

Six Rivers Watershed Interactions Team



FishXing

version 2.1

Helpfiles

November 1999

This document is a compilation of the help system built into FishXing v. 2.1. Users may find it easier to find information by using the embedded help system in the software, where the topics are hyperlinked and more extensively indexed. Review of this document will provide an overview of the help system, the analytical basis of FishXing, and the fundamentals of fish passage through culverts.

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Data Requirements for FishXing

Fish Passage Design Flows

Design Flow Guidelines

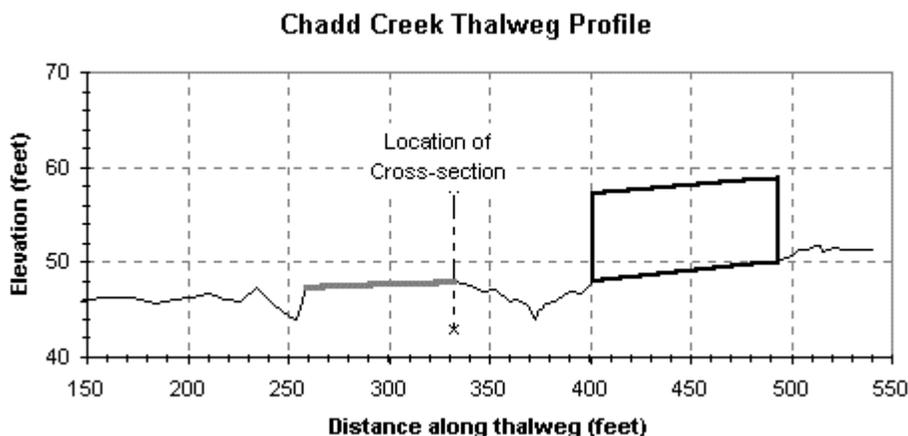
Many state and Federal agencies have standards and guidelines for fish passage through culverts. Typically, the guidelines include regional methods for determining the low passage and high passage design flows. Most design flow guidelines are tailored to the migration behavior of the concerned fish species and to the regional hydrology.

| <u>Agency</u> | <u>Species of Concern</u> | <u>Low Passage Design Flow</u> | <u>High Passage Design Flow</u> |
|--|----------------------------------|---|--|
| California Dept. Transportation District 1(1) | Adult Anadromous Salmonids | None. | 10% exceedence discharge during migration period. |
| USDA Forest Service(2) | Adult Anadromous Salmonids | None. | 10% exceedence discharge during migration. |
| Alaska Dept. Transportation(3) | All | | 2-day duration with 2-yr. return period. |
| California Dept. Fish and Game(4) | Adult Anadromous Salmonids | The median discharge (50th percentile). | 10% exceedence discharge during migration period, or 5% exceedence discharge on annual basis. |
| Washington Dept. Fish and Wildlife(5,6) | Adult Anadromous Salmonids | 7-day low flow duration with 2 yr. return period. | 10% exceedence discharge during migration period. |
| Oregon Forest Practices Draft Proposal(7) | Adult Anadromous Salmonids | 95% exceedence flow during migration period. | 10% exceedence discharge during migration period. |
| Manitoba Dept. Natural Resources Fisheries Branch(8) | Spawning Migrant Fish | None | 3-day duration for the average annual flood, and 7-day duration with 50-yr. return period. |
| British Columbia Ministry of Forests(9) | All | Natural low-flow summer levels | Discharge occupied by the cross-sectional area of the stream channel when filled to the "channel maintenance level." |

- (1) Kay, A.R. and R.B. Lewis. 1970. Passage of anadromous fish thru highway drainage structures. State of California, Division of Highways, Research Report 629110, June 1970, 15 pp.
- (2) Evans, Willis A. and Beryl Johnston. 1980. Fish migration and fish passage: A practical guide to solving fish passage problems. USDA Forest Service, June 1980, 63 pp.
- (3) Ashton, William S. and Robert F. Carlson. 1984. Determination of seasonal, frequency and durational aspects of stream flow with regard to fish passage through road drainage structures. State of Alaska, Dept. Transportation and Public Facilities, Div. Planning and Programming Research Section, Report No. AK-RD-85-06, November 1984, 51 pp.
- (4) Department culvert criteria for fish passage. In: Departmental Guidelines. State of California, Dept. Fish and Game, p. VIII-9.
- (5) Powers, Patrick D. and Caleb S. Saunders. 1998. Fish passage design flows for ungaged catchments in Washington. Lands and Restoration Services. Prepared for: Washington State Dept. Transportation, March 1998, 9 pp.
- (6) Bates, Ken. 1999. Fish passage design at road culverts: A design manual for fish passage at road crossings. Washington Dept. Fish and Wildlife, Habitat and Lands Program, Environmental Engineering Division, March 1999, 49 pp.
- (7) Applegate, Rick and Elizabeth Holmes Gaar. 1998. A draft proposal concerning Oregon forest practices. National Marine Fisheries Service, Northwest Region, February 1998, pp. VI.1-5.
- (8) Manitoba Department of Natural Resources. 1984. Recommended fish protection procedures for stream crossings in Manitoba. Manitoba Dept. Natural Resources, Fisheries Branch, 46 pp.
- (9) Poulin, V.A. and H.W. Argent. 1997. Stream crossing guidebook for fish streams: A working draft for 1997/1998. Prepared for: British Columbia, Ministry of Forests, Ministry of Employment and Investment, Ministry of Environment, Lands and Parks, Dept. Fisheries and Oceans, 81 pp.

Existing Road Crossings

Field Collection of Required FishXing Inputs



Click on hotspots within the example above to obtain detailed descriptions.

A surveyed channel profile is needed to obtain the data required for *FishXing*. Choose from two levels of surveying, depending on the **tailwater method** you wish to use. The **constant tailwater method** requires the least information.

The survey must capture the following features:

- Inlet bottom,
- Outlet bottom,
- Tailwater control, and
- The downstream channel.

When you use the **channel cross-section method** for creating a tailwater rating curve you must survey these additional features:

- A channel cross-section at the site of the tailwater control, and
- The slope of the downstream channel or water surface, beginning at the tailwater control and ending at the next significant break in slope.

In addition, you will need to estimate a **Manning's roughness coefficient**. If possible, we recommend back-calculating the roughness coefficient, which requires a field measurement of the discharge to accompany the surveyed downstream water-surface slope and cross-section. If the discharge is not measured, you will need to estimate the roughness coefficient based on the size and shape of the bed material at and immediately downstream of the cross-section.

Running FishXing

Project Format

FishXing organizes culverts into project folders. When opening *FishXing* you have the choice of opening an existing project or creating a new project. Projects allow you to organize culverts into groups, such as:

- All culverts within a watershed.
- Multiple designs for a specific site.
- Analysis of a single culvert for different fish species and migration timings.

Opening a project gives you the **Project Summary**. The Project Summary displays all the culverts within the project and gives a brief summary of each one.

Also see:

[Project Summary](#)

[File Management](#)

Project Summary

All culverts in a project can be viewed in the Project Summary. It summarizes each culvert in the project by displaying descriptive fields. You can customize the list of displayed fields by clicking on the **Customize** button. The default fields included in the Project Summary are the following:

Project Summary

File Name - Name of file containing culvert input and output. Culvert data files end with (*.xng).

ID No. - Identification number given to each culvert by the user.

Name - User specified name for each culvert.

Type - Culvert shape and size.

Species - Design fish species for the culvert.

Low Passage Flow – Lowest discharge fish passage is required. Defines the bottom of the fish passage flow window.

High Passage Flow - Highest discharge fish passage is required. Defines the top of the fish passage flow window.

Passage Limitations at High Passage Flow- Identifies potential fish passage problems at the high passage flow based on both the water surface profile and uniform flow outputs.

Opening, Creating and Deleting Culverts

Buttons along the bottom of the sheet allow you to manage your files. You can open an existing culvert, create new culvert, delete existing culverts from the project, or create a copy of an existing culvert. To open or copy an existing culvert, click on the desired culvert in the list to make it highlighted. Then click on the appropriate button below.

Also see:

[Starting a new culvert](#)

File Management

When installing *FishXing*, the software automatically creates a folder named **Data** for importing and exporting cross-sections, rating curves, and other output.

The **Project** folder, also created during installation, contains all of the different projects as separate folders. In each folder are the individual culvert files, ending with (.xng). All of the projects must remain in the **Project** folder which must remain in the **FishXing** folder. Otherwise, *FishXing* will not be able to locate your projects.

Software Inputs

Culvert Information Sheet

The Culvert Information Sheet is the first screen to appear when you open an existing culvert or create a new culvert. The culvert information sheet allows you to input the location and a general description of each culvert site. The information is not used in any calculations, but it is used to help uniquely identify each culvert and set priorities based on available upstream habitat and existence of other upstream and downstream barriers. None of the information on this page is required, but we recommend that a unique ID number be assigned to each culvert.

Culvert ID Number - The program assigns a default ID number to each new culvert; you may change the number, but we recommended it be a unique for each culvert. The ID Numbers can be useful when you run several different analyses for the same culvert. For example, repeating an analysis of the same culvert for different fish species.

Culvert Name - Give the culvert a unique name.

Road and Milepost - Enter the road name and the milepost for locating the proposed or existing culvert.

Stream Name - Enter the name of the stream at the road crossing.

Latitude and Longitude – Include latitude and longitude when the stream crossing has been located by using GPS (Global Positioning Systems).

Length of Historical Upstream Habitat - Identify the historical range of the fish species in your particular stream. Enter the length of stream above the culvert that has, or is thought to have contained the fish species of concern before any instream structures existed that now function as migration barriers, that is, culverts, diversion weirs, small dams, log jams.

