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FISH PROTECTION STRATEGIES FOR THE DESIGN AND CONSTRUCTION OF THE ALASKA SEGMENT OF THE ALASKA NATURAL GAS TRANSPORTATION SYSTEM

Draft - Final

Prepared for and Funded by

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1.0 INTRODUCTION

Construction of the Alaska Natural Gas Transportation System (ANGTS) will involve a variety of potential disturbances to aquatic habitats including pipeline stream crossings, workpad drainage structures, floodplain material sites, and numerous potential impacts from ancillary activities. Protection of fish resources and the habitats they depend on is clearly mandated by the Alaska Natural Gas Transportation Act of 1976 as well as applicable State and Federal resource laws and regulations. The means by which this protection is to occur and the criteria designating what constitutes adequate protection are less straightforward. It is the intent of this document to provide the necessary framework to effectively incorporate aquatic habitat protection features into construction planning and design activities. This document is primarily intended to outline measures to protect designated fish streams or their tributaries, although some of its provisions will be useful also in other areas. It should be emphasized that engineering standards and cost concerns are not represented in the following discussion unless they are in some way related to protection of aquatic resources. In many cases, design calculations or planning decisions will be required in addition to those outlined in this document in order to address the other relevant aspects of design and construction.

Sections 2 through 13 comprise the bulk of the report and consist of a compilation of protection measures that can be applied over the range of activities involved in constructing a gas pipeline. For each specific kind of activity, two kinds of listings are usually presented. The first consists of standards for design or construction; these measures have been accorded the status of "standards" because of their importance or because they have been formally instituted through stipulations or regulations. The second list includes optional mitigation measures or construction techniques that can be applied on a site-specific basis depending on site characteristics and environmental sensitivity. The standards and mitigation measures are derived or adapted from several different sources including State and Federal stipulations for ANGTS (U.S. Dept. of Interior 1980), proposed State regulations for implementing existing Alaska fish and game laws (ADF&G 1980a), consultation with agency resource management personnel, literature review, consultation with NWA/Fluor design and construction staff, and professional judgement of the authors. It is intended that these sections will provide a ready reference source for the design engineer or construction planner.

It should be noted that ANGTS stipulations have, in some cases, been shortened, combined, and/or paraphrased for convenience. The reference number of the stipulation is included after each statement where applicable and the reader is encouraged to consult the original text if doubt exists as to the specific wording.

The last portion of the report provides a system for classifying streams according to their sensitivity to impacts from pipeline activities and provides a rationale for applying mitigation measures and construction timing restraints to streams within each of the classes.

2.0 DESIGN AND CONSTRUCTION STANDARDS HAVING GENERAL APPLICABILITY

A. Free passage and movement of fish must be assured (temporary blockage approved by the applicable State and Federal agencies on a case-by-case basis) - Stip. 2.5.1.

B. Disturbance to fish special use areas (spawning, rearing, and over-wintering) is to be avoided where possible. If not possible, the applicable State and Federal agencies must approve modes and mitigative measures - Stip. 2.5.4.4.

C. Fish use areas must be protected from construction-caused sediment - Stip. 2.5.4.5, 2.5.4.6, and 3.4.2.

D. Permanent alteration of existing surface water configurations and hydraulics must be avoided unless approved by the applicable State and Federal agencies - Stip. 2.8.1.

E. All disturbed areas must be stabilized and "restored" as defined in Stip. 2.12.

F. All in-stream work must attempt to avoid periods of biological sensitivity, to the greatest extent feasible. Where this is not feasible, mitigative measures will be required. The document "Fish Resource Areas of the Northwest Alaska Gas Pipeline Corridor" (ADF&G 1980b) is the standard for sensitive time periods. These periods have been transposed onto Environmental Master Guide (EMG) Level 1 and Level 2 environmental backup.

G. Extent and duration of disturbance to natural streambed (within the mean annual flood line) and exposure of cut soil surfaces to flowing water must be minimized.

H. Flow in fish streams must be maintained above a stream-specific minimum (see Section 9.1 for guidelines). No flow interruptions will be allowed; allowable diversions are discussed in Section 7.0.

I. Duration of in-stream work must be minimized. Each in-stream project must be completed with rapid sequencing of all phases through final installation of erosion protection.

J. All debris resulting from clearing operations and construction that may block stream flow, delay fish passage, contribute to flood damage, or result in stream bed scour or erosion must be removed within 48 hours unless otherwise approved or directed by the applicable State and Federal agencies - Stip. 2.7.2.4.

K. Mobile ground equipment must not be operated in streams, lakes, wetlands, rivers, or other water bodies without prior approval by the applicable State and Federal agencies - Stip. 2.2.2.2.

L. Fueling of any type of wheeled or tracked equipment or storage of any hazardous substance must not occur in any stream, river or lake, or in any part of a floodplain covered by a mean annual flood (ADF&G 1980a).

3.0 BRIDGES

3.1 Bridges - Design and Construction Standards

A. Abutments and armored banks must be designed to protect against scour, channel migration, ice, permafrost degradation, etc. - Stip. 3.4.1.2.3.

B. Extent and duration of disturbance to natural streambed must be minimized.

C. Constriction of highwater flows must be avoided. Where upstream migration of fish is likely, abutments should be outside of bankfull width (to prevent loss of low velocity shoreline areas).

D. In-channel piers are preferable to shoreline abutments that do not comply with Item C above.

E. Pile driving must not occur within 200 feet of known spawning areas when eggs, alevins, or adults are present without prior approval of the appropriate State and Federal agencies.

3.2 Bridges - Mitigation Measures and Construction Techniques

The primary concern during any bridge construction effort, whether single or multiple span or temporary or permanent, is minimization of streambed or bank disturbance. Construction planning and design efforts should consider carefully means of avoiding these impacts. Although each bridge site is different, there are some general measures that can be applied where appropriate.

3.2.1 Single Span Crossings of Smaller Streams

A. Single span bridges can be effectively constructed without touching or crossing the stream or its exposed banks either by accessing the stream bank on both sides or by using a crane to hoist materials across until the bridge is in place. Methods that avoid in-stream work have the additional advantage of not being constrained by sensitive time periods.

B. Staging area should be minimized and kept back from the stream as much as possible. Heavy equipment should utilize the bridge approach roadway.

3.2.2 Multiple Span Crossings

A. Avoid designs that involve long-term stream disturbance during construction; e.g., driven piles may be preferable to use of poured concrete and caissons. However, at certain times of the year, restrictions may be placed on proximity of pile driving operations to important fish areas or on allowable daily work period.

B. If possible, in-stream work should occur during periods of no flow.

C. Duration of in-stream work should be minimized by having all equipment on hand and in good mechanical condition before initiating the work.

D. In some situations, stream diversion should be considered to avoid working in flowing water.

4.0 CULVERTS

4.1 Culverts - Design and Construction Standards

A. Velocity of water within a culvert is one of the primary considerations in ensuring that culvert design is adequate to permit upstream movement of fish. The velocity criteria applied to any given stream crossing must generally be adequate to protect the weakest swimming upstream migrant at the time that the migration occurs (ADF&G 1980a). Table 1 groups the fish species likely to be encountered according to four categories of swimming ability. The design fish group for any particular stream must be determined on a stream-by-stream basis. However, it should be noted that most streams along the ANGTS will fall into Group II (C. Yanagawa, personal communication). Group I is generally reserved for special situations where upstream migrations of small fish are known to be of particular importance. Groups III and IV will apply only rarely since most streams containing strong swimmers (e.g. salmon) also contain weaker swimmers (e.g. grayling).

B. Because of the complex nature of culvert hydraulics, some confusion has arisen in the past regarding culvert velocity parameters. In order to avoid problems of confusion and to realistically address fish passage, a new concept, occupied area velocity ($V_{occupied}$), has been developed. $V_{occupied}$ describes the velocity in that portion of the culvert where fish have been demonstrated, in controlled observations, to move upstream (M. Bell, personal communication). Figure 1 shows the location of the "occupied area" for various types of culverts. Appendix A shows the relationship between $V_{occupied}$ and other measures of culvert velocity (average velocity and maximum velocity).

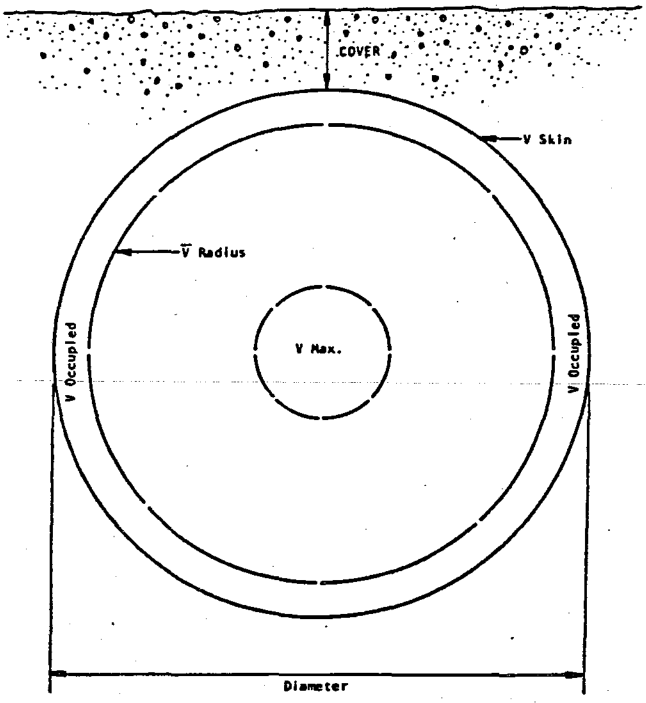
C. The culvert velocity through which a fish can successfully swim is dependent on the length of time that the swimming speed must be sustained and, therefore, dependent on culvert length. Figure 2 indicates the speeds that various species of Alaska fish can attain under various

TABLE 1

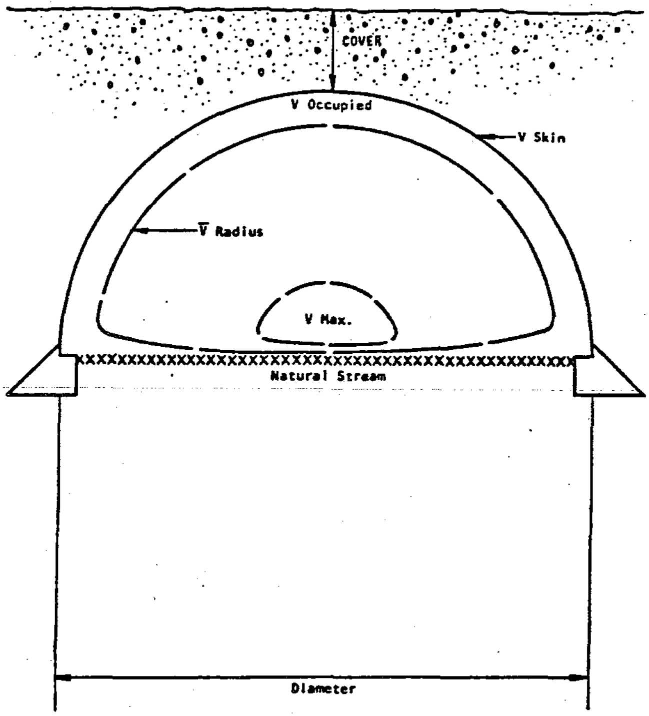
FISH STREAM GROUPINGS BASED ON THE SWIMMING ABILITY OF RESIDENT FISH SPECIES[a]

Group I	Group II	Group III	Group IV
Very slow swimmers:	Adult slow swimmers:	Adult moderate swimmers:	Adult high performance swimmers:
Salmon fry	Broad whitefish	Pink salmon	King salmon
Other immature fish	Humpback whitefish	Chum salmon	Coho salmon
	Burbot		Sockeye salmon
	Sheefish		Steelhead
	Arctic grayling		
	Long-nose suckers		
	Northern pike		
	Dolly varden		
	Arctic char		

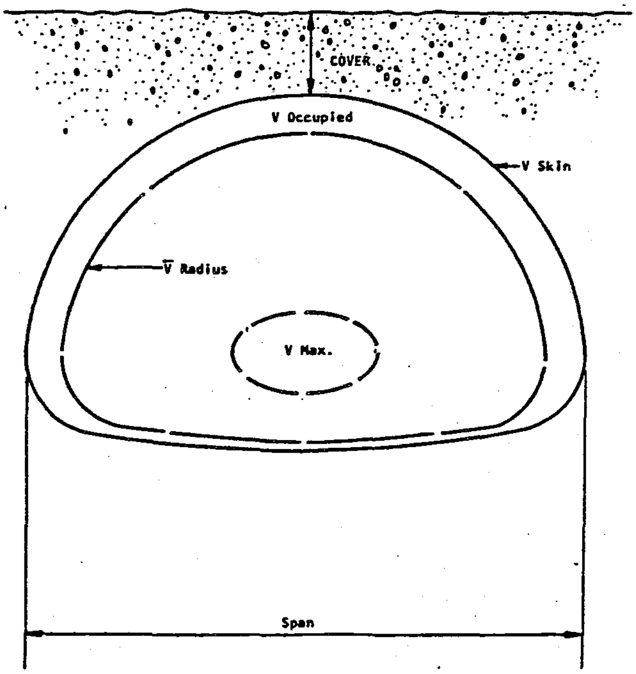
[a] Modified from Alaska Dept. of Fish and Game, 1980a.



