TECHNICAL NOTES

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BIOLOGY TECHNICAL NOTE NO. 58

DESIGN INFORMATION FOR FISH PASSAGE AT ROADWAY-STREAM CROSSINGS

The information below is from the Federal Highways Administration and is intended to provide an understanding of fish biology related to the design of fish passage at roadway-stream crossings.

Fish Biology

How to use this chapter

- Consult this chapter when using Hydraulic Design or some Hydraulic Simulation methods
- Introduction to fish swimming abilities\Examples of fish passage requirements
- Introduction on determining presence of fish in stream reach and region

The capacity of fish to traverse physical obstacles will dictate the appropriate design of a culvert crossing. An understanding of resident fish biology and swimming ability will allow culvert designers to create a culvert design suitable for local conditions. This information is most commonly used when assessing fish passage at an existing culvert (Section 4.2), retrofitting an existing culvert for fish passage (Section 7.3), or designing a new culvert using the Hydraulic Design technique (Section 7.3) and some Hydraulic Simulation techniques (Section 7.2). Specific fish biological requirements are not needed for Geomorphic Design procedures. The following discussion outlines fish biology, swimming abilities, and requirements, providing a basic understanding of what fish need to successfully move throughout their environment. This brief introduction does not obviate the need to have a fisheries biologist on the design team.

2.1 Anatomy

Fish possess two muscle systems to accommodate different modes of travel: a red muscle system (aerobic) for low-intensity activities and a white muscle system (anaerobic) for shorter, high-intensity movements (Webb 1975). Extensive use of the white muscle system causes extreme fatigue, requiring extended periods of rest.

2.2 Capabilities and Abilities

2.2.1 Swimming and Jumping

Fish movement can be divided into three categories based on speed and muscle use: sustained, prolonged or burst speeds (Bell 1986). A fish at sustained speed uses the red muscle system exclusively, allowing extended periods of travel at low speeds. Prolonged speed involves the use of both red and white muscle tissue, and allows the fish to reach quicker speeds for minutes at a time. Burst speed allows the fish to reach top speeds for a few seconds by exclusive utilization of white muscle tissue, requiring a significant rest period. Table 2.1 summarizes the muscle system use as it relates to fish movement.