Upstream- Downstream Barrier Information

Barrier information primarily helps describe the benefits of fixing passage problems at this culvert. If the culvert is considered a migration barrier, this information can be used to determine the amount of fish habitat that will be made accessible if the culvert is modified or upgraded.

Upstream Barriers Exists - Check the box if any upstream migration barriers exist between the current culvert and the end of the historical upstream habitat.

Number of upstream barriers - If upstream barriers exist, enter the total number of barriers above the culvert.

Distance to next barrier - Enter the stream length to the next upstream barrier. Include the units with the length. For example, enter “130 ft”)

Downstream Barrier Exists - Check box if any downstream barriers exist.

Number of downstream barriers - If downstream barriers exist, enter the total number.

Distance to next barrier - Enter the stream length to the next downstream barrier. Include the units with the length. For example, enter “130 ft”)

Comments – Your notes, comments, and remarks can be entered and stored for each culvert.

Also see:

[Culvert Input Sheet](#)

Input Sheet

The Input Sheet is used to specify the characteristics of the stream crossing and the design fish species. The Input Sheet is divided into two sections:

- [Biological Considerations \(Fish Characteristics\)](#)
- [Culvert Hydraulics](#)

The **Tailwater Option** button in the bottom left corner of the sheet opens the [Tailwater Options Sheet](#) allowing you to specify the elevation of the water surface at the culvert outlet.

Profile Flows

Choose up to three distinct discharges to generate water surface and velocity profiles through the selected culvert. The low and high passage flows are automatically entered as two of the profile flows, and *FishXing* requires that the one of the flows be the high passage flow. *FishXing* will generate the profiles after you click on the **Calculate Button** on the Input Sheet.

When all the required fields have been inputted, click on the **Calculate Button** for the results.

Fish Inputs

Fish Information

Fish Information is part of the data input sheet associated with each culvert. The various data fields pertain to the swimming abilities and migration behavior of the selected fish species.

Fish Information

Species – Select or enter a fish species.

Age Class – Select or enter the species' age-class. For several selections, default values specific to the species' and age-class will be entered automatically below.

Fish Length - Enter the total length of the fish in millimeters. The default swimming ability of several species is determined based on the fish length.

Additionally, for culverts with [perched outlets](#) that require the fish to leap, the fish length is used to check for sufficient depth in the outlet pool.

Minimum Water Depth - Select or enter the minimum water depth required in the culvert for upstream passage of the selected fish species and age class. This is the depth required for the fish to swim efficiently. Default values are available for several species.

For a list of swimming abilities of various North American fish species, click here  .

Migration Period

Choose the beginning and ending months of upstream migration for the selected fish

species/age class. **The migration period is optional and not used in calculations.**

Default/Custom Swim Speeds

FishXing contains default swim speeds for many North American fish species. If you wish to use default speeds select the Default Swim Speeds tab. FishXing uses a combination of constant and variable swim speeds as defaults. For more information on default swim speeds, click here [»](#).

Swimming Ability

Prolonged and Burst - Swimming speeds are commonly classified as sustained, prolonged, and burst. Sustained swimming speeds can be maintained indefinitely and are typically not used for design or analysis of culverts. Prolonged swimming can last between 15 seconds and 200 minutes before resulting in fatigue. Burst swimming can cause fatigue within 15 seconds and cannot be repeated without an extended rest. Choose the swimming type you wish to use in the analysis.

Choose **Use Both** if you wish for the design fish to be able to switch between prolonged and burst speeds, as needed. This can be particularly useful when water velocities within the culvert barrel are low enough for passage in prolonged swim mode but the inlet and outlet zones contain higher velocities, requiring burst swim speeds for successful passage.

Note: Most fish passage guidelines recommend using the prolonged swimming speed.

Swim Speed – The prolonged and burst swimming speeds for the selected fish species and age-class.

For a list of swimming abilities for numerous fish species, click here [»](#).

For a list of the different swim speed equations used by *FishXing*, click here [»](#).

Time to Exhaustion – Select the time to exhaustion for the chosen species and swimming speed. For all fish, the default Time to Exhaustion is set at 5 seconds for burst speeds and 30 minutes for prolonged speeds.

Max Leap Speed – Select the initial speed at which the fish can leap out of the outlet pool to enter a **Perched Outlet**. *The speed is only applicable if the fish must leap into the culvert outlet.* Default values are typically set equal to the burst speed for the selected fish.

No Outlet Leap Required – Click on this box if the stream crossing does not require the fish to leap into the outlet. Checking this box prevents leap calculations from being performed. This is appropriate for culvert outlets that are only slightly perched, often prompting the fish to swim, instead of leap, into the culvert. **If you are unsure, leave it unchecked.**

Velocity Reductions

Observations of fish swimming through culverts have revealed that many fish utilize areas of lower water velocities within the culvert when faced with challenging situations. This has encouraged the use of velocities less than the average water velocity when designing culverts for fish passage. Reduction factors are multiplied by the average water velocities to determine the water velocity encountered by the fish.

Inlet – The region between the culvert inlet and 2-3 feet into the barrel.

Barrel – The region between the inlet and outlet zones.

Outlet – The outlet zone only exist if the culvert is mildly sloped and perched. It begins when the water surface passes through critical depth. Otherwise, the barrel zone extends to the end of the culvert.

Caution should be given when using reduction factors, since changing conditions can influence the velocity distribution within the region occupied by the fish. For a thorough description of reduction factors, click here [»](#)

Hydrologic Criteria

The **High Passage Flow** and **Low Passage Flow** define the range of discharges that will be analyzed for fish passage. There are few situations in which fish passage can be maintained during flood flows. Additionally, it is not necessary to provide adequate upstream passage conditions during periods when fish are not attempting to move upstream. Many state and Federal agencies have guidelines for selecting the high and low passage flows, commonly referred to as fish passage design flows. For a list of current design flow guidelines, click here [»](#).

Fish Capabilities

The swimming abilities for many different species have been tested in the laboratory and observed in field studies. The table below lists the reported range of observed swimming speeds for different species and references. *FishXing* uses the middle of the range of swim speeds as defaults when no **swim speed equation** is available.

| Fish Species and Age Class | Swimming Ability Reported Range | Reference |
|---|--|--------------------------|
| Bigeye Shiner | 1.08 ft/s for 10 min (90% success) 1.18 ft/s for 4 min (95% success) 1.28 ft/s for 2 min (90% success) | Layher and Ralston, 1997 |
| Brown Trout | Prolonged (2.3 ft/s - 7.5 ft/s) Burst (7.5 ft/s - 12.2 ft/s) | Bell, 1991 |
| Carp | Prolonged (1.5 ft/s - 4.0 ft/s) Burst (4.0 ft/s - 14.0 ft/s) | Bell, 1991 |
| Central Stoneroller | Fork length range: 1.46 in -3.94 in, Swim speed ranged: 1.21 ft/s* - 1.50 ft/s* | Layher and Ralston, 1997 |
| Chinook Salmon | Prolonged (3.4 ft/s-10.8 ft/s) Burst (10.8 ft/s - 22.4 ft/s) | Bell, 1973 |
| Coho Salmon | Prolonged (3.4ft/s - 10.6 ft/s) Burst (10.6 ft/s - 21.5 ft/s) | Bell, 1973 |
| Cutthroat Trout | Prolonged (2.2 ft/s - 4.0 ft/s) Burst (4.0 ft/s - 13.5 ft/s) | Bell, 1991 |
| Goldfish | Prolonged (0.7 ft/s - 3.5 ft/s) Burst (3.5 ft/s - 5.0 ft/s) | Bell, 1991 |
| Grayling | Prolonged (2.5 ft/s - 5.0 ft/s) Burst (5.0 ft/s - 14.0 ft/s) | Bell, 1991 |
| Greenside Darter Redfin Darter Orangebelly Darter | mean = 1.02 ft/s* s.d.=0.27 mean = 0.92 ft/s* s.d.=0.37 mean = 0.97 ft/s* s.d.=0.37 | Layher and Ralston, 1997 |

| | | |
|--|---|--------------------------|
| Lamprey | Burst (3.0 ft/s - 7.0 ft/s) | Bell, 1991 |
| Lamprey | Burst (6.23 ft/s) | Watts, 1974 |
| Large Central Stoneroller | 2.17 ft/s for 82 min | Layher and Ralston, 1997 |
| Longear Sunfish Length (50-136 mm) | 0.62 ft/s for 14 min (100% success) 0.72 ft/s for 6 min (91% success) 1.08 ft/s for 2 min (88% success) | Layher and Ralston, 1997 |
| Pink and Chum Salmon | Prolonged (2.6 ft/s - 7.7 ft/s) Burst (7.7 ft/s - 15.0 ft/s) Estimated from leap heights at waterfalls | Bell, 1973 |
| Seined Golden Shiners | Swim speed (ft/s)* = $0.563 + 1.608L(\text{in})$ R-square = 0.707 | Layher and Ralston, 1997 |
| Shad | Prolonged (3.0 ft/s - 7.6 ft/s) Burst (7.6 ft/s - 14.5 ft/s) | Bell, 1991 |
| Sockeye | Prolonged (3.2 ft/s - 10.2 ft/s) Burst (10.2 ft/s - 20.6 ft/s) | Bell, 1973 |
| Steelhead | Prolonged (4.6 ft/s - 13.7 ft/s) Burst (13.7 ft/s - 26.5 ft/s) | Bell, 1973 |
| Stickleback | Burst (3.0 ft/s - 3.5 ft/s) | Bell, 1991 |
| Suckers | Prolonged (2.5 ft/s - 5.0 ft/s) Burst (5.0 ft/s - 10.0 ft/s) | Bell, 1991 |
| Whitefish | Prolonged (1.5 ft/s - 4.5 ft/s) Burst (4.5 ft/s - 9.0 ft/s) | Bell, 1991 |
| Juvenile Bighead Carp | mean = 0.81 ft/s* s.d.=0.13 | Layher and Ralston, 1997 |
| Juvenile Salmonids: Coho, Chinook, Steelhead, Chum, Pink | swim speed (ft/s) = $0.638L(\text{in}) - 0.0172$ | Barber and Downs, 1996 |

* Reported as velocity of failure point, causing swimming to quickly terminate in exhaustion.