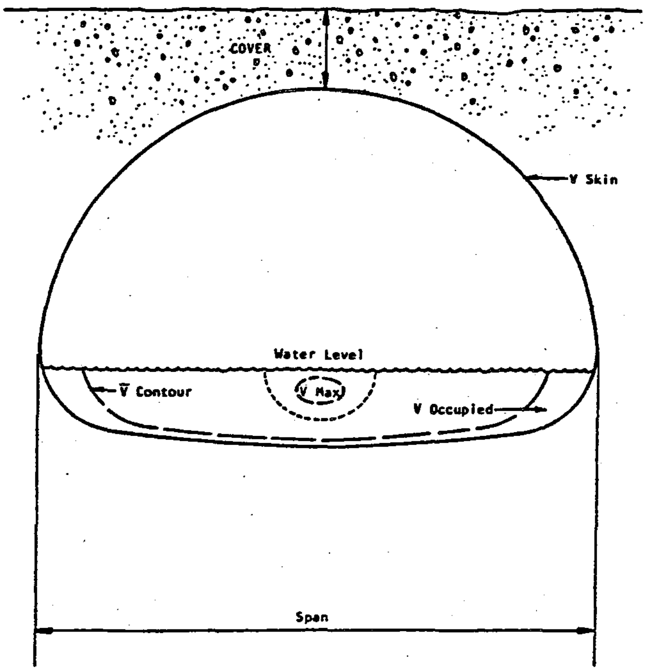
A. PIPE (CIRCULAR) CULVERT AT 100% FULLNESS.



B. ARCH CULVERT AT 100% FULLNESS.



C. PIPE-ARCH CULVERT AT 100% FULLNESS.



D. PIPE-ARCH CULVERT AT DEPTH = RISE - R.

FIGURE 1

SCHEMATIC OF VARIOUS CULVERTS SHOWING LOCATION OF V MAX. AND V OCCUPIED

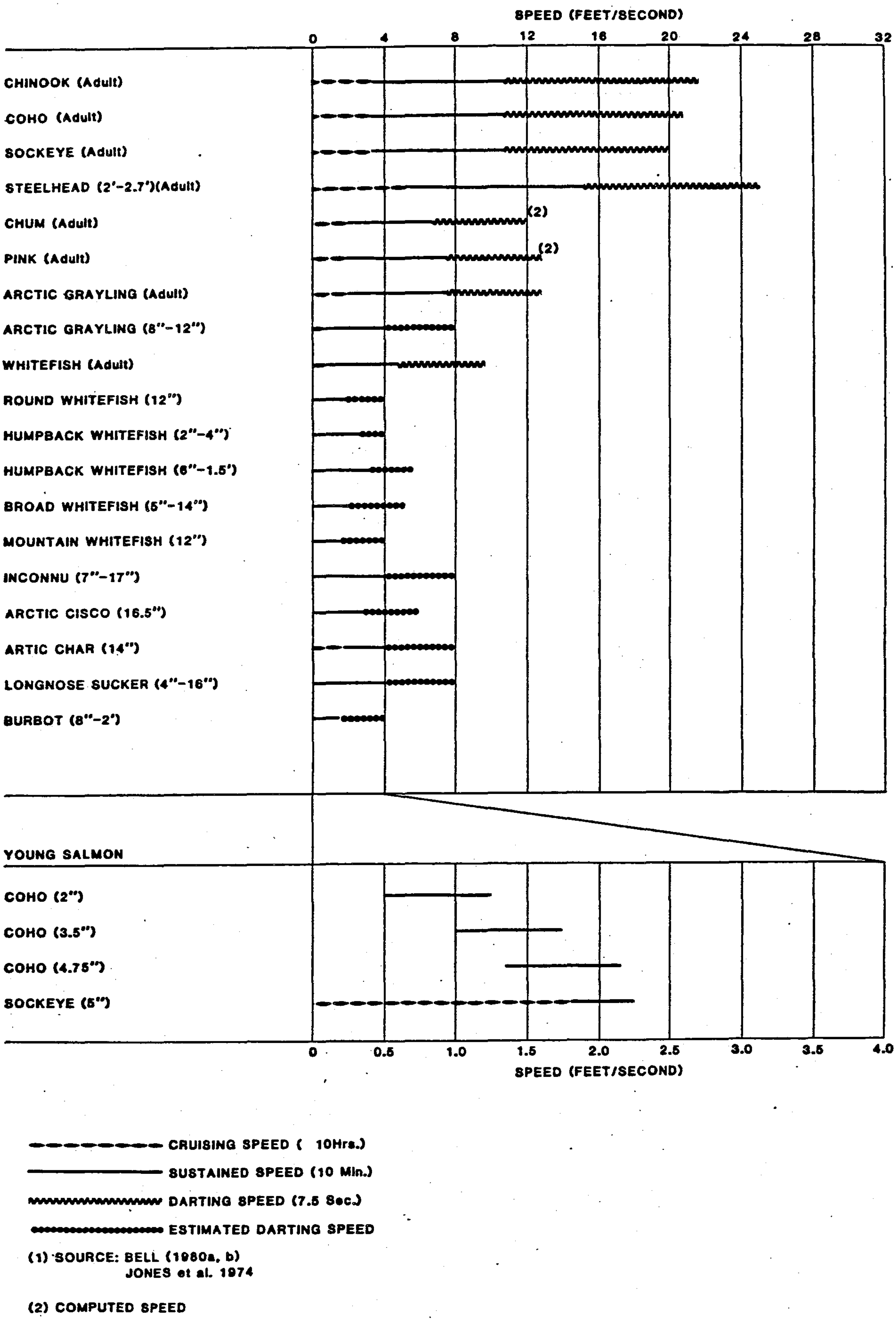


FIGURE 2

SUGGESTED RELATIVE SWIMMING SPEEDS FOR VARIOUS FISH IN ALASKA WATERS[1]

TABLE 2

OCCUPIED AREA CULVERT VELOCITY ($V_{occupied}$)[a] THAT WILL ALLOW FISH OF VARIOUS SWIMMING ABILITIES TO PASS CULVERTS OF VARIOUS LENGTHS

Darting Speed of the Design Fish Species[b] (ft/sec)	Culvert Length (feet)																													
14	1,500	1,200	960	780	640	535	450	380	330	280	250	210	190	170	150	130	120	110	100	90	80	70	65	60	55	50	50	45	40	
12	960	760	605	490	405	340	280	240	205	180	155	135	120	105	95	85	75	70	60	55	50	45	40	40	35	30	45	30	25	Group IV
11	740	580	465	380	310	260	220	185	160	140	120	105	90	80	70	65	60	50	45	40	40	35	30	30	25	25	20	20	20	
10	555	435	350	285	235	195	165	140	120	105	90	80	70	60	55	50	45	40	35	30	30	25	25	20	20	20	15	15	15	Group III
9	405	320	255	205	170	140	120	100	90	75	65	60	50	45	40	35	30	30	25	25	20	20	15	15	15					
8	285	225	180	145	120	100	85	70	60	55	50	40	35	30	30	25	20	20	15	15	15									
7	190	150	120	100	80	70	60	50	40	35	30	30	25	20	20	15	15													Group II
6	120	95	75	60	50	40	35	30	25	20	20	15	15																	
5	70	55	45	35	30	25	20	20	15																					
4	35	30	20	20	15																									
3	15																													Group I
2	4																													
Scale I Sustainable Swimming Speed[c]	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25	8.50	8.75	9.00	9.25	9.50	9.75	10.0	
Scale II $V_{occupied}$ Required to Allow Fish Passage[d]	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	

(a) Occupied Area Velocity ($V_{occupied}$) = V_{skin} + 0.25 ($\overline{V}$ - V_{skin})
where: V_s = the water velocity adjacent to the sides of a culvert of $Diameter_x$, and $\overline{V}$ = the average water velocity within a culvert of $Diameter_x$.

(b) Darting speed equals the swimming speed that can be maintained for 7.5 seconds; i.e., an approximation of maximum speed.

(c) Calculation of sustainable swimming speed is based on the following assumptions: (1) 60-second sustainable speed is one-half of darting speed (Bell 1980a) (2) the velocity/time equation ($V_1^3 t_1 = V_2^3 t_2$) is a reasonable estimation of swimming speed as related to duration of swimming (3) fish are swimming at a rate 2 feet per second greater than $V_{occupied}$.
For example, consider a Group II fish passing a 100 foot culvert: (1/2 darting speed)^3 (60 sec) = V_2^3 (time required to swim 100 feet at 2 fps net speed).
$(3.5)^3 (60) = V_2^3 (50)$ $\quad V_2 = 3.72$.

(d) $V_{occupied}$ is assumed to be 2 feet per second less than the sustainable swimming speed to allow the fish adequate net forward speed (Yanagawa 1980).

conditions of duration. Table 2 provides a means for determining the occupied area velocity required to pass fish of various swimming abilities through culverts of various lengths. Table 2 is entered by selecting the swimming ability group from Table 1 (or, if available, the known darting speed of the weakest swimming upstream migrant) appropriate to the stream in question. The line corresponding to the proper swimming velocity is traced horizontally until the necessary culvert length is attained. Then by tracing vertically downward, the swimming speed that a fish can maintain through a culvert of that length is indicated by Scale I and the occupied area velocity that will allow a fish swimming at Scale I speed to pass is indicated by Scale II. The Scale II occupied area velocity must be used in the design of culverts on fish streams. An example of the integrated use of Tables 1 through 5 is presented in Section 4.2.

D. The slope of the culvert must not exceed 0.005 (0.5 percent). The culvert slope may match the natural river or streambed slope up to a slope of 0.005, provided that the above velocity criteria can be attained. A natural streambed having a slope greater than .005 may be culverted, provided that the culvert can reasonably be installed at a slope less than .005. If the natural streambed slope or other non-site conditions preclude installation of a culvert to this standard, an alternative drainage structure, such as a bridge, must be used (modified from ADF&G 1980a).

E. The design flow for purposes of fish passage design must be at least the mean annual flood or $Q_{2.33}$ (ADF&G 1980a). It should be noted that the design flow for hydraulic design of permanent culverts is the Q_{50} as per Stip. 3.4.3.1. The $Q_{2.33}$ can be extrapolated from longer frequency flood events via standard equations.

F. At least one-fifth of the diameter of round pipe culverts at the outlet end must be set below the lowest elevation of the natural stream bottom at the place of installation. At least 6 inches of all pipe-arch culverts should be similarly set (modified from Stip. 3.4.3.2 and ADF&G 1980a). Depth of burial of the inlet for circular or pipe-arch culverts will be determined by the slope of the culvert relative to the streambed slope.

G. If control for culverts (assuming no flared inlet) is at the entrance, then a coefficient of contraction of 0.9 can be applied, giving an increase in average velocity of 10 percent for a short distance at the culvert entrance. Culverts should be designed for no-head buildup (headwater depth less than or equal to culvert diameter $[\frac{HW}{D} \leq 1]$) at the intake during the period of the fish passage design maximum flow ($Q_{2.33}$). Table 2 should provide adequate conservatism to allow passage through this zone if tabulated $V_{occupied}$ values are not exceeded.

H. Circular culverts less than 30 inches in diameter are generally unsuitable for fish passage and must not be utilized unless approved by the appropriate State and Federal agencies.

I. Culvert dimensions necessary to satisfy the above criteria are presented in Tables 3, 4, or 5 for circular, bottomless arch, or pipe-arch (semi-elliptical) culverts, respectively. Data required to enter these tables are $Q_{2.33}$, $V_{occupied}$ (from Table 2), and preferred culvert slope. These tables are derived from a variety of standard references provided in Section 16. A more complete explanation of their derivation can be found in Appendices A through D. These calculations have been checked using the "Rule of 10" (King 1954) and are found to be within 6 percent. An example demonstrating the integrated use of Tables 1 through 5 is presented in Section 4.2 below.

It should be noted that the flow calculations provided in Tables 3 and 5 for circular and pipe-arch culverts assume that all streambed materials

TABLE 3

Q AND $V_{occupied}$ VALUES FOR CIRCULAR CORRUGATED METAL PIPE CULVERTS OF VARYING DIAMETER AND FULLNESS SET AT GRADIENTS OF 0.001 AND 0.005[a]

Culvert Diameter (feet)	Culvert Area (% of maximum)	Water Depth (% of diameter)	Gradient	Flow, Q[b] (cfs)	$V_{occupied}$[c]
2.5	100	100	0.001	7.0	.89
			0.005	15.7	2.00
	75	70	0.001	5.9	1.00
			0.005	13.2	2.24
	50	50	0.001	3.5	.89
			0.005	7.9	2.00
	37	40	0.001	2.4	.81
			0.005	5.3	1.80
3.0	100	100	0.001	11.4	1.01
			0.005	25.5	2.26
	75	70	0.001	9.6	1.13
			0.005	21.4	2.53
	50	50	0.001	5.7	1.01
			0.005	12.8	2.26
	37	40	0.001	3.9	0.91
			0.005	8.6	2.04
3.5	100	100	0.001	17.2	1.12
			0.005	38.5	2.50
	75	70	0.001	14.4	1.25
			0.005	32.3	2.80
	50	50	0.001	8.6	1.12
			0.005	19.3	2.50
	37	40	0.001	5.8	1.01
			0.005	13.0	2.26
4.0	100	100	0.001	24.6	1.22
			0.005	55.0	2.74
	75	70	0.001	20.6	1.37
			0.005	46.1	3.06
	50	50	0.001	12.3	1.22
			0.005	27.5	2.74
	37	40	0.001	8.3	1.10
			0.005	18.5	2.47

(a) For additional data including maximum velocity, average velocity and skin velocity and backup calculations, see Appendix A.