2.1 Movement Type as It Relates to Muscle System Utilization (adapted from Bell 1986)

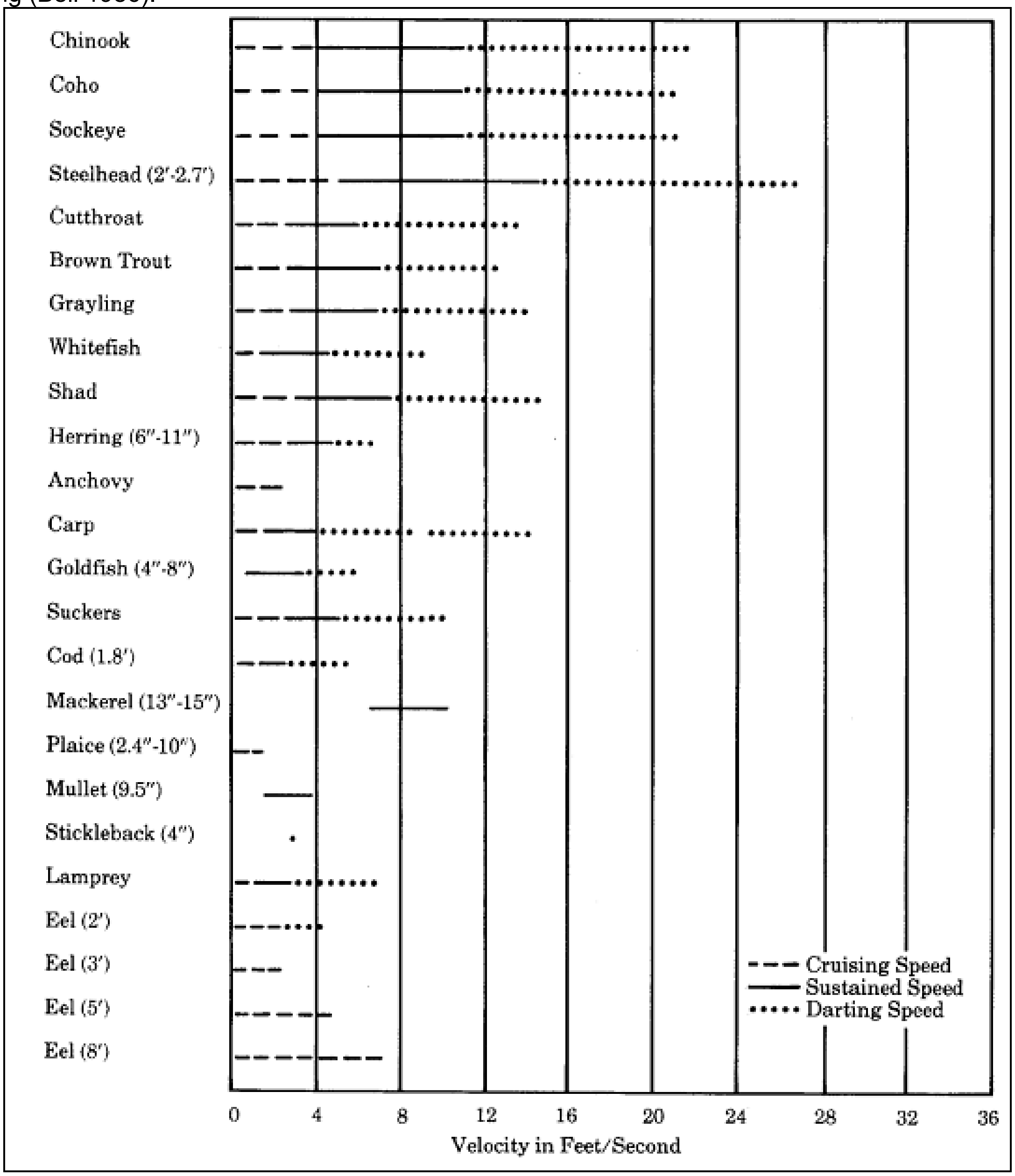
Movement Type	Description	Muscle System	Period
Sustained	Used for long periods of travel at low speeds.	Red (purely aerobic)	Hours
Prolonged	Short periods of travel at high speeds	Red and White	Minutes
Burst	Maximum swimming speed or jumping, inducing fatigue.	White (purely anaerobic)	Seconds

Fish can fail to pass a culvert for a variety of reasons. An outlet drop or high velocity zone will act as a barrier when it exceeds the fish's darting ability, while a continuous section of culvert with relatively low velocity may require sustained swimming speeds to be maintained beyond a fish's natural ability. It is important to note that these criteria are not cumulative, and a fish that reaches exhaustion in any category will require a period of rest before continued movement.

A number of studies have been completed to ascertain the swimming and jumping ability of different fish species (e.g. Jones et al. 1974; Bainbridge 1959; Stuart 1962; Hinch and Rand 1998; Rand and Hinch 1998; Ellis 1974; Toepfer et al. 1999). An excellent database is maintained within the US Forest Service FishXing computer program (US Forest Service, 2006a). Before designing a particular culvert crossing using a Hydraulic Simulation (Section 7.2) or Hydraulic Design approach (Section 7.3) it will be necessary to check local conditions including fish species present and time periods/flows at which movement is required.

2.2.2 Species and Life Stages

Swimming and jumping capabilities can vary greatly between species. The following examples are from Bell (1986). It should be noted that the original sources in the figures are not known nor cited. Designers should seek studies performed for the specific species of interest. The figures are only for comparative purposes. For example, Figure 2.1, taken from Bell's Fisheries Handbook, depicts the relative swimming abilities of adult fish. Burst speeds reaching 7.92 m/s (26 ft/s) give adult steelhead a velocity potential more than twice that of an adult brown trout, and almost four times that of an adult herring (Bell 1986).