Culvert Inputs

Culvert Hydraulics

The Culvert Hydraulics portion of the [Culvert Input Sheet](#) (right side of the sheet) allows the user to specify the culvert type, size, and placement.

Culvert Shape - Choose a culvert type from the list. If Pipe-Arch is chosen, a window will open containing a list of predefined sizes to select from. For a description of the different culvert types and shapes, click here [»](#) .

Culvert Construction - Choose the construction material of the culvert. Click here for a brief description of different materials [»](#) .

Installation – This field has two options, At Grade and Sunken:

At Grade - Standard installation, with culvert invert placed on the surface of the channel bed.

Sunken - Culvert invert depressed (countersunk) below the stream bed to retain bed material, producing a natural channel bottom throughout the culvert. The sunken installation can also be used if the culvert invert has been lined with concrete or other material. After selecting Sunken enter the effective depth the invert is placed below the original stream bed (if it is concrete lined, enter the depth of the concrete). For additional information about installing a sunken culvert, click here [»](#) .

Culvert Diameter - This field is only active when a circular culvert is selected. Choose the diameter of the culvert from the drop-down menu or enter a custom diameter. All diameters are in inches, and circular culverts are typically manufactured in 6-inch increments.

Culvert Span and Rise

Span and Rise fields are used to display the Height and Width of pipe-arches and open-bottom arches. The field will only be editable when an Open-Bottom Arch is selected as the culvert shape. Pipe-Arch shapes are selected from predefined sizes in a separate window, opened by clicking on Pipe-Arch in the Culvert Shape field.

Span - The Span for open- bottom arches is the width of the arch, measured either at the stream-bed or from the footings.

Rise - The Rise for Open- Bottom Arches is the vertical height of the arch, measured either from the stream-bed or from the footings.

Note: If Span and Rise are measured from footings, you must select Sunken in the Installation field and define the depth below the streambed to which the top of the footings are placed.

Height - Height and width fields are active when Box Culvert is selected. The height is measured vertically from inside of box.

Width - The width is measured horizontally from inside the box.

Culvert Roughness Coefficient - Enter or select a Manning's **roughness coefficient** for the selected culvert. Default values are entered automatically when you select the culvert Construction Type.

Bottom Roughness Coefficient - This field is only activated for sunken or open-bottom arch culverts. Enter or select a Manning's **roughness coefficient** for the material along the culvert bottom. This is likely streambed material similar to the material in the upstream channel, but it can also be concrete or other material.

Culvert Length - Enter the total length measured from the culvert inlet to the culvert outlet.

Culvert Elevation and Slope

FishXing allows you to choose between entering the elevation of the culvert inlet or entering the culvert slope. The other is auto-calculated once the culvert length and outlet elevation have been entered. To select which field you wish to enter, click on the option button (open circle) adjacent to the field. The nonselected field will be grayed-out and display the auto-calculated value. This feature allows you to either use a surveyed inlet elevation or enter a culvert slope to determine the resulting inlet elevation.

Elevation of Inlet Bottom - If the elevation of the inlet bottom (inlet invert) is selected, enter it. If the culvert is sunken or an Open-Bottom Arch, the inlet invert is defined as the elevation of the channel bed at the inlet.

Culvert Slope - If selected, enter the percent slope of the culvert bottom. If the culvert is sunken or is an open-bottom arch, enter the slope of the bottom material.

Note: *FishXing* can NOT model hydraulics of culverts containing a bottom slope substantially different from the slope of the installed culvert. For example, the depth sunken at the culvert inlet is much less than at the outlet).

Elevation of Outlet Invert - Enter the elevation of the outlet invert (culvert bottom). If the culvert is **sunken** or is an **Open-Bottom Arch**, the outlet invert is defined as the elevation of the channel bed at the outlet.

Note: All elevations should be tied to a common datum.

Inlet Head Loss Coefficient - The head loss coefficient is a parameter that describes the amount of energy lost as the water passes through the culvert inlet. Select or enter the appropriate head loss coefficient for the particular culvert inlet configuration. Larger coefficients are associated with greater head loss. For more information about inlet head loss coefficients, click here  .

Also see:

[Biological Considerations](#)

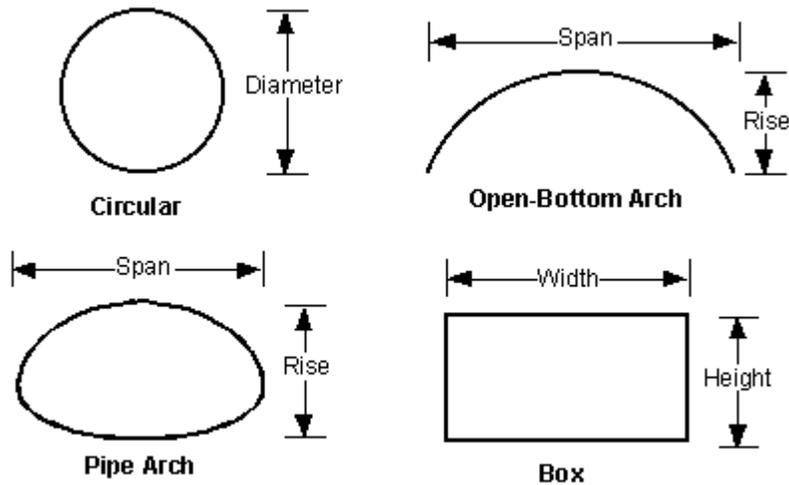
[Culvert Input Sheet](#)

[Tailwater Options Sheet](#)

[Collection Field Data](#)

Culvert Types

FishXing allows you to choose from the four predefined culvert shapes shown below.



Also see:

[Construction Materials](#)

Construction Materials

Descriptions of different construction materials that can be selected:

| Construction | Description |
|--|--|
| CMP (2 2/3- X 1/2-inch corrugation) | Galvanized steel or aluminum with 1/2 inch high corrugations, spaced 2 2/3 inches apart. |
| CMP (3- X 1-inch corrugations) | Galvanized steel or aluminum with 1 inch high corrugations, spaced 3 inches apart. |
| CMP (5- X 1- inch corrugations) | Galvanized steel or aluminum with 1 inch high corrugations, spaced 5 inches apart. |
| Structural Plate Pipe (6- X 2- inch corrugations) | Galvanized steel plates bolted together, with 2 inch high corrugations, spaced 6 inches apart. |
| Spiral CMP | Galvanized steel or aluminum with helical corrugations, typically 1/2 -inch high, spaced 2 2/3-inches apart. |
| Concrete | Rough concrete associated most often with box culverts. |
| PVC | Plastic with varied corrugation sizes. |

Roughness Coefficients

A value that represents resistance to flow in a channel or culvert. *FishXing* uses Manning's roughness coefficients. Values for different culvert materials are widely published and given as default values in *FishXing*. Roughness coefficients for natural channels and culverts containing natural channel substrate differ widely and need to be measured or estimated from

experience.

Also see:

[Manning's Equation](#)

[Weighted Roughness](#)

Inlet Head Loss Coefficients

$$H_L = K_e \frac{V^2}{2g}$$

The inlet head-loss coefficient, K_e , is a constant in the head-loss term of the energy equation for open-channel flow. The head-loss coefficient is a measure of the efficiency of the inlet to smoothly transition flow from the upstream channel into the culvert.

The coefficient can range in value between 0 and 1. Larger Head-loss coefficients are associated with increased flow contraction in the inlet zone. Culverts having a width less than the upstream channel will constrict flow and can create a steep drop in the water surface profile at the inlet, often resulting in a velocity barrier for fish attempting to exit the culvert.

The inlet head-loss coefficient is a function of the flow. Most coefficients given by manufacturers are for relative depths (headwater depth/culvert rise) of about 1.2, well above fish passage flows.

Attempts should be made to minimize the head-loss at the culvert inlet to improve passage. Sizing the culvert large enough to avoid constricting the flow will result in a inlet head-loss coefficient of 0 for fish passage flows. Another means of reducing the head-loss at the inlet is to build wingwalls to direct the flow smoothly into the culvert.

Bates (1992) suggests that inlet coefficients should not exceed 0.7 for adult salmonid fish passage, 0.5 for sites with marginal passage conditions, and 0.2 for juvenile salmonid passage.

Tailwater Options

Tailwater Options Sheet

The Tailwater Conditions Sheet is opened by clicking on the **Tailwater Option button** on the Culvert Input Sheet. It specifies [tailwater](#) elevations. As discharge through the culvert increases, the tailwater elevation may also increase. *FishXing* offers three different methods for defining tailwater elevation:

[Constant Tailwater Method](#)

[User Defined Rating Curve Method](#)

[Channel Cross-Section Method](#)

To select the desired tailwater method to use in the culvert calculations:

- Choose from the list under the **Tailwater Methods** pull-down menu or click into the

appropriate box on the Tailwater Conditions Sheet. The text in the activated box will be highlighted, leaving the other methods grayed-out.

- If you select the User Defined Rating Curve Method or the Channel Cross-Section Method, click on the **Enter Data** button on the Tailwater Conditions Sheet.