(b) Q values are based on a Manning's coefficient of 0.024 (from test data, Bonneville Hydraulics Laboratory, Corps of Engineers). To meet ADF&G criteria, this should be the flow at the 2.33-year flood. Calculations assume that the culvert is free of deposited material.

(c) $V_{occupied}$ = the occupied area velocity, or the area within a culvert of a particular gradient and fullness, through which a fish swims while traversing the length of a culvert.

TABLE 3
(Continued)

Culvert Diameter (feet)	Culvert Area (% of maximum)	Water Depth (% of diameter)	Gradient	Flow, Q[b] (cfs)	$V_{occupied}$[c]
4.5	100	100	0.001	33.7	1.32
			0.005	75.3	2.96
	75	70	0.001	28.2	1.48
			0.005	63.1	3.31
	50	50	0.001	16.8	1.32
			0.005	37.7	2.96
	37	40	0.001	11.4	1.19
			0.005	25.4	2.67
5.0	100	100	0.001	44.6	1.42
			0.005	99.8	3.18
	75	70	0.001	37.3	1.59
			0.005	83.5	3.55
	50	50	0.001	22.3	1.42
			0.005	49.9	3.18
	37	40	0.001	15.0	1.28
			0.005	33.6	2.86
6.0	100	100	0.001	72.5	1.60
			0.005	162.2	3.59
	75	70	0.001	60.7	1.80
			0.005	135.8	4.02
	50	50	0.001	36.3	1.60
			0.005	81.1	3.59
	37	40	0.001	24.4	1.45
			0.005	54.7	3.23
7.0	100	100	0.001	109.4	1.78
			0.005	244.7	3.97
	75	70	0.001	91.6	1.99
			0.005	204.8	4.45
	50	50	0.001	54.7	1.78
			0.005	122.3	3.97
	37	40	0.001	36.9	1.60
			0.005	82.5	3.58
8.0	100	100	0.001	156.2	1.94
			0.005	349.4	4.34
	75	70	0.001	130.8	2.18
			0.005	292.5	4.86
	50	50	0.001	78.1	1.94
			0.005	174.7	4.34
	37	40	0.001	52.7	1.75
			0.005	117.7	3.92

TABLE 3
(Continued)

Culvert Diameter (feet)	Culvert Area (% of maximum)	Water Depth (% of diameter)	Gradient	Flow, Q[b] (cfs)	$V_{occupied}$[c]
9.0	100	100	0.001	213.9	2.10
			0.005	478.3	4.70
	75	70	0.001	179.1	2.35
			0.005	400.4	5.26
	50	50	0.001	106.9	2.10
			0.005	239.1	4.70
	37	40	0.001	72.1	1.90
			0.005	161.2	4.24
10.0	100	100	0.001	283.3	2.25
			0.005	633.4	5.04
	75	70	0.001	237.1	2.52
			0.005	530.3	5.64
	50	50	0.001	141.6	2.25
			0.005	316.7	5.04
	37	40	0.001	95.5	2.03
			0.005	213.5	4.55

TABLE 4

Q AND $V_{occupied}$ VALUES FOR (SEMI-CIRCULAR) BOTTOMLESS ARCH CULVERT BRIDGES OF VARYING DIAMETER AND FULLNESS (90, 72, 50, AND 25 PERCENT) SET AT GRADIENTS OF 0.001 AND 0.005[(a)]

Culvert Diameter (feet)	Culvert Fullness (percent)	Wetted Area (feet^2)	Hydraulic Radius	Gradient	Flow, Q[(b)] (cfs)	$V_{occupied}$[(c)]
10	90	35.34	1.82	0.001	103.19	1.83
				0.005	230.77	4.08
	72	28.27	1.72	0.001	79.74	1.76
				0.005	177.82	3.93
	50	19.64	1.39	0.001	47.92	1.53
				0.005	107.04	3.41
	25	9.82	0.82	0.001	16.89	1.08
				0.005	37.71	2.40
12	90	50.90	2.19	0.001	167.97	2.06
				0.005	375.64	4.64
	72	40.72	2.06	0.001	129.08	1.98
				0.005	288.70	4.43
	50	28.27	1.66	0.001	77.77	1.72
				0.005	174.49	3.86
	25	14.14	0.99	0.001	27.43	1.21
				0.005	61.51	2.72
14	90	69.27	2.55	0.001	252.84	2.28
				0.005	565.94	5.11
	72	55.42	2.40	0.001	194.52	2.19
				0.005	435.05	4.91
	50	38.49	1.94	0.001	117.39	1.91
				0.005	262.12	4.26
	25	19.24	1.15	0.001	41.37	1.34
				0.005	92.54	3.01
16	90	90.48	2.92	0.001	361.92	2.50
				0.005	808.89	5.59
	72	72.38	2.74	0.001	277.22	2.39
				0.005	620.30	5.36
	50	50.27	2.22	0.001	167.40	2.08
				0.005	374.51	4.66
	25	25.13	1.32	0.001	59.31	1.48
				0.005	132.44	3.29

(a) For additional data including V_{max}, $\overline{V}$, and V_{skin}, and backup calculations, see Appendix B.

(b) Q = flow, or discharge in cubic feet per second (cfs). This value is flow carried in excess of bank-full flow with the assumption that abutments are placed at high water line and the natural stream profile is unaltered.

(c) $V_{occupied}$ = the occupied area velocity, or the area within an arch culvert, of a particular gradient and fullness, through which a fish swims while traversing the length of a culvert.

TABLE 4 (Continued)

Culvert Diameter (feet)	Culvert Fullness (percent)	Wetted Area (feet^3)	Hydraulic Radius	Gradient	Flow, $Q^{(b)}$ (cfs)	$V_{occupied}^{(b)}$
18	90	114.51	3.28	0.001	494.68	2.70
				0.005	1,107.31	6.04
	72	91.61	3.09	0.001	380.18	2.59
				0.005	851.06	5.81
	50	63.62	2.50	0.001	229.67	2.26
				0.005	512.78	5.04
	25	31.81	1.48	0.001	80.80	1.59
				0.005	181.00	3.56
20	90	141.37	3.64	0.001	654.54	2.89
				0.005	1,464.59	6.48
	72	113.10	3.48	0.001	503.30	2.78
				0.005	1,126.48	6.23
	50	78.54	2.77	0.001	303.16	2.41
				0.005	678.59	5.40
	25	39.27	1.65	0.001	107.21	1.71
				0.005	239.94	3.82
22	90	171.06	4.01	0.001	845.04	3.09
				0.005	1,890.21	6.91
	72	136.85	3.77	0.001	648.67	2.96
				0.005	1,451.98	6.63
	50	95.03	3.05	0.001	391.52	2.58
				0.005	875.23	5.76
	25	47.52	1.81	0.001	138.28	1.82
				0.005	308.88	4.06

TABLE 5

Q AND $V_{occupied}$ VALUES FOR CORRUGATED METAL PIPE-ARCH CULVERTS OF VARYING SPAN SIZE AND FULLNESS SET AT GRADIENTS OF 0.001 AND 0.005[a]

Culvert Span Size	Culvert Fullness (percent)	Water Depth in Culvert (inches)	Gradient	Flow, Q[b] (cfs)	$V_{occupied}$[c] (fps)
6'1"	33	18.2	0.001	14.03	1.21
			0.005	31.45	2.72
	100	55	0.001	50.82	1.44
			0.005	113.52	3.23
7'0"	30	18.7	0.001	17.30	1.28
			0.005	38.58	2.85
	100	61	0.001	70.56	1.58
			0.005	157.64	3.52
8'2"	31	20.1	0.001	28.37	1.49
			0.005	63.41	3.33
	100	69	0.001	106.40	1.75
			0.005	237.88	3.91
9'6"	27	19.7	0.001	29.79	1.41
			0.005	66.56	3.16
	100	77	0.001	147.00	1.88
			0.005	329.28	4.20
10'3"	25	19.5	0.001	30.50	1.39
			0.005	68.29	3.11
	100	81	0.001	171.05	1.94
			0.005	382.25	4.34
11'5"	18	17.6	0.001	20.63	1.13
			0.005	46.07	2.51
	100	87	0.001	204.80	2.00
			0.005	458.24	4.48

(a) For additional data including area, wetted perimeter, hydraulic radius, $\overline{V}$, V_{max}, and V_{skin}, and backup calculations, see Appendices C and D.

(b) Q values are based on a Manning's coefficient of 0.024 (from test data, Bonneville Hydraulics Laboratory, Corps of Engineers). To meet ADF&G criteria, this should be the flow at the 2.33-year flood. Calculations assume that the culvert is free of deposited material.

(c) $V_{occupied}$ = the occupied area velocity, or the area within a pipe-arch culvert of a particular gradient and fullness, through which a fish swims while traversing the length of a culvert.

TABLE 5 (Continued)

Culvert Span Size	Culvert Fullness (percent)	Water Depth in Culvert (inches)	Gradient	Flow, Q[(b)] (cfs)	$V_{occupied}$[(c)] (fps)
12'6"	20	19.5	0.001	33.54	1.33
			0.005	75.15	2.97
	100	95	0.001	265.20	2.13
			0.005	593.58	4.75
13'5"	20	20.3	0.001	40.77	1.42
			0.005	91.24	3.18
	100	101	0.001	321.29	2.25
			0.005	717.34	5.04
14'3"	20	21.1	0.001	47.38	1.44
			0.005	105.83	3.23
	100	107	0.001	375.72	2.33
			0.005	840.32	5.20
15'6"	15	19.0	0.001	31.73	1.19
			0.005	70.76	2.66
	100	113	0.001	431.66	2.39
			0.005	966.15	5.35
16'5"	15	19.8	0.001	37.69	1.26
			0.005	84.34	2.83
	100	119	0.001	501.48	2.49
			0.005	1,121.40	5.56

will be flushed from the culverts during design flow conditions. For example, deposited loose gravel (up to 1-inch diameter) will be transported at and above water velocities of 2 feet per second (fps; Bell 1980a). Velocities above 3 fps will transport gravel up to 2 inches in diameter. Depending on the stream velocities that will transport gravel to a culvert, the culvert should, except at lower flows, purge stream-carried gravels and, therefore, it is not normally necessary to size culverts to allow for lost capacity resulting from burial. Design flood conditions will usually cause erosion of the stream bottom at the culvert entrance and the stream gradient will adjust itself to match the culvert invert, thus removing any flow restriction resulting from burial of the culvert inlet. However, if the culvert is oversized, then culvert velocities may be sufficiently low to allow deposition. If culvert size and inlet burial depth are sufficient to cause permanent deposition of streambed material, then the culvert will assume hydraulic characteristics similar to a bottomless arch. It should be emphasized that the latter situation is generally beneficial to fish because of the "natural" streambed material within the culvert and lower culvert velocities resulting from increased streambed roughness. The use of oversized, deeply buried culverts should be considered in some situations, especially where stream gradients make culvert velocity criteria difficult to meet or where unusually low velocities are required.

J. Where alignment and other conditions allow, locate stream crossings in reaches of lower gradient (i.e., pools or slower runs rather than riffles or cascades). Culverts can thus be placed as near horizontal as possible, allowing lower in-pipe velocities and less restrictive design constraints. For other general criteria for locating culvert crossings, see also Section 6.3.

K. Where the velocity criteria cannot be met by culverts crossing the full workpad width, "necking down" to shorten the length of culvert may achieve criteria compliance. Otherwise, alternative drainage structures, other than standard culverts, must be installed.

L. Stream alignment must not be changed to accommodate culvert installation without prior approval from the appropriate State and Federal agencies (ADF&G 1980a).

M. All bank cuts, slopes, fills, and exposed earth work attributable to culvert installation in all bodies of water containing fish must be stabilized to prevent erosion during and after the project. Inlets and outlets must be stabilized with riprap or other appropriate method - Stip. 3.4.2 and ADF&G 1980a.

N. Design must allow for the control of ice and debris. Ice or debris must not interfere significantly with the natural stream flow at any time of year or cause velocities in excess of the design velocity. Icing contingency plans must be developed to deal with unanticipated icing problems.

O. Culverts must conform with applicable technical stipulations as well as environmental stipulations.

P. Culverts must be monitored to assure compliance with A through O above. Field verification of the occupied area velocity can be attained by using a current meter to measure velocity near the culvert skin at the outlet end. Alternatively the maximum velocity can be estimated using the "floating chip" method and converted to $V_{occupied}$ using the conversion formulas presented in Appendices A, B or C, whichever is applicable.

Q. The above fish passage standards apply to both temporary and permanent culverts.

4.2 Example of Use of Tables 1 Through 5

Assume that a workpad traffic structure 60 feet long must be designed for Stream X. Assume further that the following information is available from the EMG and the river crossing data sheets:

Fish species presence: grayling (upstream migration for spawning)

Fish passage design maximum flow ($Q_{2.33}$) = 50 cfs
Thalweg slope at the alignment = 0.005 (0.5 percent)

Solution alternatives:

Presence of upstream migrating adult grayling (assumed to be 7 inches or longer) classifies the stream as Group II (Table 1). Turning to Table 2, Group II fish are assumed to have a maximum swimming speed (darting speed) of 7 fps. Entering Table 2 at 7 fps in the left-hand column, follow to the right until 60 feet is encountered. Follow this column down to Scale I. The maximum swimming speed that Group II fish can sustain for the 30 seconds required to traverse this distance (assuming a 2 fps net swimming speed) is 4.5 fps (Scale I). Thus, the velocity encountered by the fish in that portion of the culvert cross-sectional area in which the fish travels (outside of the center thread of maximum velocity) can be a maximum of 4.5 minus 2.0 or 2.5 fps (Scale II).