2.1 Relative swimming abilities of adult fish, in customary units (Bell 1986)

Even within a given species, there can exist a large variation between individual capabilities. This can be the result of life stage, condition or individual prowess. Figure 2.2 depicts a similar collection of swimming abilities for young fish. If passage for these life stages is required, velocities thresholds drop significantly. For example, a young Coho salmon can reach sustained speeds up to 0.6 m/s (2 ft/s), while an adult is able to sustain almost 3.35 m/s (11 ft/s) (Bell 1986). Individual fish will also exhibit dissimilar swimming capabilities, resulting in the velocity ranges depicted in Figures 2.1 and 2.2. This has serious ramifications for the selection of velocity criteria. Design for maximum swimming speed may create passage for the strongest swimmers, while maintaining a barrier to average or weak swimming individuals. Design for the weakest swimming fish will create a structure that is quite conservative.

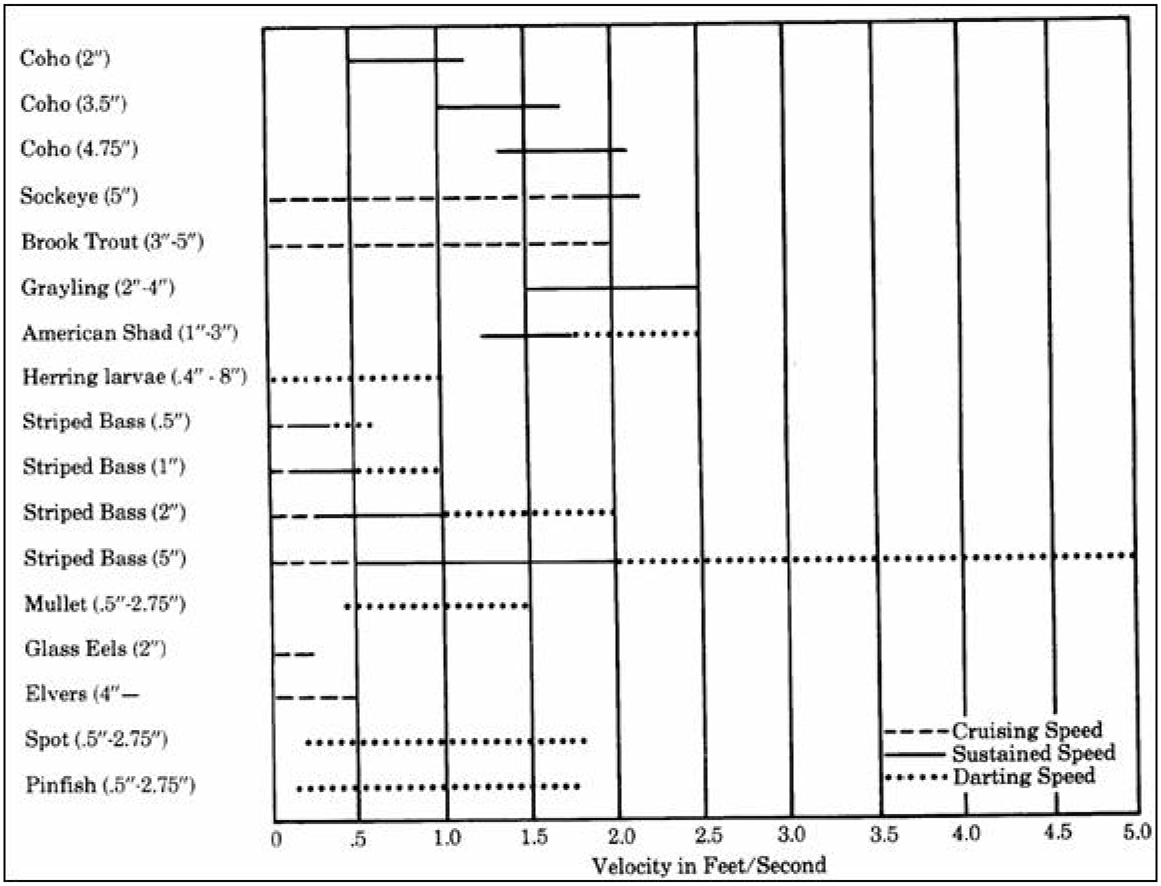


Figure 2.2 Relative swimming abilities of young fish, in customary units (Bell 1986)

2.2.3 Depth Requirements

Fish require a minimum depth of flow to allow them to reach swimming potential (Dane 1978). Total submergence eliminates a fish's risk of oxygen starvation, allows the fish to create maximum thrust, and lowers the risk of bodily injury through contact with the culvert bottom (Forest Practices Advisory Committee on Salmon in Watersheds 2001). For example, Table 2.2 from Everest et al, summarizes depth requirements for a variety of salmonid and trout species from the Pacific Northwest (1985). Data for other species and regions is under development but not yet available.