To change the Method for calculating tailwater elevations:

- Activate the desired method by selecting from the **Tailwater Methods** pull-down menu or clicking into the grayed-out box on the Tailwater Conditions Sheet. The data entered into the previously selected method(s) will be saved, allowing you to switch between tailwater methods without losing entered data.

Constant Water Surface Method

The Constant Water Surface Method is useful where tailwater elevation does not change with changes in discharge. This method requires the least amount of site information and may be appropriate for preliminary culvert assessments.

Pool Surface Elevation - Enter the water surface elevation of the outlet pool.

Outlet Pool Bottom Elevation – Enter the elevation of the lowest point in the outlet pool. This Pool Bottom Elevation will be used to calculate the pool depth at the culvert outlet.

Note: All elevations should be tied to the surveyed elevation of the culvert inlet and outlet by use of a common datum.

User Defined Rating Curve Method

The Rating Curve Method allows you to specify tailwater elevations corresponding to discharges, forming a stage-discharge rating curve. For more information about how the rating curve is used in calculations, click here [»](#).

Outlet Pool Bottom Elevation – Enter the elevation of the lowest point in the outlet pool relative to the elevation of the culvert outlet invert. This Pool Bottom Elevation will be used to calculate the pool depth at the culvert outlet.

Elevation – The tailwater elevation at the corresponding discharge.

Discharge – The discharge corresponding to the tailwater elevation.

Entering Elevation and Discharge:

- Enter the tailwater elevation in the field directly under **Elevation**. Then press tab to move to the next field.
- Enter the corresponding discharge into the field directly under **Discharge**. Then press the Enter key or click on the **Enter** button to input the point into the table on the right.
- To delete a point(s) that has been entered into the table on the right, highlight the row you wish to delete using the mouse. Then click on the **Remove Rows** button.
- When all the points are entered, click on the **Done** button.

Note: The first tailwater elevation must have a corresponding discharge value equal to

zero. Also, the tailwater elevation cannot be less than the Outlet-Pool Bottom Elevation.

Importing and Exporting Survey Cross-Sections

FishXing allows you to import and export the rating table (water surface elevation and discharge).

Exporting Rating Table

Exported files contain two columns of numbers. The first column contains the elevation, and the second column contains the corresponding discharge. The file is exported as comma-delineated ASCII text and can be read by any text editor, imported into a spreadsheet, or imported back into *FishXing*.

To Export:

- Click on the **Export** button.
- Choose a location and file name for the exported rating table. The default extension for cross-section data files is (.xcs), and the default location for export is the **Data** folder created by *FishXing*. The file will be saved in ASCII format.

Importing Cross-Sections

FishXing allows the import of text files containing two columns that may be delimited with commas, spaces, or tabs. The first column must contain the elevation data and the second should contain the discharge data. No extra lines of text or numbers are permitted.

To Import:

- Click on the **Import** button.
- Choose an existing ASCII format file for import. The default extension for rating table data files is (.xcs), and the default location is the **Data** folder created by *FishXing*.

Channel Cross-Section Method

The Channel Cross-Section Method allows you to specify the shape and roughness of the stream channel downstream of the culvert outlet. *FishXing* then estimates tailwater elevations at different discharges by using **Manning's equation**, creating a tailwater elevation-discharge rating curve. This method requires a surveyed downstream channel cross-section, the channel slope, and an estimate of the **roughness coefficient**.

For more information about how the Rating Curve is used in calculations, click here .

Channel Bottom Slope – Enter the percent slope of the channel bottom downstream of the culvert. The slope should be taken through the surveyed cross-section.

Outlet Pool Bottom Elevation – Enter the elevation of the lowest point in the outlet pool. This Pool Bottom Elevation will be used to calculate the pool depth at the culvert outlet.

Note: All elevations should be tied to the surveyed elevation of the culvert inlet and outlet by use of a common datum.

Manning's Roughness Coefficient, n – Select or enter a value for the **Manning's**

roughness coefficient. The coefficient can be estimated based on the size and shape of the streambed material or back-calculated. The default roughness values in the drop-down box came from the USGS publication, *Roughness Characteristics of Natural Channels* (Barnes, 1967).

Max Elevation – After the rating table is calculated, the maximum tailwater elevation is shown in this field (the maximum elevation containing both left and right bank.).

Step Size – After the rating table is calculated, the default tailwater-elevation step size is shown in this field. The step size is the difference between each calculated tailwater elevation in the rating table. You may adjust the step size and recalculate the rating table.

Note: A smaller step size creates more points in the rating table leading to less interpolation error, but it also increases the size of the data file.

Cross-Section Survey

The cross-section should be taken at the control point in the channel, downstream of the culvert outlet. The control point is a channel section that influences the upstream tailwater elevation. Control points are often found at changes in channel grade or at constrictions in the channel cross-section. If an outlet pool exists, the control point would lie near the pool tail crest immediately downstream of the pool.

Click here to view an example of a channel profile and cross-sectional survey,  .

Entering Survey Points:

- Enter the station (horizontal distance across the channel) in the field directly under **Station**. Then press the tab key to move to the next field.
- Enter the corresponding elevation into the field directly under **Elevation**. Then press Enter key or click on the **Enter** button to input the survey point into the table on the right. As you enter points into the table, the channel cross-section is auto-drawn in the graph below. All entries are auto-sorted in the table by station, and negative elevations are allowed.
 - Note:** Elevation in the channel cross-section should be tied to the surveyed elevation of the culvert inlet and outlet by use of a common datum.
- To delete a point(s) entered into the table on the right, highlight the row(s) you wish to delete by using the mouse. Then click on the **Remove Rows** button.
- When all the surveyed points in the cross-section are entered, click on the **Compute** button. The tailwater–discharge rating curve is computed and displayed in a pop-up sheet.

Importing and Exporting Survey Cross-Sections

FishXing allows you to import and export the channel cross-section (station and elevation).

Importing Cross-Sections

FishXing allows the import of text files containing two columns that may be delimited by commas, spaces, or tabs. The first column must contain the station data, and the second

should contain the elevation data. No extra lines of text or numbers are permitted.

To Import:

- Click on the **Import** button.
- Choose an existing ASCII format file for import. The default extension for cross-section data files is (.xcs), and the default location is the **Data** folder created by *FishXing*. The data will be imported, sorted by station, and entered into the data table.

Exporting Cross-Sections

Exported files contain two columns of numbers. The first column contains the station, and the second column contains the corresponding elevations of the channel bottom. The file is exported as comma-delineated ASCII text and can be read by any text editor, imported into a spreadsheet, or imported back into *FishXing*.

To Export:

- Click on the **Export** button.
- Choose a location and file name for the exported cross-section. The default extension for cross-section data files is (.xcs), and the default location for export is the **Data** folder created by *FishXing*. The file will be saved in ASCII format.

Rating Curves

Tailwater Rating Curves

A tailwater rating curve is used to define the water surface elevation at the culvert outlet for a range of discharges. A rating curve is constructed from a tailwater rating table containing discharges and corresponding tailwater elevations. A rating table is used to determine tailwater elevations when you select either the User Defined Rating Curve Method or the Channel Cross-Section Method in the Tailwater Conditions Sheet.

FishXing uses the rating table to estimate the tailwater elevations at specific discharges for both Uniform Flow and Water Surface Profile calculations using linear **interpolation** and **extrapolation**.

Tailwater Rating Curve Created from Cross-Section Method

The tailwater-discharge rating curve is created after clicking on the **Compute** button when you are in the Cross-Section Input Sheet. The rating table lists the discharge and corresponding tailwater elevation in the first two columns. The last two columns list the wetted perimeter and cross-sectional area:

Perimeter – The wetted perimeter of the channel cross-section at the corresponding tailwater elevation. The wetted perimeter is the length of the submerged portion in the cross-section, beginning and ending at the left and right banks.

Area – The cross-sectional area of the flow in the channel. The water surface is at the

corresponding tailwater elevation.

Rating Curve Range

The discharge is calculated for tailwater elevations ranging from the lowest point in the channel to the highest elevation that contains both a left and right stream bank according to the input cross-section. The interval between tailwater elevations in the rating table is determined by the step size. You can return to the Channel Cross-Section Input Sheet and adjust the step size or make changes to the channel cross-section by clicking on the **Back** button.

Viewing Results

What Now? Sheet

The What Now? Sheet is displayed after *FishXing* finishes its calculations.

The What Now? Sheet offers you the following options:

| | |
|------------------------|--|
| WSP | Displays water surface and velocity profiles. |
| Uniform | Displays the results of the Uniform Flow Calculations. |
| Save | Saves the culvert input information. You will be able to save the culvert file in the Project folder. Saving the culvert now, after having performed the calculations, is a good idea. |
| Project Summary | Return to the Project Summary to open the file for another existing culvert or start a new culvert. |
| Report | Generates a detailed analysis summary for the current culvert. |
| Exit | Closes <i>FishXing</i> . |
| < Back | Returns to the Culvert Input Sheet. |

Generating a Report

FishXing can generate a custom report for you. After clicking on the **Calculate** button, the What Now? sheet appears. Click on the **Report** button and a window will appear with a list on the left side containing all of the different sections you may include in your report. Highlight the first section you would like to have in your report and then click the **Add to Report** button. The section name will appear in the right hand column. Continue adding sections to the right hand side until you are satisfied. Use the **Remove from Report** button to delete unwanted sections from the right side.