Turn now to Table 3 for a circular culvert or Table 5 for a semi-elliptical culvert. Follow down the flow column until a flow in excess of 50 cfs ($Q_{2.33}$) is encountered. Note from Table 3 that this flow would be passed by a 4.0-foot circular culvert running "full" and set at a slope of 0.005, but that the $V_{occupied}$ is unacceptably high (2.79 fps). Continuing down Table 3, it can be seen that the desired flow can be passed with an acceptable $V_{occupied}$ using a 6-foot diameter culvert set at a slope of 0.001 running 100 percent or 75 percent full. However, since this slope is less than the thalweg slope, there may be a need to compensate for the cross-sectional area lost to gravel building into the culvert. Our recommendation would be to set the downstream end of the culvert 6 inches or 0.5 feet (invert) below the thalweg, the upstream end invert will be 60 feet x [0.005 - 0.001] + 0.5 feet or 0.74 feet below the thalweg. Under this circumstance, building of streambed materials into the culvert would probably occur during low flow periods. These materials would be picked up and flushed from the culvert by flood flows and should not restrict capacity to pass the design flood.

An alternative to the 6-foot culvert would be to choose more than one smaller culvert having a combined flow of 50 cfs or greater. For example, two 4.5-foot culverts set at a slope of 0.001 would each carry 28 cfs (75 percent full) with a $V_{occupied}$ of 1.5 fps. Use of multiple structures may be the only way velocity criteria for Group I can be reasonably met with culverts in larger streams.

4.3 Culverts - Mitigation Measures and Construction Techniques

A. Overdesign of culvert size should be considered in areas where inadequate flow records exist or where culvert freeze-up is likely.

B. Ice protection measures such as thaw pipes should be incorporated into the design wherever icing is a possibility. Proper installation and maintenance of thaw pipes are essential to insure proper functioning. Thaw pipe installation at the top of the culvert is generally not adequate.

C. Water flow through disturbed streambed should be minimized. Therefore, preparation of the culvert bed should occur "in the dry" in sensitive streams and in other streams where practical. Stream diversion or fluming (see discussion in Section 3.2.3) may be possible in special situations. The use of a temporary dam and pumps to route water around the culvert site often is a practical method for smaller streams.

D. Temporary dams should be composed of sand bags, visqueen contained fill, or other method that does not expose erodable material to flowing water.

E. Bypass pumps should be adequate for the job to avoid buildup of water behind the dam and to assure sufficient flow downstream. Extra backup pumps should be in place in case of mechanical failure.

F. Pump discharge points should be armored to dissipate energy and prevent erosion.

G. Culvert installation in flowing water can be very difficult and should be avoided on fish streams unless absolutely necessary. If culvert installation occurs in flowing water, then the upstream end should be sandbagged or backfilled first to immediately direct flow through the culvert. Armoring of the upstream end should occur as soon as possible.

H. During culvert removal when water is flowing through the site (prior to stream restoration, permanent LWC installation or culvert replacement), the following sequence of operations should be used: remove fill starting from downstream end and work upstream leaving a plug of material at the upstream end; restore stream channel as much as possible with culvert in place then remove plug and roll or lift culvert out of stream.

I. Hand labor should be utilized to the greatest practical extent when armoring culvert inlet and outlet areas.

J. Culvert installation should not generally occur during frozen conditions unless channel alignment, <u>thalweg</u> slope, and <u>thalweg</u> elevation (inlet and outlet) are properly surveyed and marked before freezeup; otherwise, critical design factors such as slope and recess below grade can be difficult to attain.

5.0 LOW WATER CROSSINGS (FORDS)

5.1 Low Water Crossings - Design and Construction Standards

A. Low Water Crossings (LWC's) are generally considered unsuitable for continued heavy equipment traffic use in fish streams when flow is present. LWC's must not be used during the construction period unless approved by the appropriate State and Federal agencies.

B. Existing streambed gradient must be matched.

C. Depth comparable to that in adjacent stream must be maintained. LWC's in streams having intermittent or seasonally low flow must be designed with a V-bottom. A minimum water depth of 4 inches must be maintained in flat-bottomed LWC's to provide adequate swimming depth for fish.

D. Average water velocity within the LWC must either (1) not exceed the average velocity in adjoining stream sections or (2) satisfy the velocity criteria presented in Section 4.1 (Tables 1 and 2).

E. In-stream fill material used during LWC construction must not contain greater than 10 percent fine materials (<0.075 mm; 200 sieve) if installed during flowing water conditions without prior approval from the appropriate State and Federal agencies.

F. In streams where an LWC is planned as a permanent structure but a culvert is planned for the construction period, the LWC foundation must be installed prior to placement of the culvert whenever feasible to minimize the amount of in-stream excavation. However, if the temporary culvert satisfies all technical and environmental criteria, then it should be left in place rather than disturb the stream again to construct the LWC.

5.2 Low Water Crossings - Mitigation Measures and Construction Techniques

A. Water flow through disturbed streambed should be minimized. Therefore, preparation of the LWC foundation should occur "in the dry" in sensitive streams and in other streams where practical. Stream diversion may be possible in special situations. The use of a temporary dam and pumps to route water around the LWC site is a practical method for smaller streams.

B. Temporary dams should be composed of sandbags, visqueen contained fill, or other method that does not expose erodible material to flowing water.

C. Bypass pumps should be adequate for the job to avoid buildup of water behind the dam and to assure sufficient flow downstream.

D. Extra backup pumps should be in place in case of mechanical failure.

E. Pump discharge points should be armored to dissipate energy and prevent erosion.

F. When working in flowing water, machinery and techniques should be selected to minimize downstream siltation, e.g., use of a backhoe or gradall to shape the channel may be preferable to driving a crawler tractor back and forth across the bed.

G. Hand labor should be utilized to the greatest practical extent for armoring and shaping the LWC inlet and outlet areas.

H. Composition of the LWC bottom substrate should consider the potential for subsurface flow and the possible loss of surface flow through a "french drain" effect. Where applicable, the streambed should be sealed to prevent excessive subsurface flow by employing sufficiently fine material or by use of an impervious membrane.

6.0 PIPELINE STREAM CROSSINGS

6.1 Pipeline Stream Crossings - Design and Construction Standards

A. The pipeline stream crossing must be designed to prevent long-term alteration of the natural hydraulic and thermal characteristics of the stream - Stip. 3.4.1.1.

B. Selection of the exact crossing location is an important factor in mitigating impacts, and must consider protection of aquatic resources as well as hydraulic and engineering aspects (see Section 6.3).

C. Crossings must be timed to avoid biologically sensitive periods to the greatest practicable extent unless a lower level of overall impact can be achieved (e.g., by more rapid completion of work) during other periods. Such scheduling is to be determined on a stream-by-stream basis.

D. Methods used in the construction of pipeline stream crossings must consider protection of fish resources as well as construction expediency. Sensitive streams will require special mitigative measures. Such construction procedures must be considered on a stream-by-stream basis. State and Federal agencies must be provided with methods and specific sequence of operations for excavating and constructing crossings and backfill of trench - Stip. 3.4.1.2.5.

E. Excavated material must not be stockpiled within flowing water - Stip. 2.4.3.2. Where possible, stockpiling must occur above the normal high water mark.

F. Crossing design must consider and prevent possible adverse effects of a cold pipe on the stream's thermal regime. The temperature of natural surface or ground waters shall not be changed significantly by the pipeline system - Stip. 2.2.2.3 (see Section 6.4).

G. Channelization of waters along the pipe must be avoided - Stip. 3.4.1.2.4.

H. Slopes of cuts through stream banks shall be designed and constructed to minimize erosion and prevent slides - Stip. 3.4.2.2.

6.2 Pipeline Stream Crossings - Mitigation Measures And Construction Techinques

The construction of buried pipeline crossings represents one of the more significant potential impacts to aquatic habitats of any pipeline activity. Therefore, mitigation measures should be carefully considered.

As is the case with any in-stream work, the duration and extent of disturbance should be minimized.

6.2.1 General Mitigation Measures

A. Timing, both in terms of stream flow regime and fish use, is one of the most important factors in mitigating the effects of pipeline crossings. Construction schedule should be determined on a stream-by-stream basis and should consider the following elements: fish sensitivity, overall stream sensitivity, sedimentation potential at varying flow levels, and ease of constructability. If stream flow ceases at any time of the year, then that time should be seriously considered for construction.

B. Preconstruction planning should occur prior to all stream crossings, both major and minor. Construction procedures, duration of in-stream work, sequence of operations, and equipment to be used should be reviewed by environmental staff prior to initiation of work.

C. All equipment plus backups should be ready at crossing site before initiation of work. Equipment should be in good mechanical condition.

D. Buried stream crossings should be completed in the shortest possible time. Once in-stream work has been initiated, work should continue 24 hours per day. Where possible, equipment should work on both sides of the river simultaneously.

E. Pump discharge points and necessary hose lengths should be determined prior to pump need.

F. There should be no in-stream storage of ditch spoil. If spoil is composed of wet fine material, then berms or other measures to prevent runoff into the stream should be utilized.

G. The in-stream pipe ditch should be backfilled with material containing less than 10 percent fine materials (<0.075 mm; 200 sieve) when flowing water is present unless otherwise approved by the appropriate State and Federal agency. Natural streambed material should be utilized whenever possible. Replacement streambed materials should approximately match the natural bed materials to prevent aggradation or degradation and assure a return to equilibrium.

H. Stream bank restoration and stabilization should occur immediately after pipe burial, except that if the pipe is placed during a dry or fully frozen period, these activities must occur prior to flow reestablishment or breakup.

I. Precautions should be taken to minimize the potential of water pollution from petroleum products resulting from spills and equipment leaks. The time equipment is in flowing water should be minimized. Refueling should occur well back from the stream bank. Oil spill contingency equipment should be kept on hand.

6.2.2 Major River Crossings

A. Temporary stream diversion should be considered as an alternative method under some special circumstances, especially when crossing braided streams within wide gravel floodplains. Flow should be returned to the original channel immediately following pipeline installation.

B. A variety of ditching sequences and methods can be used to minimize siltation. Such methods may be more difficult than those that would be chosen on the basis of construction expediency or cost and, therefore, their use should be based on a site-specific evaluation of stream sensitivity and method applicability. These alternatives include:

(1) Hard plug method - With this method, excavation starts at the far ends of the pipe ditch and proceeds toward the river leaving a plug of natural material at the river's edge. The flowing water portion of the crossing is then excavated toward the bank with the plug material removed last. The pipe is installed, the river bank area is backfilled, the stream is restored, and the remaining ditch is backfilled. The advantage of this method is that the cut soils and pipe trench are exposed to flowing water for the minimum amount of time. Disadvantages include the necessity to excavate the hard plug from the side rather than digging the entire ditch in a continuous operation.

(2) Modified hard plug method - Basic operations are the same as above except that a small segment of ditch is excavated just inside of each river bank and filled with granular material. The loose fill area can then be used as a ramp for equipment to use while removing the hard plug and can be subsequently removed with relatively little difficulty because of its loose nature.

(3) Soft plug method - Excavation proceeds in the conventional manner from the active channel proceeding outward to the ends of the crossing ditch. However, when the river bank portion has been removed it is replaced with a plug of granular material that prevents silty water from running down the pipe ditch and entering the river during excavation of the lateral ditches. The soft plug is removed before installing the pipe.

(4) Many combinations of procedures may be applied on a site-specific basis.

C. Silt curtains made of canvas or filter cloth should be considered for use during summer crossings in the absence of ditch plugs. Curtains should be placed across the pipe ditch to isolate flowing water from the ditch. It should be emphasized that ditch plugs are generally preferable to silt curtains.

6.2.3 Minor Stream Crossings

A. With smaller streams, it is often practical and desirable to pipe (flume) stream flow over the pipe ditch while the excavation process is occurring. With this procedure, a culvert or other pipe is installed in the stream prior to ditching with all stream flow directed through the flume. The pipe ditch is then excavated underneath the flume and the pipe is installed by pulling it under the flume. The stream channel can be nearly restored before removing the flume, resulting in a very clean procedure.

B. An alternative to fluming is bypass pumping. Techniques are the same as described for culvert installation.

C. Temporary dams should be composed of sandbags, visqueen-contained fill, or other method that does not expose erodible material to flowing water.

D. Bypass pumps should be adequate for the job to avoid buildup of water behind the dam and to assure sufficient flow downstream.

E. Extra backup pumps should be in place in case of mechanical failure.

F. Pump discharge points should be armored to dissipate energy and prevent erosion.

G. A combination of fluming and bypass pumping may be appropriate in some circumstances. At the time of pipe installation, it may be advantageous to remove a flume and switch to pumps so that the pipe can be lowered directly into the ditch rather than pulled under the flume.

6.3 Selection of Specific Crossing Locations

A. Aquatic habitat values should be considered along with other design criteria when selecting precise locations of pipeline and workpad crossings of fish streams.

B. All aspects of pipeline interaction with the stream area should be considered when selecting locations. Such aspects may include the pipe crossing proper, adjacent workpad crossings of the stream if applicable (bridge, culvert, etc.), staging area requirements, need for clearing, and ease of restoration. The goal should be to minimize the combined impacts of the above activities by applying an integrated approach to crossing design and location. The best way to implement the above approach is via interdisciplinary field evaluation.