Table 2.2 Minimum Depth Criteria for Successful Upstream Passage of Adult Salmon and Trout, Customary Units (Everest et al. 1985)
(Note - fish may not be able to migrate long distances at the depths listed; information is based on species found in Washington and Oregon)

Fish Species	Minimum Depth (ft)
Pink Salmon	0.59
Chum Salmon	0.59
Coho Salmon	0.59
Sockeye Salmon	0.59
Spring Chinook	0.79
Summer Chinook	0.79
Fall Chinook	0.79
Steelhead Trout	0.79

Specific depth requirements vary with species and life stage of concern, and are generally much more conservative than studies suggest. Alaska requires that depth be greater than 2.5 times the depth of a fish's caudal fin, as depicted in Figure 2.3 (Alaska Department of Fish and Game and Alaska

Department of Transportation 2001). The Washington Department of Fish and Wildlife specifies a minimum depth of 0.24 m (0.8 ft) for Adult Trout, Pink and Chum Salmon, and a depth of 0.30 m (1.0 ft) for adult Chinook, Coho, Sockeye or Steelhead (Bates et al. 2003). Maine employs a depth requirement of 1.5 times body depth (Maine Department of Transportation 2004).

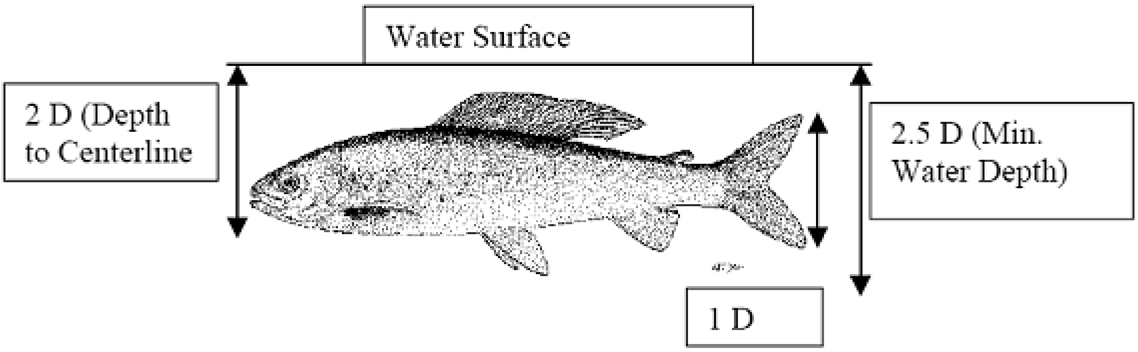


Figure 2.3 Minimum water depths for fish passage in Alaska
(Alaska Department of Fish and Game and Alaska Department of Transportation 2001)
(D = height of caudal fin)

2.2.4 Example of Fish Criteria

Exhaustion criteria have been experimentally derived for a variety of fish species, allowing the development of culvert velocity thresholds. Table 2.3 from Washington's fish passage manual demonstrates how exhaustion and swimming speed criteria can be used to create relationships between allowable length and velocity based on fish species. In Washington State, adult trout represent a conservative lower design threshold, and are considered the species of concern in any area where specific fish species presence has not been determined (Bates et al. 2003). Further discussion of culvert criteria is included in Chapter 3.

Table 2.3 Fish-Passage Design Criteria for Culvert Installations, Customary Units (Bates et al. 2003)

(Greater culvert lengths require lower velocity thresholds, while the increased swimming ability of larger fish (Adult Chinook, Coho, Sockeye and Steelhead) allows larger hydraulic drops and barrel velocities, but require a larger minimum depth.)