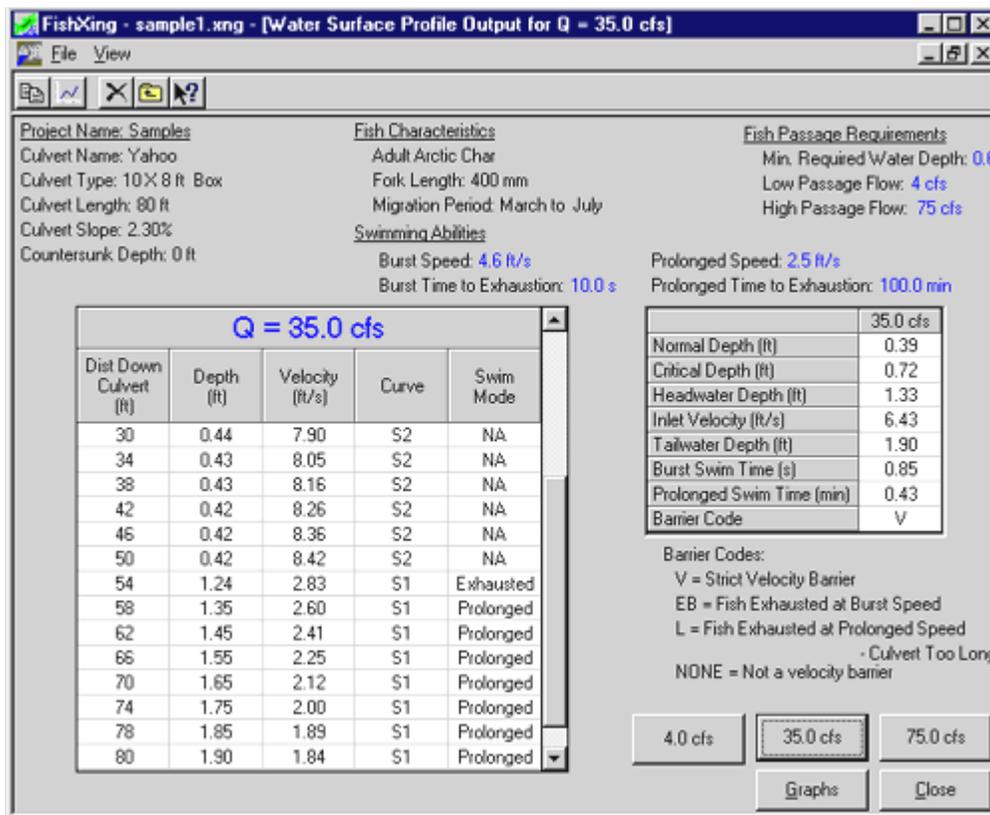
You can change the order that the sections will appear in the report by using the **Up** and **Down** buttons. When finished, click the **View Report** button and a print preview screen will appear.

You can view and print the report from the print preview screen. Currently, there is no way of saving the report or copying and pasting sections of it. If you wish to copy graphs into other documents, you can export them as Bitmap files (.bmp) when viewing them.

Water Surface Profiles

Water Surface Profiles (WSP)

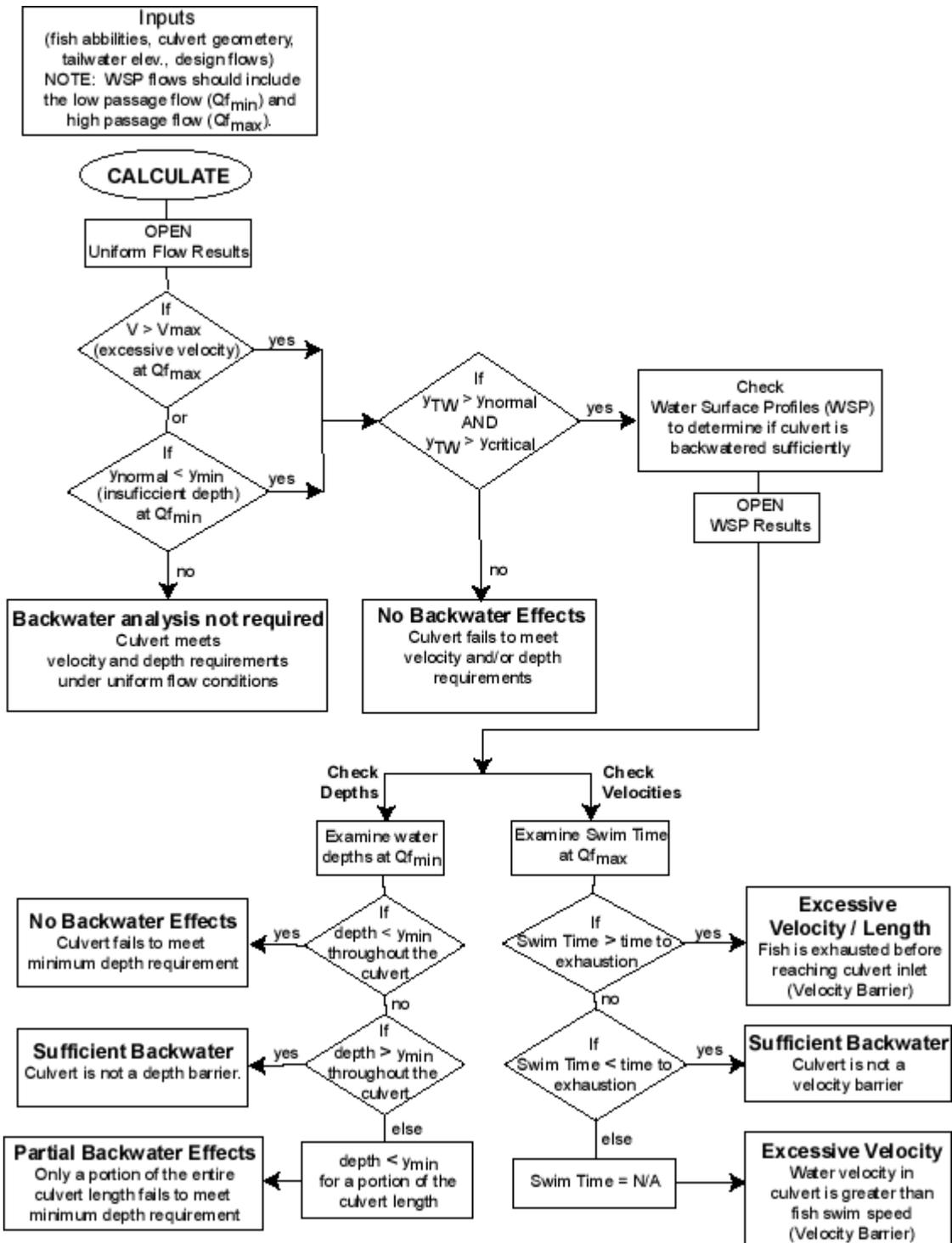
Water Surface Profiles (WSP) are generated for three user-specified flows to allow for a more complete analysis of the culvert hydraulics. Unlike the Uniform Flow Results, the water surface profiles do not assume uniform flow. Instead, they are generated by using gradually varied flow equations based on steady-state nonuniform flow. The water surface profiles also identify hydraulic jumps.



Click on image for more information

Interpreting Backwater Effects

Backwatering of the flow in the culvert can be beneficial to fish passage by increasing depth and decreasing water velocity. The following flowchart outlines the process of identifying when backwater effects are present and how to interpret water surface profiles with respect to fish passage.



where,
 Q_{fmin} = Low fish passage flow,
 Q_{fmax} = High fish passage flow,
 V_{max} = Maximum allowable water velocity,
 y_{normal} = Normal depth,
 y_{min} = Minimum required depth,
 y_{TW} = Tailwater depth, and

Swim Time = Time fish spent swimming at burst and/or prolonged speed (on WSP results sheet).

Uniform Flow Results

Uniform Flow Results

The Uniform Flow Results display the calculations of:

- Water velocity and depth under uniform flow conditions,
- Critical depth,
- Tailwater and pool depths, and
- Required leaping distance and speed to enter the culvert outlet.

Culvert Information

The Uniform Flow Results displays general information about the culvert in the left column of the header.

Fish Characteristics

The characteristics and swimming ability of the selected fish are presented in the center column of the header. The information includes fish species, age class, migration timing, fish length, and:

Time to Exhaustion - The duration of swimming that will result in exhaustion. The selected fish is not able to swim longer than its specified time to exhaustion.

Fish Passage Requirements

The right column in the header contains the requirements and constraints for fish passage associated with the selected culvert and fish capabilities.

Burst-Prolonged Max Allowable Water Velocity - The maximum speed of the water, *assuming uniform flow*, the fish can successfully swim against for the length of the culvert. *FishXing* will report only prolonged maximum water velocity if you chose to use both swim modes. The Max Allowable Water Velocity, V_{max} , is calculated with the following equation . When the calculated maximum water velocity is negative, it is displayed as 0.0. If the Max Allowable Water Velocity is negative for the swim mode(s) you selected then the following warning is issued.

Not Passable. Fish Exhausted!

The value is negative when, at all water velocities, the culvert is too long for the fish to swim through without resting. This situation is most common for burst swimming speeds, which the fish can only maintain for a short period.

If you receive this warning and are using only burst swim speeds for your selected fish, try using either strictly prolonged swim speeds or a combination of both burst and prolonged. If the Max Allowable Water Velocity for the prolonged swim speed is 0.0, the culvert is likely too long and an alternative culvert design should be considered. For more information about swimming abilities of fish, click here .

Min Required Water Depth - Displays the minimum depth the selected fish needs for

swimming, as entered in the Input Sheet.

Max Leap Speed - Displays the maximum speed the selected fish can leap out of the water, as entered in the Input Sheet. This speed is typically the same (or close to) the burst swimming speed of the selected fish.

Low-Passage Flow - Displays the lower flow limit for which fish passage should be accommodated. The flow value is entered in the Culvert Input Sheet. Fish passage is not necessary for the selected fish when flows are below the low-passage flow.