C. Physical and biological criteria for use in selecting crossing locations are presented in Table 6. The biological criteria emphasize avoidance of disturbance to valuable habitat areas. The physical criteria emphasize those features that will allow a crossing to be constructed with minimal physical impact and thus protect aquatic resources as well. Some of the criteria may be mutually exclusive, and relative importance will vary from stream to stream. Therefore, the planning process should involve a consideration of all criteria, and site-by-site judgements will be required regarding the weighting of various input elements.

6.4 Consideration of Cold Pipe Effects

A. The temperature of natural surface or ground waters shall not be changed significantly by the pipeline system unless approved by the applicable State and Federal agencies - Stip. 2.2.2.3.

TABLE 6
PHYSICAL AND BIOLOGICAL CRITERIA FOR USE IN SELECTING PIPELINE STREAM CROSSING LOCATIONS

DESIRABLE PHYSICAL FEATURES	UNDESIRABLE PHYSICAL FEATURES
1. Stream reach with single channel or, if braided, few active channels.	Multiple or split channels
2. Stream channel perpendicular to pipeline alignment and workpad crossing. No need to re-align or channelize stream.	Stream channel diagonal to pipeline and workpad alignment. Re-channelization necessary.
3. Straight stream reach (erosional forces equal on both banks).	Curved stream reach (erosional forces greater on one stream bank than the other).
4. If multiple channels, channel spacing and orientation conducive to minimizing construction problems.	Closely spaced or inconveniently located channels as related to constructability.
5. Low gradient stream approach; minimal potential for surface drainage into the stream.	High gradient stream approach; high potential for stream siltation.
6. Low, stable banks.	High, unstable or easily erodable banks.
7. Coarse bank, bed and subsurface soils.	Fine, erodable soils.
8. Permafrost absent.	Permafrost present.
9. Moderate to shallow stream depth.	Deep stream depth.
10. Absence of sloughs, backwater areas and high water channels.	Presence of sloughs, backwater areas and high water channels.
11. Absence of ground water flow into the stream or immediate floodplain.	Presence of springs or ground water seepage that would influence or be influenced by crossing activities.
12. Presence of stable unvegetated or sparsely vegetated terrain adjacent to the crossing for construction staging.	Lack of suitable staging area.
13. Presence of suitable area for discharge of pumped water (upland area draining away from stream, isolated floodplain depression, etc.).	Lack of suitable pump discharge area.
14. Presence of suitable area for storage and containment of ditch spoil.	Lack of suitable area for storage and containment of ditch spoil.
15. Low to moderate current velocity.	High current velocity.
DESIRABLE BIOLOGICAL FEATURES	**UNDESIRABLE BIOLOGICAL FEATURES**
A. Absence of critical, important or sensitive fish habitats (such as spawning grounds, overwintering areas, rearing areas or other areas of known significance) in the area to be directly affected by the pipeline crossing or ancillary facilities.	Presence of critical, important or sensitive fish habitats in immediate crossing area.
B. Absence of critical, important or sensitive fish habitats downstream from the crossing within the potential siltation impact zone (about 2 miles).	Presence of critical, important or sensitive fish habitats downstream from the crossing within the potential siltation impact zone (about 2 miles).
C. Absence of atypical habitat zones that might be used by fish, e.g. sloughs, backwaters, ground water seepage areas, deep pools, overhanging banks, wetlands, etc.	Presence of atypical habitat zones that might be used by fish in the immediate crossing area.
D. Absence of aquatic vegetation or vegetated islands.	Presence of aquatic vegetation or vegetated islands.
E. Riffle type aquatic habitat preferred at crossing (if not spawning area).	Presence of deep pool type aquatic habitat at crossing.
F. Low numbers of aquatic invertebrates (fish food organisms).	High numbers of aquatic invertebrates.
G. Sparsely vegetated stream banks.	Heavily vegetated stream banks.

B. Burial of a cold pipe beneath streams may result in a variety of physical impacts to the stream system and secondarily affect aquatic resources. Cold pipe effects have not been studied in detail; therefore, impacts cannot be accurately predicted nor can mitigation measures be accurately developed. Studies of cold pipe effects are currently underway and reports dealing with this topic in detail will be forthcoming.

7.0 STREAM DIVERSION CHANNELS - DESIGN AND CONSTRUCTION STANDARDS

A. Stream channel diversions must be avoided unless absolutely necessary.

B. Temporary diversion channels must be capable of carrying flows anticipated to occur during the construction period.

C. Under most circumstances during excavation or construction, the temporary diversion channel must be isolated from water of the stream to be diverted by natural plugs left in place at the upstream and downstream ends of the diversion channel (ADF&G 1980a).

D. The bed of the diversion channel must be constructed of material that will not erode at expected flows.

E. Under most circumstances, diversion of water flow into the temporary diversion channel must be conducted by first removing the downstream plug, then removing the upstream plug, then closing the upstream end and then the downstream end of the natural channel of the diverted stream (ADF&G 1980a). Other methods must be approved on a case-by-case basis.

F. Under most circumstances, rediversion of flow into the natural stream will be conducted by removing the downstream plug from the natural channel and then the upstream plug, then closing the upstream end and then the downstream end of the diversion channel (ADF&G 1980a). Other methods must be approved on a case-by-case basis.

G. Average water velocity within the diversion channel must either (1) not exceed the average velocity in the natural stream at that location or (2) satisfy the velocity criteria presented in Section 2.2.2 (Tables 1 and 2).

H. Abandoned diversion structures must be removed or plugged and stabilized - Stip. 2.5.3.

8.0 BLASTING - DESIGN AND CONSTRUCTION STANDARDS

A. No blasting shall be done under water or within 1/4-mile of streams or lakes with identified fisheries or wildlife resources unless approved by the applicable State and Federal agencies - Stip. 2.11.2.

B. Blasting within 1/4-mile of fish waters must be considered on a site-by-site basis according to criteria to be developed pending completion of Northwest Alaska Pipeline Company studies.

As a mitigating measure, blasting near fish habitat should attempt to reduce impact by using the smallest effective charge; when more than one charge is employed, the charges should be wired in series with a sufficiently long detonation delay to avoid magnification of shock waves.

9.0 WATER WITHDRAWAL

Water withdrawal from fish streams or lakes may be associated with a variety of activities including, but not limited to, hydrostatic testing, camp domestic water supply, dust control, and gravel washing. The rate and duration of withdrawal will vary widely depending on the particular need.

9.1 Water Withdrawal - Design and Construction Standards

A. Water must not be withdrawn from fish spawning, rearing, or overwintering areas or from waters that replenish those areas unless specifically approved by the appropriate State and Federal agencies - Stip. 2.5.4.7.

B. In-stream flow must not be reduced below that necessary to support spawning, incubation, rearing, migration, overwintering, and survival of fish. During the open-water season, in-stream flow after water withdrawal must exceed 30 percent of the average annual flow (based on criteria established by Tennant 1975). During frozen conditions or when unaltered flow is less than 30 percent of average annual flow, water withdrawal must be considered and approved on a site-specific basis. Withdrawal during low flow, if permitted, generally must not exceed 10 percent of the flow at the time of withdrawal.

   Water withdrawal from lakes supporting fish resources must be evaluated on a site-specific basis.

C. To minimize fish entrainment and impingement, each water intake equipment structure must be centered and enclosed in a screened box. Screen mesh may not exceed 1/4 inch. Four square feet of wetted screen area is required for each 450-gpm withdrawal to provide a 0.5-fps or lesser approach velocity with up to 50 percent of the wetted area fouled with debris. Withdrawal rates are likely to vary from 300 to 3000 gpm depending on pump size and percentage of pump capacity utilized. A square sided screened box 3 ft x 3 ft x 3 ft will normally be sufficiently large to satisfy the above criteria for larger pumps, assuming that at least three-fourths of the box is submerged. The screened box must be built with the screen outside of the frame such that no inside angles are formed to trap fish. Screen must be kept clear of debris to prevent localized high through-screen velocities.

D. Stationary pumps must have provisions to contain spilled petroleum products.

E. Water withdrawal must be monitored to assure compliance with A through D above. The extent of the monitoring must be appropriate to the scope of the operation and the sensitivity of the water body involved.

9.2 Water Withdrawal - Mitigation Measures And Construction Techniques

A. Bodies of water not containing fish should be considered for water withdrawal before utilizing fish waters. Other options not involving direct withdrawal from fish habitat may also be appropriate, depending on site conditions and water needs; e.g., excavation of an isolated sump within a floodplain area may be desirable in some circumstances. Some gravel pits may be useful as water sources, especially if such use is considered prior to mining and incorporated into the mining plan.

B. Water withdrawal locations within fish streams should be selected to minimize conflicts with fish resources and should consider the following factors:

- Stream Flow - Streams with low flow relative to the withdrawal volume should be avoided (see Section 8.1B). If necessary, stream flow measurements should be made at the time of year planned for withdrawal.

- Stream Depth - Deep stream reaches are generally preferred over shallow areas in order to provide adequate depth for the intake (see Section 8.2 C).

- Fish Habitat Value - Important fish habitat areas at, and downstream from, the withdrawal site should be avoided (see Section 8.1A).

- Fish Presence - Withdrawal sites should avoid known areas of fish concentration especially where juvenile fish are present.

C. Intake structures should be placed where depth is adequate to submerge the screen box and prevent surface vortices. It is generally preferable to withdraw water from mid-stream rather than along the shore. Excavation of an in-stream sump should be avoided unless absolutely necessary.

D. Winter withdrawal sites should be selected only where historical stream flow data and biological information are adequate to assure minimal impact.

E. Intake and discharge hoses should be sufficiently long to preclude damage to stream banks by tank trucks, pumps, or other equipment.

10.0 DISCHARGE OF WATER

Discharge of water into fish streams or lakes from a point source may be associated with a variety of activities including, but not limited to, hydrostatic testing, pipeline ditch dewatering, and bypass pumping during pipeline crossing construction or culvert installation. The rate and duration of the discharge will vary widely depending on the particular activity.

10.1 Discharge of Water - Design and Construction Standards

A. Quality of the discharged water must comply with applicable State and Federal water quality regulations. Exceptions to the above must be permitted and/or approved by the appropriate State and Federal agencies. Stip. 2.2.2.1.

B. Discharge points must be armored or provided with energy dissipation devices to prevent streambed or bank erosion and in-stream turbulence.

C. Discharge of water into a stream must not cause flow to increase by more than 50 percent or to exceed the mean annual flood without prior approval of the appropriate State and Federal agencies.

D. Discharge of water must be monitored to assure compliance with A through C above. The extent of the monitoring must be appropriate to the scope of the operation and the sensitivity of the water body involved.

10.2 Discharge of Water - Mitigation Measures and Construction Techniques

A. Bodies of water not containing fish should be considered for water discharge before utilizing fish waters, especially if the discharge water is polluted. Upland discharge sites may also be appropriate in some circumstances, particularly where the effluent has a high suspended solids content. However, it should be noted that discharge of unpolluted water directly into a stream is generally preferable to upland discharge since the possibility of erosion and subsequent stream siltation are minimized.

B. Discharge locations within fish streams should be selected to minimize conflicts with fish resources. Considerations should include:

- Stream flow - Streams with low flow relative to the discharge volume should be avoided.

- Streambed substrate - Areas of coarse substrate are preferred over areas with fine, easily erodible bottom material.

- Stream depth - Deep stream areas are preferred over shallow areas.

- Fish habitat value - Important fish habitat use areas should be avoided.

- Fish presence - Discharge location should avoid areas where sensitive life history stages of fish are known to be present.

C. The discharge structure should be placed so that erosion of the stream bank or bed is minimized. Discharge directly into the middle of the stream may be desirable in some circumstances.

D. Discharge water should not fall or shoot downward into the stream; rather, the discharge stream should be oriented horizontal to the natural stream surface and at equal elevation. This procedure will avoid gas supersaturation that could lead to gas bubble disease in fish.

11.0 MATERIAL AND DISPOSAL SITES

11.1 Material and Disposal Sites - Design and Construction Standards

A. Spoil disposal sites must not be located within floodplain areas (within the 5 year [Q_5] flood line) unless approved by the appropriate State and Federal agencies.

B. Material and disposal sites must be located so as to provide a buffer of undisturbed land at least 500 feet wide between the site and streams, lakes, and wetlands unless approved by the appropriate State and Federal agencies - Stip. 2.3.2.

C. Prevention of the destruction of fish resources must be a primary emphasis when formulating material removal plans associated with active floodplain areas - Stip. 2.6.2.1.

D. Standards and guidelines to accomplish (C) above for floodplain material sites are presented in the document "Gravel Removal Guidelines Manual for Arctic and Subarctic Floodplains" prepared by the U.S. Fish & Wildlife Service (1980). This manual provides detailed criteria for selection of site location, site planning, operating procedures, and restoration.

E. The location of disposal sites and upland material sites must be selected to minimize potential adverse impacts on aquatic environments. The following factors should be considered:

- Distance from water bodies, especially those containing fish.
- Topography and drainage patterns relative to potential for erosion and siltation of nearby aquatic habitats.
- Characteristics of surrounding soils and vegetation relative to erodibility and stability.

- Probable effectiveness of erosion control, stabilization, and other restoration measures.

- Possibility of long-term erosion and siltation of aquatic habitats.

