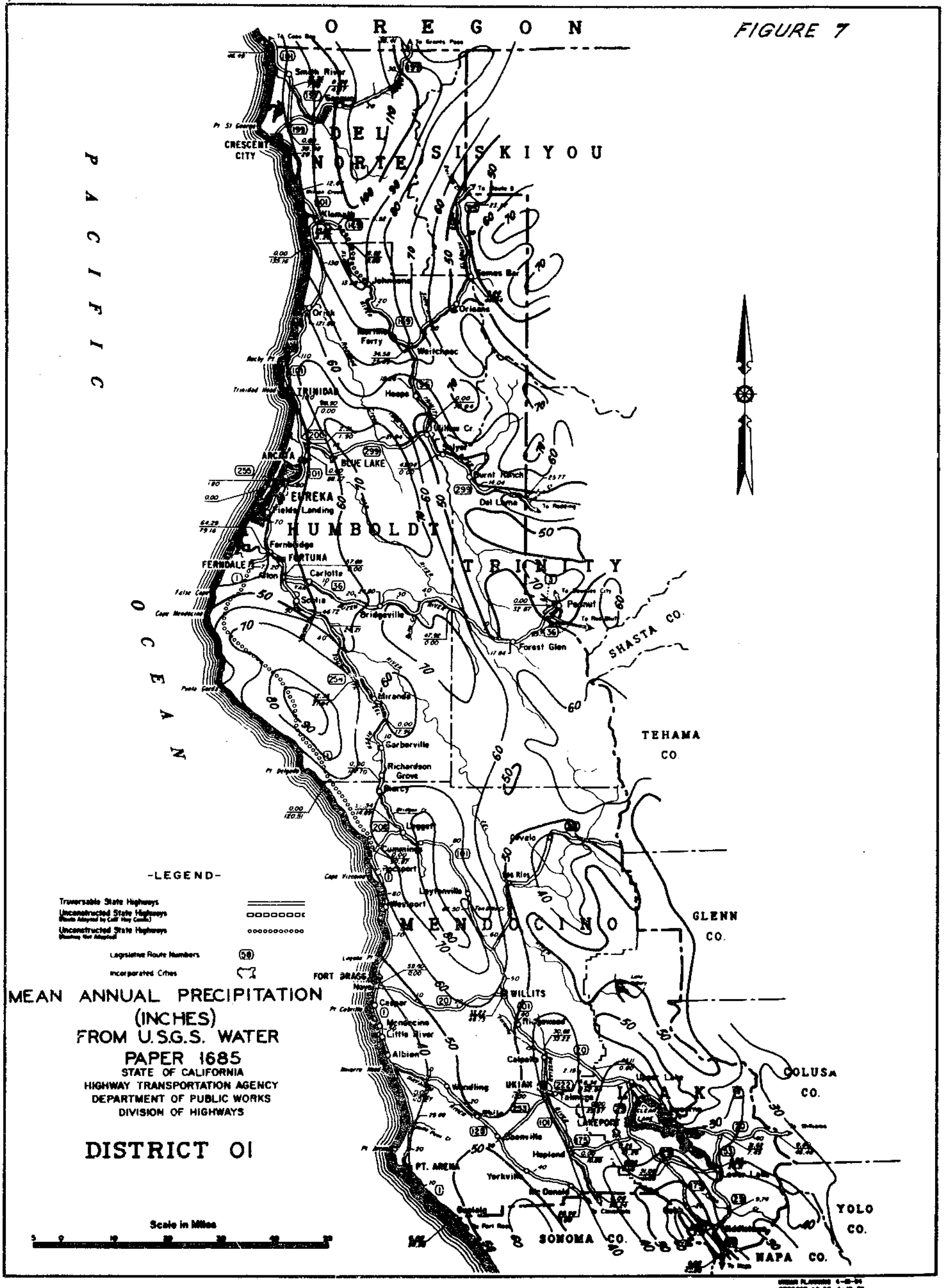


FIGURE 6



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