High-Passage Flow - Displays the upper flow limit for which fish passage should be accommodated. The flow value is entered in the Culvert Input Sheet. Fish passage is not necessary for the selected fish when flows are above the high-passage flow.

For more information about passage flows, click here [»](#).

Uniform Flow Results Table

The Uniform Flow Results table contains information about the hydraulics in the culvert barrel and the conditions at the culvert outlet over a wide range of flows. The numbers in the table are calculated at depth intervals of 0.10ft (0.30 m). The table contains flows ranging from 0.0 to about 170% of the high-passage flow (Q_{hp}). Calculations will be stopped before reaching 170% Q_{hp} , if normal depth becomes greater than the height of the culvert.

Click on the column headings to obtain a description of the information contained in each column.

| Uniform Flow Output for Cow Creek (HUM12) | | | | | | | | | |
|---|-----------------|-------------------|------------------------------------|------------------------|----------------------|-----------------|--|--------------------------|------------|
| Project Name: Samples | | | Fish Characteristics | | | | Fish Passage Requirements | | |
| Culvert Name: Cow Creek (HUM12) | | | Adult Coho | | | | Max. Allowable Water Velocity 6.0 ft/s | | |
| Culvert Type: 36 in Circular | | | Migration Period: October to April | | | | Min. Required Water Depth 0.6 ft | | |
| Construction: CMP (2 2/3 X 1/2 in corr.) | | | Fork Length: 600 mm | | | | | | |
| Culvert Length: 42 ft | | | Swimming Abilities | | | | Max Leap Speed: 11.8 ft/s | | |
| Culvert Slope: 0.12% | | | Burst Speed: 11.8 ft/s | | | | Prolonged Speed: 6.00 ft/s | | |
| Countersunk Depth: 1.3 ft | | | Burst Time to Exhaustion: 5.0 sec | | | | Prolonged Time to Exhaustion: 30.0 min | | |
| Discharge (cfs) | Velocity (ft/s) | Normal Depth (ft) | Critical Depth (ft) | Outlet Velocity (ft/s) | Tailwater Depth (ft) | Pool Depth (ft) | Min Rqd. Leap Velocity (ft/s) | Vert. Leap Distance (ft) | Comments |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.87 | 0.82 | | | |
| 0.22 | 0.37 | 0.10 | 0.03 | 0.03 | 0.99 | 0.94 | 0.00 | 0.00 | Depth |
| 0.70 | 0.57 | 0.20 | 0.08 | 0.09 | 1.13 | 1.08 | 0.00 | 0.00 | Depth |
| 1.38 | 0.74 | 0.30 | 0.12 | 0.18 | 1.16 | 1.11 | 0.00 | 0.00 | Depth |
| 1.90 | 0.84 | 0.36 | 0.15 | 0.24 | 1.18 | 1.13 | 0.00 | 0.00 | LPF; Depth |
| 2.23 | 0.89 | 0.40 | 0.16 | 0.28 | 1.20 | 1.15 | 0.00 | 0.00 | Depth |
| 3.24 | 1.03 | 0.50 | 0.21 | 0.39 | 1.24 | 1.19 | 0.00 | 0.00 | Depth |
| 4.41 | 1.15 | 0.60 | 0.26 | 0.51 | 1.28 | 1.23 | 0.00 | 0.00 | |
| 5.71 | 1.26 | 0.70 | 0.30 | 0.63 | 1.33 | 1.28 | 0.00 | 0.00 | |
| Comment Codes: | | | | | | | | | |
| LPF - Low Passage Flow, HPF - High Passage Flow, Depth - Insufficient Depth | | | | | | | | | |
| Vel - Excessive Velocity, Leap - Excessive Leap, Pool - Shallow Leap Pool | | | | | | | | | |
| | | | | | | | | Show Graphs | |
| | | | | | | | | Close | |

Discharge

Discharge is calculated from 0.0 to about 170% of the high-passage flow in the Uniform Flow

Results table. The discharge is calculated by using Manning's equation, and the associated water depths and average velocities assume uniform flow conditions throughout the culvert.

Velocity at Normal Depth

The reported velocity is the average cross-sectional velocity in the culvert for the associated discharge, assuming the water is flowing at normal depth. The average velocity is calculated:

$$V = Q/A,$$

where Q = discharge, and A = cross - sectional area of the flow at normal depth.

$$V = \frac{Q}{A}$$

Where :

Q = Discharge

A = Cross – sectional area of the flow at normal depth

Normal Depth

Normal depth in the culvert for the corresponding flow. Normal depth is displayed at intervals of 0.10 ft (0.03 m). Discharge and average water velocity are calculated at each depth. For an explanation of normal depth, click here [»»](#)

The water depth in a culvert reaches normal depth when no backwater conditions exist and the culvert is long enough. Backwatering causes the water depth to increase and slows water velocities, generally improving passage conditions.

Critical Depth

Critical Depth is the water depth possessing the minimum energy at the given discharge, and has a **Froude Number** equal to 1. When the water depth in the culvert is greater than critical depth, the flow is subcritical. When the water depth is less than critical depth, the flow is supercritical.

By comparing normal depth to critical depth, the user can determine the culvert slope type.

- If normal depth is the same as critical depth, the culvert is on a **Critical Slope**.
- If normal depth is greater than critical depth, the culvert is on a **Mild Slope**.
- If normal depth is less than critical depth, the culvert is on a **Steep Slope**.

Note: Most weak swimming fish require subcritical flow for successful passage through culverts.

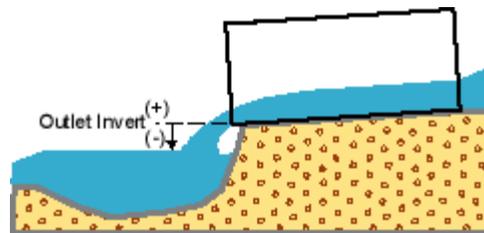
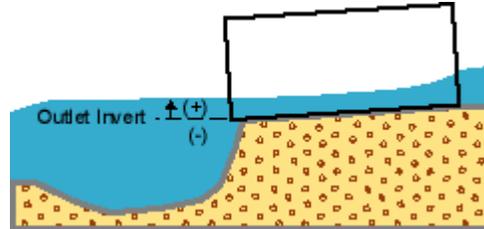
Outlet Velocity

The average water velocity at the culvert outlet. The outlet velocity depends on the tailwater depth and the culvert slope type (mild or steep).

Tailwater Depth

Tailwater depth is the water depth immediately downstream of the culvert outlet measured from the culvert outlet bottom (invert).

- Depths are positive when the tailwater elevation is greater than the outlet bottom elevation. No leap is required for the fish to enter the culvert when the tailwater depth is positive.
- Depths are negative when the tailwater elevation is less than the outlet bottom elevation. That is, when the culvert outlet is perched above the downstream channel. Under these conditions, the fish may have to leap to reach the culvert outlet.



NOTE: If the tailwater depth is greater than both the critical and normal depths, a backwater effect may be caused in the culvert. In general, backwater effects are beneficial to fish passage because they reduce water velocities and increase water depth. Check the **water surface profiles (WSP)** to determine the extent of the backwater effect.

Pool Depth

The pool depth is the maximum water depth immediately downstream of the culvert outlet. It is defined as:

$$\text{Pool depth} = (\text{tailwater elevation} - \text{pool bottom elevation}).$$

Where a fish is required to leap into the culvert outlet, pool depth is checked to determine if it is sufficient. The pool depth is considered insufficient for leaping if:

$$\text{Pool depth} < (1.5 \times \text{fish length}).$$

Horizontal Leap Distance

The calculated horizontal distance the fish must leap to enter the culvert outlet. It is measured

from the culvert outlet to the outermost point that the nappe intersects the downstream pool. If the culvert outlet has no drop, the horizontal leap distance is 0.

For a detailed description of how outlet leaps are estimated, click here [»»](#) .

Vertical Leap Distance

The vertical leap distance is the height the fish must leap to enter the culvert outlet. The height is measured from the water surface in the culvert outlet to the surface of the outlet pool. If culvert outlet has no drop, the Horizontal Leap Distance is 0.

For a detailed description of how outlet leap parameters are calculated, click here [»»](#) .

Min Required Leap Velocity

The Minimum Required Leap Velocity is the initial velocity the fish must leap out of the outlet pool to successfully land horizontally on the water surface at the culvert outlet.

NOTE: FishXing assumes the fish leaps at the correct angle, and air friction is negligible.

For a detailed description of how outlet leap parameters are calculated, click here [»»](#) .

Comments

The comments column notifies you of potential problems with meeting fish passage conditions. Warnings are issued to identify the limiting factor or factors for passage at each discharge.

Here are the conditions that produce the following comments:

Insufficient Depth - *Normal depth* in the culvert is less than the *minimum required depth*.

Excessive Velocity - The average *velocity* in the culvert (assuming uniform flow) is greater than the *maximum allowable water velocity*.

Excessive Leap - The *minimum required leap velocity* is greater than the *maximum leap speed*. The culvert is a vertical barrier.

Shallow Leap Pool - The outlet *pool depth* is less than (1.5 x *fish length*) of the selected fish, possibly producing unsatisfactory take-off conditions for leaping into the culvert outlet. Comment only arises if the culvert is perched.

Low-Passage Flow - The low-flow limit for fish passage. Fish passage is not required at lower flows.

High-Passage Flow - The upper flow limit for fish passage. Fish passage is not required at higher flows.

Culvert Hydraulics

Defining Normal Depth

Normal depth is the depth of flow in a channel or culvert when the slope of the water surface and channel bottom are the same (water depth remains constant). In culverts, water flows at normal depth when outside the influence of the inlet and outlet tailwater. *FishXing* uses [Manning's Equation](#) to estimate normal depth at each calculated discharge.