F. Erosion and siltation of aquatic habitats must be prevented while material and disposal sites are in operation.

G. Abandoned material and disposal sites must be stabilized and restored as defined in Stipulation 2.12.

11.2 Material and Disposal Sites - Mitigation Measures and Construction Techniques

A. The selection of material sources and disposal sites in any particular area should involve an integrated approach combining environmental aspects with other project needs. In general, upland material sites are preferred over floodplain sites in those areas where both are available. However, individual site characteristics must be considered.

B. Mitigation measures and mining techniques for protection of aquatic resources in relation to floodplain material sites are presented in detail in the document "Gravel Removal Guidelines Manual for Arctic and Subarctic Floodplains" (U.S. Fish and Wildlife Service 1980).

C. Site location and site planning provide the greatest opportunity for mitigation. Interdisciplinary field evaluation should be utilized to maximize protection of aquatic resources and other environmental values.

12.0 STREAM RESTORATION

12.1 Stream Restoration - Design and Construction Standards

A. All disturbed areas must be left in a stabilized condition - Stip. 2.12.2.

B. Restored stream configuration must be as near to the original condition as practical. Avoid rechannelization or straightening.

C. Restored stream gradient must correspond as near as is feasible to the original stream gradient as referenced to surveyed control points both upstream and downstream.

D. Composition of the restored substrate must be at least as coarse as the original streambed but should not contain greater than 10 percent fine materials (0.075 mm; 200 sieve) if installed during flowing water conditions without prior approval from the appropriate State and Federal agencies. Actual composition of the restored stream bottom must be determined on a site-specific basis.

E. Average water velocity within the restored channel must either (1) not exceed the average velocity in adjoining stream sections or (2) satisfy the velocity criteria presented in Section 2.2.2 (Tables 1 and 2).

F. Netting and mats used for bank stabilization must be biodegradable.

12.2 Stream Restoration - Mitigation Measures And Construction Techniques

A. Stream restoration should be accomplished immediately following stream disturbance and should follow a site-specific plan.

B. Natural materials should be used in the restoration and stabilization process to the greatest extent feasible. Artificial stabilization materials such as gabions and sacked concrete may add additional impacts, alter stream hydraulics, and are difficult to revegetate. Of the two, gabions are much preferred.

C. Hand labor should be utilized wherever feasible to put finishing touches on channel restoration, install bank riprap, etc.

D. Restoration of stream bottom substrate should consider the potential for subsurface flow and the possible loss of surface flow through a "french drain" effect. Where applicable, the streambed should be sealed to prevent excessive subsurface flow by employing sufficiently fine material or by use of an impervious membrane.

E. In fast waters, placement of boulders within the restored streambed is an effective way of increasing bed roughness, decreasing average velocity and enhancing fish habitat. Care should be taken, however, that boulders are not placed so as to increase erosion of stream banks or cause stream diversion.

F. Revegetation of stream banks, where practical, should be accomplished as soon as possible.

13.0 SEDIMENT CONTROL

13.1 Sediment Control - Design and Construction Standards

A. Settling basins must be designed to remove 90 percent of the suspended particles in the sand size range (0.075 mm; 200 sieve and larger).

B. In order to accomplish the above standard, basins must be sufficiently deep to assure a velocity through the basin of less than 0.5 feet per second and to allow sufficient storage capacity for settled materials.

C. To assure adequate retention time, minimum basin surface area must be computed on the basis of the following (Hansen 1973):

Surface area (sq. ft.) = 300 x Q (discharge through the basin in cubic feet per second)

D. Inlet and outlet must be sufficiently wide to prevent channelization of flow. Outlet weir must be designed to skim water from the surface of the pond.

E. Settling basins must be maintained and dredged, if necessary, to assure proper functioning over time.

13.2 Sediment Control - Mitigation Measures and Construction Techniques

A wide variety of pipeline activities result in the generation of muddy water adjacent to streams. Such activities include pumping water from pipeline ditches, drainage of wet spoil material, and runoff from disturbed areas during rain or snow melt.

A. All pump operations should carry sufficient discharge hose so that flexibility of discharge location is possible.

B. Temporary discharge of heavily silted water onto vegetated terrain away from the stream can be an effective means of minimizing stream siltation depending on site characteristics. In this situation, possible damage to terrestrial vegetation must be weighed against potential damage to stream habitat. This technique applies both to pump discharge and possible diversion of turbid surface water flow (not applicable in permafrost areas or where dewatering of fish habitat would occur). Energy dissipators should be used to prevent damage to vegetation and the organic mat.

C. Spoil containment berms should be considered where fine spoil materials must be placed immediately adjacent to a stream.

D. Settling basins should be utilized where entry of silty water into a stream is inevitable. The basin should be large enough to allow settlement of a significant portion of the suspended materials as per the standards presented in Section 2.9.

E. Settling basins should be designed to allow periodic maintenance and removal of accumulated sediment.

14.0 STREAM SENSITIVITY CLASSIFICATION

The large number of streams potentially disturbed by construction of ANGTS and the need to provide design and construction planning for the various stream-related activities suggested that a system for classifying streams according to their sensitivity could aid the decision process. Such a classification system would be particularly helpful in suggesting the degree to which special mitigation measures and timing constraints need be applied. It is recognized that there is no substitute for site-specific planning. The classification system proposed in this chapter is not intended to replace the process of stream-by-stream analysis; rather, it is intended to aid that process by organizing data and applying objective criteria.

Table 7 presents a system for rating streams according to various categories of biological value (with emphasis on fish). Additionally, ratings are presented on the basis of physical susceptibility or vulnerability to disturbance. It is felt that a combination of these two factors - biological value and vulnerability to perturbation - provides a reasonable basis for assessing overall sensitivity. Table 7 is utilized by picking the appropriate description in each category for a particular stream and entering the numerical value for that description in the right column. The numerical ratings are totalled separately for the "biological value" and "susceptibility to disturbance" factors.

Table 7 also translates the numerical totals into three classes of biological value and three classes of susceptibility. These classes can then be combined (e.g., IA, IIB, etc.) for a total of 9 combination classes. It is, therefore, possible using Table 7 to assign an overall sensitivity classification to any of the streams to be affected by ANGTS, assuming that the stream data is complete.

Any system of rating and classification is to some degree arbitrary and it is expected that some streams will have special conditions that will not be

TABLE 7

STREAM SENSITIVITY RATING AND CLASSIFICATION WORK SHEET[a]

STREAM NAME:______________

	Rating Category			Assigned Value
Biological Value				
Overall Productivity	Low 1	Moderate 2	High 3	--
Species Factor	Non-Salmonids Only 1	Salmonids[b] without Salmon 2	Salmon 3	--
Overwintering Use	No 0	Yes 2		--
Spawning Use	No 0	Non-Salmon 1	Salmon 2	--
Rearing Use	No 0	Non-Salmon 1	Salmon 2	--
Migration	No 0	Non-Salmon 1	Salmon 2	--
TOTAL				
Susceptibility to Disturbance				
Design Flood	>10000 cfs 1	1000-10000 cfs 2	<1000 cfs 3	--
Minimum Flow	0 cfs (intermittent) 1	>10 cfs 2	<10 cfs 3	--
Stream Morphology	Braided Channel 1	Single non-incised Channel 2	Single Incised Channel 3	--
Soil Characteristics	Gravel & Cobble 1	Moderately Erodable Mixed 2	Highly Erodable Fine 3	--
Gradient	<0.2% 1	0.2 - 0.5% 2	>0.5% 3	--
Permafrost	No 0	Yes 2		
TOTAL				

Biological Value Classification

Rating Points	Value	Class
9-14	High	I
5-8	Moderate	II
2-4	Low	III

Susceptibility to Disturbance Classification

Rating	Susceptibility	Class
12-17	High	A
9-11	Moderate	B
5-8	Low	C

COMBINED CLASSIFICATION

____

(a) After the method under development by N. Netsch, USFWS.
(b) Family Salmonidae considered to include whitefish and grayling.

adequately reflected in the classification system. Nevertheless, it is anticipated that this system will in most cases provide a reasonable estimation of the sensitivity of a stream and its fish resources to physical disturbance.

15.0 STREAM SENSITIVITY CLASSES VS. APPLICATION OF MITIGATION MEASURES AND TIMING RESTRAINTS

15.1 Timing Restraints For In-Stream Work

The Environmental Master Guide, Level 1 and Level 2 provide the standard for the sensitivity of fish resources on an annual basis within all fish streams affected by ANGTS. Construction during the least critical period is generally desirable. However, other factors such as construction cost, construction feasibility, hydrology, and geotechnical concerns must be taken into consideration. The extent to which fish sensitive times influence the construction planning process logically depends on the nature of the fish resources within the stream and the likelihood that physical disturbance will affect those resources.

15.1.1 Buried Pipeline Stream Crossings

The following guidelines are suggested to apply the stream classes proposed in Chapter 4 to use of timing restraints:

Stream Class	Guideline
IA IB IIA	Construct during the least sensitive time only. Use all practicable mitigation measures.
IC IIB IIC IIIA	Construct during the least sensitive time when possible. Do not construct during "critical" times. Construction during "sensitive" times may occur with appropriate mitigation.
IIIB IIIC	Avoid construction during critical times if possible. Construct at other times using normal good procedure.

15.1.2 Other Activities

Other stream disturbing activities such as culvert installation generally involve less impact than buried pipeline crossings and are more easily mitigated. The following guidelines are suggested for these activities:

Stream Class	Guidelines
IA IB IIA	Avoid construction during "critical" or "sensitive" times unless absolutely necessary. Construction during these times will require a detailed mitigation plan.
IC IIB IIC IIIA	Avoid construction during "critical" times if possible. Construction during "critical" or "sensitive" times may occur with proper mitigation measures.
IIIB IIIC	Construction during critical times may occur with proper mitigation measures. Construct at other times using normal good procedure.

15.2 Application Of Mitigation Measures

15.2.1 Buried Pipeline Stream Crossings

The following guidelines apply to in-stream work during periods of flowing water. If the streambed is dry, then special mitigation is not required regardless of stream sensitivity.

Stream Class	Guidelines
IA IB IIA	Special mitigation required. Bypass water with pump or flume on small streams. Use hard plug method or other special procedure on large streams.
IC IIB IIC IIIA	Moderate level of mitigation required. Bypass water on small streams whenever practical. Use soft plug method or silt curtain on large streams where applicable.
IIIB IIIC	Low level of mitigation required. Employ normal good construction procedures.

15.2.2 Other Activities

The range and level of disturbance caused by other activities such as culvert installation and LWC construction is too great to allow practical application of specific guidelines. The following general guidelines, however, will aid in application of the measures described in Sections 2 through 13.

Stream Class	Guidelines
IA IB IIA	Special mitigation required. Avoid work in flowing water. Prevent siltation to greatest feasible extent.
IC IIB IIC IIIA	Moderate level of mitigation required. Minimize work in flowing waters and downstream siltation.
IIIB IIIC	Low level of mitigation required. Apply normal good construction procedures.

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APPENDIX A

Q AND $V_{occupied}$ VALUES FOR CIRCULAR CORRUGATED METAL PIPE CULVERTS OF VARIOUS DIAMETER AND FULLNESS SET AT SLOPES OF .001, .0025, AND .005[a]

Culvert Diameter (feet)	Culvert Fullness (percent)	Area (feet)	Gradient (S)	Flow, Q[a] (cfs)	$\overline{V}$[b]	V_{max}[c]	V_{skin}[d]	$V_{occupied}$[c]
2.5	100	4.909	.0010	7.0	1.43	1.79	.72	.89
			.0025	11.1	2.26	2.83	1.13	1.41
			.0050	15.7	3.20	4.00	1.60	2.00
2.5	75	3.670	.0010	5.9	1.60	2.00	.80	1.00
			.0025	9.3	2.53	3.17	1.27	1.58
			.0050	13.2	3.58	4.48	1.79	2.24
2.5	50	2.454	.0010	3.5	1.43	1.79	.72	.89
			.0025	5.6	2.26	2.83	1.13	1.41
			.0050	7.9	3.20	4.00	1.60	2.00
2.5	37	1.834	.0010	2.4	1.29	1.61	.65	.81
			.0025	3.7	2.04	2.55	1.02	1.28
			.0050	5.3	2.89	3.61	1.44	1.80
3.0	100	7.069	.0010	11.4	1.62	2.02	.81	1.01
			.0025	18.1	2.56	3.19	1.28	1.60
			.0050	25.5	3.61	4.52	1.81	2.26
3.0	75	5.285	.0010	9.6	1.81	2.26	.90	1.13
			.0025	15.1	2.86	3.58	1.43	1.79
			.0050	21.4	4.05	5.06	2.02	2.53
3.0	50	3.534	.0010	5.7	1.62	2.02	.81	1.01
			.0025	9.0	2.56	3.19	1.28	1.60
			.0050	12.8	3.61	4.52	1.81	2.26
3.0	37	2.641	.0010	3.9	1.46	1.82	.73	.91
			.0025	6.1	2.31	2.88	1.15	1.44
			.0050	8.6	3.26	4.08	1.63	2.04
3.5	100	9.621	.0010	17.2	1.79	2.24	.90	1.12
			.0025	27.3	2.83	3.54	1.42	1.77
			.0050	38.5	4.01	5.01	2.00	2.50
3.5	75	7.193	.0010	14.4	2.01	2.51	1.00	1.25
			.0025	22.8	3.17	3.96	1.59	1.98
			.0050	32.3	4.48	5.61	2.24	2.80
3.5	50	4.811	.0010	8.6	1.79	2.24	.90	1.12
			.0025	13.6	2.83	3.54	1.42	1.77
			.0050	19.3	4.01	5.01	2.00	2.50
3.5	37	3.594	.0010	5.8	1.62	2.02	.81	1.01
			.0025	9.2	2.56	3.19	1.28	1.60
			.0050	13.0	3.61	4.52	1.81	2.26

(a) Q values are based on a Manning's coefficient of 0.024 (from Test Data, Bonneville Hydraulics Laboratory, COE). Q at 100 percent fullness was extrapolated from Figure 186 Armco (1955), and interpolated for n = 0.024. Other values calculated from Q = wetted area x $\overline{V}$.