	Adult Trout >6 in. (150 mm)	Adult Pink or Chum Salmon	Adult Chinook, Coho, Sockeye or Steelhead
Culvert Length	**Maximum velocity (fps)**		
10 - 60 feet	4.0	5.0	6.0
60 - 100 feet	4.0	4.0	5.0
100 - 200 feet	3.0	3.0	4.0
Greater than 200 feet	2.0	2.0	3.0
	Minimum water depth (ft)		
	0.8	0.8	1.0
	Maximum hydraulic drop in fishway (ft)		
	0.8	0.8	1.0

2.3 Fish Movement

2.3.1 Migration

Anadromous fish, such as salmon, migrate to the ocean to feed and grow, and return upstream as mature adults to spawn (Groot and Margolis 1991). Upstream movement is triggered by time of year, flow events and a number of environmental factors. For example, the upstream migration of spawning salmon is hypothesized to be in response to maturation, the changing length of days, and temperature regimes (Groot and Margolis 1991). Recognition of the importance of seasonal spawning runs to anadromous fish persistence led to the development of early fish passage guidance documents (e.g. Baker and Votapka 1990; Gebhards and Fisher 1972; Evans and Johnston 1972). These migrations often occur over large distances, and the physical prowess of the individual fish degrades substantially over the course of its migration.

2.3.2 Juvenile and Resident Movement

Of more recent concern is the migration of resident and juvenile fish (e.g. Bates et al. 2003; Bates et al. 2006; Robison et al. 1999; Admiraal and Schainost 2004). Previous knowledge held that resident populations remained fairly stationary throughout the year (Gerking 1959); however, movement of both juvenile salmon and resident trout has been observed in response to a variety of environmental factors (Gowan et al. 1994). This includes up and downstream movement in response to extreme flows, stream temperatures, predation, lower population densities or search for food or shelter (Robison et al. 1999; Kahler and Quinn 1998; Schaefer et al. 2003).

Design to meet the needs of a spawning salmon will not necessarily guarantee that a culvert will allow passage of weaker swimming juveniles or resident fish. Although fish are capable of specific swimming energies, it does not mean that fish will choose to expend maximum swimming energy when confronted with specific obstacles (Behlke et al. 1991). This is consistent with observations of fish moving through culvert boundary layers, and holding in areas of low velocity between corrugations (Powers et al. 1997).

2.4 Local Fish Requirements

The distribution of fish species, life stage and migration timing is available from sources such as State and Federal Agencies, Tribal governments, commercial landowners and non-profit organizations. Note that studies to ascertain fish presence may focus on larger waterways, providing low-resolution distribution maps that neglect smaller streams (Clarkin et al. 2003).

It is very important to conduct site visits to check for fish presence, and regional fish presence criteria may be useful (i.e. fish are assumed absent in streams with gradients above 20%). To ensure that fish presence is adequately understood, some guidelines begin with the default assumption that passage is required for the weakest swimming fish contained in their criteria (i.e. Bates et al. 2003; Robison et al. 1999). In Oregon, designers must contact a local biologist, or prove that fish passage is not required at a site, before less conservative design requirements can be utilized (Robison et al. 1999). Although fish may not appear during a survey, it doesn't mean they don't inhabit the reach at some times of the year. Fish are often in areas where biologists do not expect them, and it is likely desirable to provide passage for native migratory fish that are or were historically present at the site (Clarkin et al. 2003). Assessments should be conducted when fish presence is most likely expected.

2.5 Conclusions

A successful fish crossing will ensure passage for the weakest swimming fish species of concern. Before beginning the Hydraulic Simulation or Hydraulic Design process, it will be necessary to ascertain all fish species for which passage is desirable, including swimming ability and timing of fish migration. Many studies have been completed to understand the swimming abilities of particular fish species, and values or formulas can be found in fish passage literature, through collections of data such as those provided for FishXing www.stream.fs.fed.us/fishxing/, or through online sources such as FishBase www.fishbase.org. It is important to consult the local fisheries biologists on your design team to understand the needs of fish in your area.