Note: Flow at normal depth in culverts often presents the highest average velocities and shallowest depths at that flow. Using normal depth in designing for fish passage is a conservative approach, and ignores potential backwater effects that can increase the range of passable flows.

Also see:

[Roughness Coefficients](#)

Max Allowable Water Velocity

$$V_{\max} = V_{fish} - \frac{L}{t_{ex}},$$

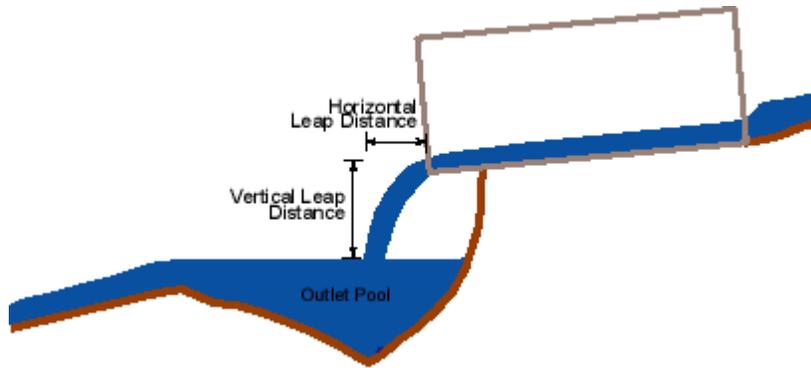
where,

V_{fish} = Adjusted prolonged swim speed

L = Length of the culvert

t_{ex} = Time to exhaustion

Leaping Calculations



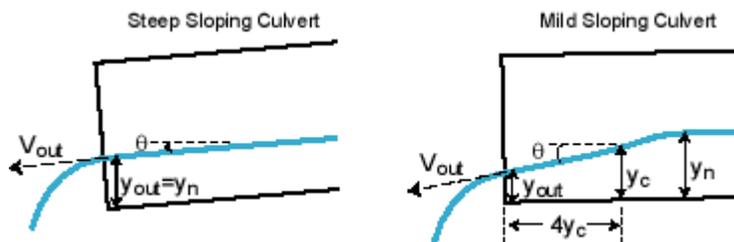
Water leaving a perched culvert has a velocity with both horizontal and vertical components. By neglecting all frictional losses, a simplified projectile equation can be applied to the exiting water. Using the projectile equation, *FishXing* calculates the horizontal distance the plunging water travels, L , before hitting the outlet pool, and then assumes this place is where the fish will leap.

The height the water plunges, H , and horizontal distance the water travels after exiting the culvert, L , is described by the following equations:

$$H = V_{out}(\sin \theta)t - \frac{1}{2}gt^2, \text{ and} \quad (1)$$

$$L = V_{out}(\cos \theta)t, \quad (2)$$

where V_{out} is the exiting water velocity at the culvert outlet, g is gravitational acceleration, t is the time for the exiting water to fall from the culvert outlet to the pool, and θ is the angle at which the water exits the culvert outlet.



For steep-sloping culverts (normal depth (y_n) < critical depth (y_c)), the water is assumed to be at normal depth at the outlet, making the exit angle, θ , equal to the culvert slope (degrees).

When the culvert slope is mild ($y_n > y_c$), the water surface profile is on a draw-down (M2) curve as it approaches the perched outlet. Based on the work presented by Rouse (1938) and Behlke et al. (1991), *FishXing* assumes the water surface passes through critical depth $4y_c$ upstream of the outlet. In addition, the water depth at the outlet, y_{out} , is a function of the culvert geometry and the cross-sectional area of the flow at critical depth:

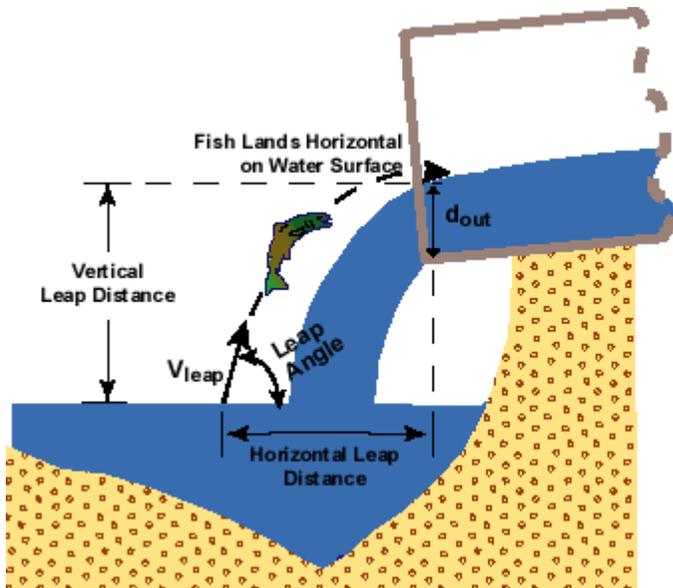
$$A_{out} = 0.71A_c \quad (3)$$

where A_{out} is the cross-sectional area of the flow at the outlet and A_c at critical depth. The exit angle, θ , on steep-sloping culverts is the summation of the culvert slope and the slope of the

water surface at the outlet, relative to the culvert:

$$\theta = \tan^{-1}\left(\frac{y_c - y_{out}}{4y_c}\right) + \tan^{-1}(\text{culvert slope}) \quad (4)$$

The time, t , can then be solved for by substituting equation (4) into equation (1). Finally, the horizontal distance, L , is solved for by using equation (2).



FishXing assumes L , the horizontal distance the water travels as it exits the culvert, is also the horizontal leap distance the fish must jump to enter the culvert outlet.

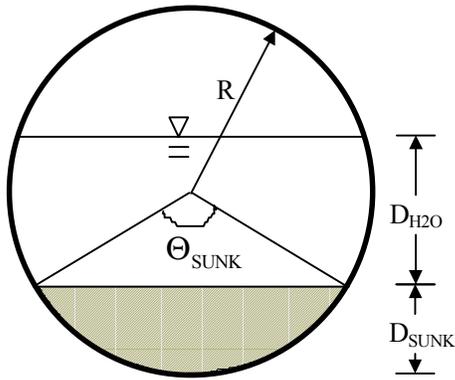
The projectile equations (1) and (2) are then applied to the leaping fish where $V_{out} = V_{leap}$ and $\theta = \theta_{leap}$. V_{leap} and θ_{leap} are the velocity and angle the fish must leap out of the pool to land horizontally on the water surface at the culvert outlet. *FishXing* uses an iterative approach to solve for the two variables and gives the velocity as the **minimum required leap velocity**. Fish leaping at a lower velocity from this place in the pool will fail to reach the water surface at the culvert outlet. Within the range of fish passage flows, if the *minimum required leap velocity* is greater than the *maximum leap speed* of the selected fish the culvert is considered a vertical barrier.

References:

- Behlke, Charles E., Douglas L. Kane, Robert F. McLean, and Michael D. Travis. 1991. Fundamentals of culvert design for passage of weak-swimming fish. Final Report, Alaska, DOT&PF, Fairbanks, AK, FHWA-AK-RD-90-10, February, 1991, 177 p.
- Rouse, Hunter. 1938. Fluid mechanics for hydraulic engineers. Engineering Societies Monographs, 1st ed. McGraw Hill Book Co., New York, NY, 415 p.

Round CMP Equations

The following equations are used in *FishXing* to calculate the wetted perimeter, top width, and cross-sectional area of the flow through a circular culvert.



$$\Theta_{\text{SUNK}} = 2 \cos^{-1} \left(\frac{R - D_{\text{SUNK}}}{R} \right)$$

$$A_{\text{SUNK}} = \frac{R^2}{2} [\Theta_{\text{SUNK}} - \sin(\Theta_{\text{SUNK}})]$$

$$P_{\text{BOTTOM}} = 2R \sin \left(\frac{\Theta_{\text{SUNK}}}{2} \right)$$

$$\Theta_{\text{H}_2\text{O}} = 2 \cos^{-1} \left[\frac{R - (D_{\text{SUNK}} + D_{\text{H}_2\text{O}})}{R} \right]$$

$$P_{\text{SIDES}} = R \Theta_{\text{H}_2\text{O}} - P_{\text{SUNK}}$$

$$W_{\text{TOP}} = 2R \sin \left(\frac{\Theta_{\text{H}_2\text{O}}}{2} \right)$$

$$A_{\text{H}_2\text{O}} = \left[\frac{R^2 (\Theta_{\text{H}_2\text{O}} - \sin(\Theta_{\text{H}_2\text{O}}))}{2} \right] - A_{\text{SUNK}}$$

Where:

D_{SUNK} = Sunken depth,

A_{SUNK} = Sunken area,

P_{SUNK} = Outside perimeter of sunken area,

P_{BOTTOM} = Perimeter of water on the bottom (0 for At Grade culvert),

P_{SIDES} = Perimeter of pipe from sunken depth to the water level, and

W_{TOP} = Top width of the water surface.

Manning's Equation

$$Q = \frac{\phi}{n} AR^{2/3} S_o^{1/2},$$

where,

Q = Discharge

ϕ = 1.00 for metric and 1.49 for english units

n = Manning's roughness coefficient

A = Cross - sectional area of flow

R = Hydraulic radius

S_o = Slope of the channel/culvert

Weighted Roughness

FishXing uses a weighted roughness coefficient to calculate flow for culverts with containing channel substrate, such as open-bottom pipe-arches and embedded or sunken culverts. The roughness values are weighted based, on wetted perimeter.

$$n = \frac{n_1 p_1 + n_2 p_2}{p_1 + p_2},$$

where,

n = weighted roughness coefficient,

n₁, n₂ = roughness coefficient of culvert and channel substrate, and

p₁, p₂ = wetted perimeter of culvert walls and channel bottom.