(b) $\overline{V}$ = the average water velocity (in feet per second) within a pipe culvert, at a particular gradient and fullness. $\overline{V} = \frac{1.486}{0.024} S^{1/2}R^{2/3}$ (S = slope or gradient, R = hydraulic radius).

(c) V_{max} = the maximum water velocity (in feet per second) within a (circular) pipe culvert at a particular gradient and fullness; where: $V_{max} = \overline{V}/0.8$.

(d) V_{skin} = the skin velocity (in feet per second) of water adjacent to the sides of a pipe culvert at a particular gradient and fullness; where $V_{skin} = 0.4\ V_{max}$, or = $0.50\ \overline{V}$.

(e) $V_{occupied}$ = the occupied area velocity or the area within a pipe culvert of a particular gradient and fullness, through which a fish swims while traversing the length of a culvert; where $V_{occupied} = V_{skin} + (\overline{V} - V_{skin})$.

Culvert Diameter (feet)	Culvert Fullness (percent)	Area (feet)	Gradient (S)	Flow, $Q^{(a)}$ (cfs)	$\overline{V}^{(b)}$	$V_{max}^{(c)}$	$V_{skin}^{(d)}$	$V_{occupied}^{(c)}$
4.0	100	12.566	.0010	24.6	1.96	2.45	.98	1.22
			.0025	38.9	3.10	3.87	1.55	1.94
			.0050	55.0	4.38	5.47	2.19	2.74
4.0	75	9.395	.0010	20.6	2.19	2.74	1.10	1.37
			.0025	32.6	3.47	4.33	1.73	2.17
			.0050	46.1	4.90	6.13	2.45	3.06
4.0	50	6.283	.0010	12.3	1.96	2.45	.98	1.22
			.0025	19.5	3.10	3.87	1.55	1.94
			.0050	27.5	4.38	5.47	2.19	2.74
4.0	37	4.694	.0010	8.3	1.77	2.21	.88	1.10
			.0025	13.1	2.79	3.49	1.40	1.75
			.0050	18.5	3.95	4.94	1.97	2.47
4.5	100	15.904	.0010	33.7	2.12	2.65	1.06	1.32
			.0025	53.3	3.35	4.19	1.67	2.09
			.0050	75.3	4.74	5.92	2.37	2.96
4.5	75	11.891	.0010	28.2	2.37	2.96	1.19	1.48
			.0025	44.6	3.75	4.69	1.87	2.34
			.0050	63.1	5.30	6.63	2.65	3.31
4.5	50	7.952	.0010	16.8	2.12	2.65	1.06	1.32
			.0025	26.6	3.35	4.19	1.67	2.09
			.0050	37.7	4.74	5.92	2.37	2.96
4.5	37	5.941	.0010	11.4	1.91	2.39	.96	1.19
			.0025	17.9	3.02	3.78	1.51	1.89
			.0050	25.4	4.27	5.34	2.14	2.67
5.0	100	19.635	.0010	44.6	2.27	2.84	1.14	1.42
			.0025	70.5	3.59	4.49	1.80	2.25
			.0050	99.8	5.08	6.35	2.54	3.18
5.0	75	14.680	.0010	37.3	2.54	3.18	1.27	1.59
			.0025	59.1	4.02	5.03	2.01	2.51
			.0050	83.5	5.69	7.11	2.84	3.56
5.0	50	9.818	.0010	22.3	2.27	2.84	1.14	1.42
			.0025	35.3	3.59	4.49	1.80	2.25
			.0050	49.9	5.08	6.35	2.54	3.18
5.0	37	7.335	.0010	15.0	2.05	2.56	1.02	1.28
			.0025	23.8	3.24	4.05	1.62	2.03
			.0050	33.6	4.58	5.73	2.29	2.86
6.0	100	28.274	.0010	72.5	2.57	3.21	1.28	1.60
			.0025	114.7	4.06	5.07	2.03	2.54
			.0050	162.2	5.74	7.17	2.87	3.59
6.0	75	21.139	.0010	60.7	2.87	3.59	1.44	1.80
			.0025	96.0	4.54	5.68	2.27	2.84
			.0050	135.8	6.42	8.03	3.21	4.02
6.0	50	14.137	.0010	36.3	2.57	3.21	1.28	1.60
			.0025	57.4	4.06	5.07	2.03	2.54
			.0050	81.1	5.74	7.17	2.87	3.59
6.0	37	10.562	.0010	24.4	2.31	2.89	1.16	1.45
			.0025	38.7	3.66	4.57	1.83	2.29
			.0050	54.7	5.18	6.47	2.59	3.23

Culvert Diameter (feet)	Culvert Fullness (percent)	Area (feet)	Gradient (S)	Flow, Q[a] (cfs)	$\overline{V}$[b]	V_{max}[c]	V'_{skin}[d]	$V_{occupied}$[c]
7.0	100	38.485	.0010	109.4	2.84	3.55	1.42	1.78
			.0025	173.0	4.50	5.62	2.25	2.81
			.0050	244.7	6.36	7.95	3.18	3.97
7.0	75	28.773	.0010	91.6	3.18	3.98	1.59	1.99
			.0025	144.8	5.03	6.29	2.52	3.15
			.0050	204.8	7.12	8.90	3.56	4.45
7.0	50	19.242	.0010	54.7	2.84	3.55	1.42	1.78
			.0025	86.5	4.50	5.62	2.25	2.81
			.0050	122.3	6.36	7.95	3.18	3.97
7.0	37	14.377	.0010	36.9	2.57	3.21	1.28	1.60
			.0025	58.3	4.06	5.07	2.03	2.53
			.0050	82.5	5.74	7.17	2.87	3.58
8.0	100	50.266	.0010	156.2	3.11	3.89	1.55	1.94
			.0025	247.0	4.91	6.14	2.46	3.07
			.0050	349.4	6.95	8.69	3.48	4.34
8.0	75	37.581	.0010	130.8	3.48	4.35	1.74	2.18
			.0025	206.8	5.50	6.88	2.75	3.44
			.0050	292.5	7.78	9.73	3.89	4.86
8.0	50	25.133	.0010	78.1	3.11	3.89	1.55	1.94
			.0025	123.5	4.91	6.14	2.46	3.07
			.0050	174.7	6.95	8.69	3.48	4.34
8.0	37	18.778	.0010	52.7	2.80	3.50	1.40	1.75
			.0025	83.2	4.43	5.54	2.22	2.77
			.0050	117.7	6.27	7.84	3.13	3.92
9.0	100	63.617	.0010	213.9	3.36	4.20	1.68	2.10
			.0025	338.2	5.32	6.65	2.66	3.32
			.0050	478.3	7.52	9.40	3.76	4.70
9.0	75	47.563	.0010	179.1	3.76	4.71	1.88	2.35
			.0025	283.1	5.95	7.44	2.98	3.72
			.0050	400.4	8.42	10.52	4.21	5.26
9.0	50	31.809	.0010	106.9	3.36	4.20	1.68	2.10
			.0025	169.1	5.32	6.65	2.66	3.32
			.0050	239.1	7.52	9.40	3.76	4.70
9.0	37	23.765	.0010	72.1	3.03	3.79	1.52	1.90
			.0025	114.0	4.80	5.99	2.40	3.00
			.0050	161.2	6.78	8.48	3.39	4.24
10.0	100	78.540	.0010	283.3	3.61	4.51	1.80	2.25
			.0025	447.9	5.70	7.13	2.85	3.56
			.0050	633.4	8.07	10.08	4.03	5.04
10.0	75	58.720	.0010	237.1	4.04	5.05	2.02	2.52
			.0025	375.0	6.39	7.98	3.19	3.99
			.0050	530.3	9.03	11.29	4.52	5.64
10.0	50	39.270	.0010	141.6	3.61	4.51	1.80	2.25
			.0025	224.0	5.70	7.13	2.85	3.56
			.0050	316.7	8.07	10.08	4.03	5.04
10.0	37	29.340	.0010	95.5	3.25	4.07	1.63	2.03
			.0025	150.9	5.14	6.43	2.57	3.22
			.0050	213.5	7.28	9.09	3.64	4.55

APPENDIX B

Q AND $V_{occupied}$ VALUES FOR (SEMI-CIRCULAR) BOTTOMLESS ARCH CULVERT BRIDGES OF VARYING DIAMETER AND FULLNESS SET AT GRADIENTS OF 0.001 AND 0.005[a]

Culvert Diameter (feet)	Culvert Fullness (percent)	Wetted Area ($feet^2$)	Hydraulic Radius[a]	Gradient (S)	Flow, Q[b] (cfs)	$\overline{V}$[c]	V_{max}[d]	V_{skin}[e]	$V_{occupied}$[f]
10	90	35.34	1.82	0.001	103.19	2.92	4.29	1.46	1.83
				0.005	230.77	6.53	9.60	3.27	4.08
	72	28.27	1.72	0.001	79.74	2.81	4.13	1.41	1.76
				0.005	177.82	6.29	9.25	3.15	3.93
	50	19.64	1.39	0.001	47.92	2.44	3.59	1.22	1.53
				0.005	107.04	5.45	8.01	2.73	3.41
	25	9.82	0.82	0.001	16.89	1.72	2.53	.86	1.08
				0.005	37.71	3.84	5.65	1.92	2.40
12	90	50.90	2.19	0.001	167.97	3.30	4.85	1.65	2.06
				0.005	375.64	7.38	10.85	3.69	4.61
	72	40.72	2.06	0.001	129.08	3.17	4.66	1.59	1.98
				0.005	288.70	7.09	10.43	3.55	4.43
	50	28.28	1.66	0.001	77.77	2.75	4.04	1.38	1.72
				0.005	174.49	6.17	9.07	3.09	3.86
	25	14.14	.99	0.001	27.43	1.94	2.85	.97	1.21
				0.005	61.51	4.35	6.40	2.17	2.72

(a) Wetted cross section area (A) divided by wetted perimeter (p) or $R = A/p$.

(b) Q calculated from area A times $\overline{V}$ (see Table 4, footnote b).

(c) $\overline{V}$ = the average water velocity (in feet per second) within an arch culvert at a particular gradient and fullness. $\overline{V} = \frac{1.486}{0.024} S^{1/2} R^{2/3}$ (S = slope or gradient, R = hydraulic radius).

(d) V_{max} = the maximum water velocity (in feet per second) within an arch culvert at a particular gradient and fullness; where: $V_{max} = \overline{V}/0.68$.

(e) V_{skin} = the skin velocity (in feet per second) of water adjacent to the sides of an arch culvert, at a particular gradient and fullness; where $V_{skin} = 0.4\ V_{max}$, or $= 0.59\ \overline{V}$

(f) $V_{occupied}$ = the occupied area velocity or the area within an arch culvert of a particular gradient and fullness, through which a fish swims while traversing the length of a culvert; where $V_{occupied} = V_{skin} + 0.25\ (\overline{V} - V_{skin})$.

Culvert Diameter (feet)	Culvert Fullness (percent)	Wetted Area (feet^2)	Hydraulic Radius[a]	Gradient (S)	Flow, Q[b] (cfs)	$\overline{V}$[c]	V_{max}[d]	V_{skin}[e]	$V_{occupied}$[f]
14	90	69.27	2.55	0.001	252.84	3.65	5.37	1.83	2.28
				0.005	565.94	8.17	12.01	4.09	5.11
	72	55.42	2.40	0.001	194.52	3.51	5.16	1.76	2.19
				0.005	435.05	7.85	11.54	3.93	4.91
	50	38.49	1.94	0.001	117.39	3.05	4.49	1.53	1.91
				0.005	262.12	6.81	10.01	3.41	4.26
	25	19.24	1.15	0.001	41.37	2.15	3.16	1.08	1.34
				0.005	92.54	4.81	7.07	2.41	3.01
16	90	90.48	2.92	0.001	361.92	4.00	5.88	2.00	2.50
				0.005	808.89	8.94	13.15	4.47	5.59
	72	72.38	2.74	0.001	277.22	3.83	5.63	1.92	2.39
				0.005	620.30	8.57	12.60	4.29	5.36
	50	50.27	2.22	0.001	167.40	3.33	4.90	1.67	2.08
				0.005	374.51	7.45	10.96	3.73	4.66
	25	25.13	1.32	0.001	59.31	2.36	3.47	1.18	1.48
				0.005	132.44	5.27	7.75	2.64	3.29
18	90	114.51	3.28	0.001	494.68	4.32	6.35	2.16	2.70
				0.005	1,107.31	9.67	14.22	4.87	6.04
	72	91.61	3.09	0.001	380.18	4.15	6.10	2.08	2.59
				0.005	851.06	9.29	13.66	4.65	5.81
	50	63.62	2.50	0.001	229.67	3.61	5.31	1.81	2.26
				0.005	512.78	8.06	11.85	4.03	5.04
	25	31.81	1.48	0.001	80.80	2.54	3.74	1.27	1.59
				0.005	181.00	5.69	8.37	2.85	3.56

APPENDIX B

Culvert Diameter (feet)	Culvert Fullness (percent)	Wetted Area (feet^2)	Hydraulic Radius[a]	Gradient (S)	Flow, Q[b] (cfs)	$\overline{V}$[c]	V_{max}[d]	V_{skin}[e]	$V_{occupied}$[f]
20	90	141.37	3.64	0.001	654.54	4.63	6.81	2.32	2.89
				0.005	1,464.59	10.36	15.24	5.18	6.48
	72	113.10	3.43	0.001	503.30	4.45	6.54	2.23	2.78
				0.005	1,126.48	9.96	14.65	4.98	6.23
	50	78.54	2.77	0.001	303.16	3.86	5.68	1.93	2.41
				0.005	678.59	8.64	12.71	4.32	5.40
	25	39.27	1.65	0.001	107.21	2.73	4.01	1.37	1.71
				0.005	239.94	6.11	8.99	3.06	3.82
22	90	171.06	4.01	0.001	845.04	4.94	7.26	2.47	3.09
				0.005	1,890.21	11.05	16.25	5.53	6.91
	72	136.85	3.77	0.001	648.67	4.74	6.97	2.37	2.96
				0.005	1,451.98	10.61	15.60	5.31	6.63
	50	95.03	3.05	0.001	391.52	4.12	6.06	2.06	2.58
				0.005	875.23	9.21	13.54	4.61	5.76
	25	47.52	1.81	0.001	138.28	2.91	4.28	1.46	1.82
				0.005	308.88	6.50	9.56	3.25	4.06

APPENDIX C

Q AND $V_{occupied}$ VALUES FOR (SEMI-ELLIPTICAL) CORRUGATED METAL PIPE-ARCH CULVERTS OF VARYING SPAN SIZE AND FULLNESS SET AT GRADIENTS OF 0.001 AND 0.005

Culvert Span Size (feet)	Water Depth in Culvert (inches)	Culvert Fullness (percent)	Area A ($feet^2$)	Wetted[a] Perimeter (inches)	Hydraulic Radius (A/p)	Gradient (S)	Flow, Q[b] (cfs)	$\overline{V}$[c] (fps)	V_{max}[d] (fps)	V_{skin}[e] (fps)	$V_{occupied}$[f] (fps)
6'1"	18.2[g]	33	7.23[h]	87.5	0.99	0.001	14.03	1.94	2.43	0.97	1.21
						0.005	31.45	4.35	5.44	2.17	2.72
	55	100	22	206.9	1.28	0.001	50.82	2.31	2.89	1.15	1.44
						0.005	113.52	5.16	6.45	2.58	3.23
7'0"	18.7[g]	30	8.48[h]	96.0	1.06	0.001	17.30	2.04	2.54	1.02	1.28
						0.005	38.58	4.55	5.69	2.28	2.85
	61	100	28	230.4	1.46	0.001	70.56	2.52	3.15	1.26	1.58
						0.005	157.64	5.63	7.04	2.82	3.52
8'2"	20.1[g]	31	11.92[h]	106.7	1.34	0.001	28.37	2.38	2.97	1.19	1.49
						0.005	63.41	5.32	6.65	2.66	3.33
	69	100	38	266.7	1.71	0.001	106.40	2.80	3.50	1.40	1.75
						0.005	237.88	6.26	7.83	3.13	3.91
9'6"	19.7[g]	27	13.18[h]	128	1.24	0.001	29.79	2.26	2.82	1.13	1.41
						0.005	66.56	5.05	6.32	2.53	3.16
	77	100	49	309.3	1.90	0.001	147.00	3.00	3.75	1.50	1.88
						0.005	329.28	6.72	8.40	3.36	4.20

(a) Graphically determined.
(b) Q = [Wetted Area (A) at a particular fullness and specified gradient] x [$\overline{V}$ at a particular fullness and a specified gradient]
(c) $\overline{V}$ = the average water velocity (feet per second) within a pipe-arch culvert at a particular flow;
where $\overline{V} = 1.486/0.024\, S^{1/2}\, R^{2/3}$ (S = gradient and R = hydraulic radius).
(d) V_{max} = the maximum water velocity (in feet per second) within a pipe-arch culvert at a particular fullness and specified gradient;
where: $V_{max} = \overline{V}/0.68$.
(e) V_{skin} = the skin velocity (in feet per second) of water adjacent to the sides of a pipe-arch culvert, at a particular fullness and specified gradient; where $V_{skin} = 0.4\, V_{max}$, or $= 0.59\, \overline{V}$.
(f) $V_{occupied}$ = the occupied area velocity, or the area within a pipe-arch culvert of a particular fullness and specified gradient through which a fish swims while traversing the length of a culvert (Figure 2) where $V_{occupied} = V_{skin} + 0.25\,(\overline{V} - V_{skin})$.
(g) The maximum depth in a pipe-arch culvert (of a particular span size) at which the culvert approximates the hydraulic characteristics of a stream channel. Depth = Rise - R.
(h) Wetted area in pipe-arch culvert (of a particular span size) at the maximum depth (see footnote g).
Wetted area = [Total Culvert Area] - [$R^2/2$]
where: total culvert area is the nominal area (see Appendix D),
and R is the radius of the semi-circular upper arc of the culvert (graphically determined).

APPENDIX C

Culvert Span Size (feet)	Water Depth in Culvert (inches)	Culvert Fullness (percent)	Area A (feet^2)	Wetted Perimeter[a] (inches)	Hydraulic Radius (A/p)	Gradient (S)	Flow, Q[b] (cfs)	$\overline{V}$[c] (fps)	V_{max}[d] (fps)	V_{skin}[e] (fps)	$V_{occupied}$[f] (fps)
10'3"	19.5[g]	25	13.74[h]	136.5	1.21	0.001	30.50	2.22	2.78	1.11	1.39
						0.005	68.29	4.97	6.21	2.49	3.11
	81	100	55	330.7	2.00	0.001	171.05	3.11	3.89	1.55	1.94
						0.005	382.25	6.95	8.69	3.47	4.34
11'5"	17.6[g]	18	11.46[h]	155.7	0.88	0.001	20.63	1.80	2.25	0.90	1.13
						0.005	46.07	4.02	5.03	2.01	2.51
	87	100	64	366.9	2.09	0.001	204.80	3.20	4.00	1.60	2.00
						0.005	458.24	7.16	8.95	3.58	4.48
12'6"	19.5[g]	20	15.82[h]	168.5	1.13	0.001	33.54	2.12	2.66	1.06	1.33
						0.005	75.15	4.75	5.94	2.37	2.97
	95	100	78	409.6	2.29	0.001	265.20	3.40	4.25	1.70	2.13
						0.005	593.58	7.61	9.51	3.80	4.75
13'5"	20.3[g]	20	17.96[h]	172.8	1.25	0.001	40.77	2.27	2.84	1.14	1.42
						0.005	91.24	5.08	6.35	2.54	3.18
	101	100	89	426.7	2.50	0.001	321.29	3.61	4.51	1.80	2.25
						0.005	717.34	8.06	10.08	4.03	5.04
14'3"	21.1[g]	20	20.51[h]	192.0	1.28	0.001	47.38	2.31	2.89	1.15	1.44
						0.005	105.83	5.16	6.45	2.58	3.23
	107	100	101	462.9	2.62	0.001	375.72	3.72	4.65	1.86	2.33
						0.005	840.32	8.32	10.40	4.16	5.20
15'6"	19.0[g]	15	16.61[h]	206.9	0.96	0.001	31.73	1.91	2.38	0.95	1.19
						0.005	70.76	4.26	5.33	2.13	2.66
	113	100	113	497.1	2.73	0.001	431.66	3.82	4.78	1.91	2.39
						0.005	966.15	8.55	10.69	4.28	5.35
16'5"	19.8[g]	15	18.66[h]	213.3	1.05	0.001	37.69	2.02	2.53	1.01	1.26
						0.005	84.34	4.52	5.65	2.26	2.83
	119	100	126	520.5	2.90	0.001	501.48	3.98	4.98	1.99	2.49
						0.005	1,121.40	8.90	11.13	4.45	5.56

APPENDIX D

DIMENSIONS OF SELECTED PIPE-ARCH CULVERTS[a]

Nominal Dimension			Layout Dimensions (in inches)			
Span	Rise	Area (feet^2)	B[b]	Rise	1/2 Span	R[c]
6'1"	4'7"	22	21.0	55.0	36.5	36.8
7'0"	5'1"	28	21.4	61.1	42.1	42.3
8'2"	5'9"	38	20.9	69.4	48.9	48.9
9'6"	6'5"	49	22.9	77.3	57.1	57.3
10'3"	6'9"	55	24.0	81.2	61.3	61.5
11'5"	7'3"	64	27.4	86.9	68.4	69.4
12'6"	7'11"	78	26.4	95.2	75.1	75.5
13'5"	8'5"	89	26.4	101.3	80.4	80.7
14'3"	8'11"	101	26.3	107.5	85.7	85.9
15'6"	9'5"	113	30.2	113.1	93.2	94.0
16'5"	9'11"	126	30.1	119.2	98.5	99.2

(a) Source: Table 8-11 of Armco (1955).
(b) B = depth of lower portion of culvert.
(c) R = radius of upper semi-circular portion of culvert.

APPENDIX E

Glossary

Adult - A sexually mature fish.

Alevin - A recently hatched salmonid fish prior to emergence from the spawning gravels.

Aufeis (German) - An ice feature that is formed by water overflowing onto a surface, such as river ice or gravel deposits, and freezing, with subsequent layers formed by repeated overflow.

Average Velocity ($\bar{V}$) - Average velocity of water through a culvert-type structure usually calculated from Manning's equation.

Braided Stream - A stream or river containing two or more interconnecting channels separated by gravel bars or sparsely vegetated islands. The floodplain is typically wide with sparse vegetation and numerous high-water channels.

Coefficient of Contraction - Loss of effective area brought about by the change of direction as water enters a confined space.

Cruising Speed - Swimming speed that a fish can maintain for a long period of time (hours).

Darting Speed - Swimming speed that a fish can maintain during a non-sustainable single effort (5 - 10 seconds).

Environmental Master Guide (EMG) Level 1 - Photomosaic pipeline alignment sheets with environmental values superimposed.

Environmental Master Guide (EMG) Level 2 - Individual stream data sheets containing information on fish use, habitat value and sensitivity.

Flume - A pipe or conduit used to divert stream flow thereby bypassing a construction area.

Fry - A young, free swimming fish, generally less than 6 months old.

Hard Plug - A dam or plug of unexcavated natural material left in place during a ditching operation to isolate one portion of a ditch from another.

Headwater Depth - Depth of water immediately above the inlet of a culvert or other drainage structure.

Hydraulic Radius - The cross-sectional area of a stream divided by the length of that part of its periphery in contact with its channel; the ratio of area to wetted perimeter.

Salmonid - Belonging to the fish family Salmonidae which includes trout, salmon, char, grayling and whitefish.

Silt Curtain - A weighted curtain designed to be suspended within a water body to isolate areas of "dirty" water from areas of clean water.

Soft Plug - A dam or plug of granular material placed in a ditch following excavation to isolate one portion of the ditch from another.

Spawning Area - Area within a stream or lake where fish spawning and egg development is known or suspected to occur.

Stipulation - A standard of performance specifically designated by either State or Federal authorities as a condition of the right-of-way grant for ANGST.

Sustained Speed - Swimming speed that a fish can maintain for a short period of time (minutes).

Thalweg - The line following the deepest part (point of lowest elevation) of the bed of a stream or river.

Incised Channel - Stream channel that is depressed below the land surface. Stream banks are typically well defined and steep and the entire stream is contained within the channel except at extreme flows.

Inlet or Upstream Control - Condition where the discharge capacity of a culvert is controlled at the culvert entrance by the depth of headwater and the entrance geometry.

In-stream Work - Activity occurring within the flowing water portion of a streambed.

Invert - The bottom of a pipe culvert at its lowest point.

Juvenile - A sexually immature fish.

Low Water Crossing (LWC) - A specially constructed ford allowing stream flow across a workpad surface while at the same time providing a stable driving surface for vehicles.

Manning's Equation - An empirical formula for the calculation of discharge in a channel: $Q = \frac{1.486}{n} R^{2/3} S^{1/2} A$ or $V = \frac{1.486}{n} R^{2/3} S^{1/2}$

Where

Q = discharge	S = slope
n = roughness coefficient	A = cross-sectional area
R = hydraulic radius	V = average velocity

Manning's Roughness Coefficient - A numerical coefficient describing the relative roughness or drag that a surface or conduit presents to a stream of water flowing over it or through it.

Maximum Velocity (V_{max}) - Velocity of water within the central portion of a culvert-type structure where velocity is at its maximum (Figure 1).

Occupied Area Velocity ($V_{occupied}$) - The velocity of water within that portion of a culvert-type structure adjacent to the outer wall; i.e. velocity where fish are most likely to swim because of favorable conditions (Figure 1).

Outlet or Downstream Control - Condition where the discharge capacity of a culvert is controlled by the tailwater elevation and the culvert barrel geometry.

Overwintering Area - Area within a stream or lake where fish are known or suspected to occur during at least part of the frozen season.

Pipe-arch - A corrugated metal pipe culvert having a seim-elliptical or "squashed" cross-sectional shape.

Rearing Area - Area within a stream or lake with known or suspected value as habitat for juvenile fish.