Froude Number

The Froude number, Fr, is a dimensionless value that describes different flow regimes of open channel flow.

$$Fr = \frac{Q^2 T}{gA^3},$$

where;

Q = Discharge,

T = Top width of free surface,

g = Gravitational acceleration, and

A = Cross - sectional area of flow.

When:

- Fr = 1, critical Flow,
- Fr > 1, supercritical flow, and
- Fr < 1, subcritical flow.

Embedded Culverts

Embedded culverts, also commonly known as sunken, countersunk, or depressed culverts, have their bottom placed below the streambed. This placement results in a culvert with natural substrate along the bottom, typically increasing the bed roughness and resulting in lower velocities.

The sunken culvert option can also be used to model metal pipes with concrete-lined bottoms. Choose **Sunken** and enter the approximate depth and roughness of the concrete.

Linear Interpolation

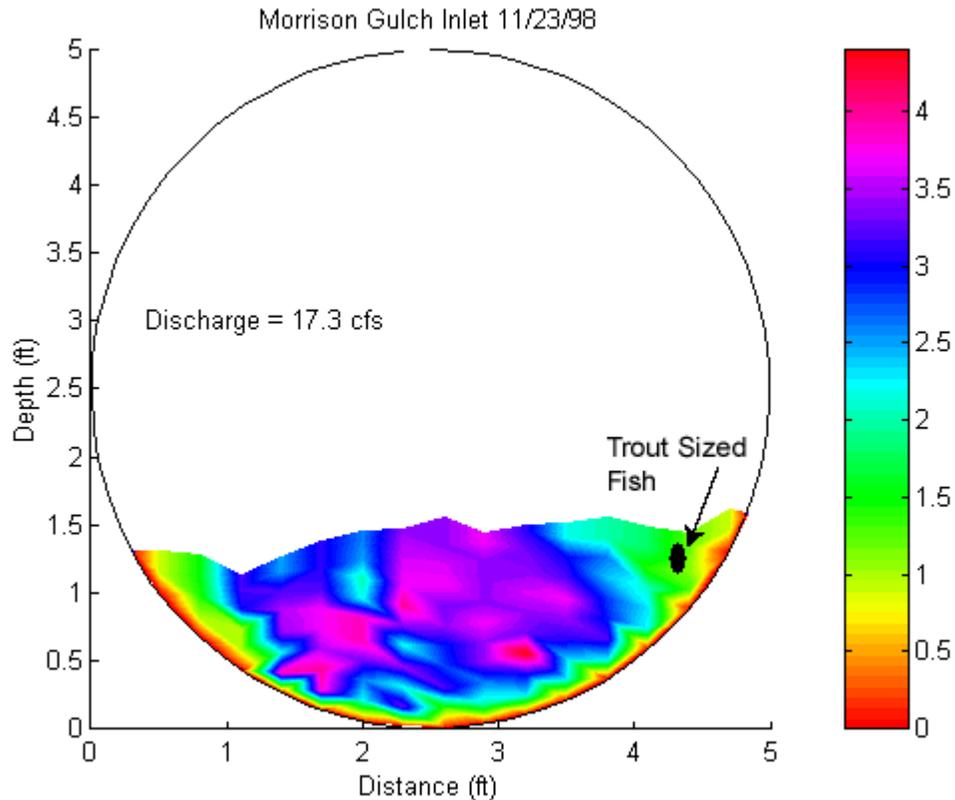
Estimates a desired value by assuming a straight line between the two known values.

Linear Extrapolation

Estimates a desired value beyond the last entry in the table by extending a straight line through the last two points.

Velocity Reduction Factors

The velocity reduction factor, K_{occ} , is multiplied by the average water velocity, V_{ave} , to determine the water velocity the fish swims through, V_{occ} .



Above is a map of water velocities in the inlet zone of a 5-foot diameter culvert. The average velocity is approximately 3.3 ft/s. Notice that a trout or similar sized fish would be able to swim through a region of lower velocities near the culvert wall. The water velocity within this region is often referred to as the *occupied velocity* (V_{occ}).

In this example $V_{occ} = 1.5$ ft/s and $V_{ave} = 3.3$ ft/s.

$$K_{occ} = V_{occ}/V_{ave} = 0.45$$

Behlke *et al.* (1991) suggests using the following velocity reduction factors for arctic grayling:

Inlet: $K_{occ} = 0.8$

Barrel: $K_{occ} = 0.6$

Outlet: $K_{occ} = 0.8$

Use caution when applying velocity reduction factors. These factors vary substantially and are influenced by the shape and roughness of the culvert, the culvert alignment with the upstream channel, and the size of the fish. Various hydraulic situations can eliminate the existence of a continuous path of lower velocities. Also, larger fish will not be able to avoid the regions of higher velocities, making reduction factors inappropriate to use.

Inlet Velocity

The hydraulic environment within the inlet zone of a culvert is typically classified as *rapidly varying flow*. There exist two distinct sections within the inlet zone: a contraction zone where streamlines contract as the water enters the culvert, and an expansion zone that exists immediately downstream of the contraction.

Head-loss occurs as water passes through the inlet zone. The magnitude of the head-loss is dependent on the selected **head-loss coefficient** and the velocity within the culvert barrel. The head-loss coefficient is a function of the transition efficiency as the water enters the culvert from the upstream channel.

As the water enters the culvert, velocities increase until they reach the point of maximum contraction. In this zone there is a drop in the hydraulic grade line (water surface) and an equal increase in kinetic energy (neglecting frictional effects). As the water moves further downstream, water velocities reduce to that within the barrel and kinetic energy is lost.

The contraction zone, due to the increased velocities, can hinder fish passage. *FishXing* approximates the maximum contraction velocity by assuming the calculated head-loss through the inlet zone is converted entirely to kinetic energy, and that this gained kinetic energy is then lost in the expansion.

FishXing uses the following equation to calculate the contraction velocity, V_{ctr} , and reports it on as the inlet velocity in the WSP Results:

$$V_{ctr} = (1 + K_e)^{1/2} V_B$$

where,

K_e = Inlet head-loss coefficient,

V_B = Water velocity within the culvert barrel, immediately downstream of the inlet (after the expansion zone).

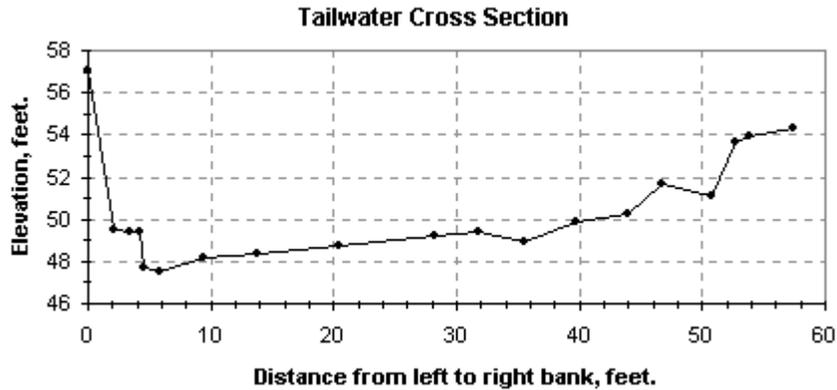
Perched Outlet

A culvert with an outlet elevated above the downstream water surface, allowing a freefall condition (also referred to as a hanging or shotgun outlet).

Tailwater

The water surface immediately downstream of the culvert. Often synonymous with the water surface of the outlet pool.

Cross-Section Example



The cross-section should always be at the site of the tailwater control.

Inlet Bottom

Measured in the center of the culvert inlet for both standard and embedded (sunken) culverts. If the culvert is embedded, this should be the elevation of the natural bottom at the inlet and not the elevation of the culvert inlet invert.

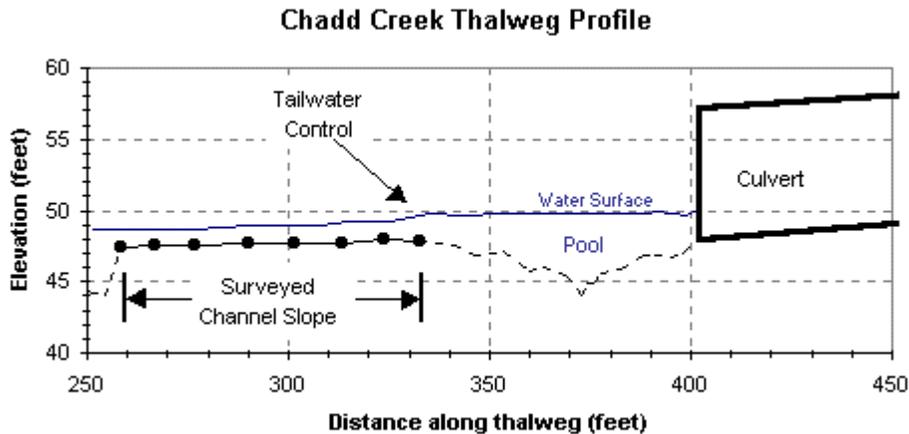
Outlet Bottom

Measured in the center of the culvert outlet for both standard and embedded (sunken) culverts. If the culvert is embedded, this should be the elevation of the natural bottom at the outlet and not the elevation of the culvert outlet invert.

Outlet Pool Bottom

Elevation surveyed at the deepest point in the outlet pool.

Channel Slope



Channel slope = 0.60%

Water-surface slope = 0.84%

Roughness, $n = 0.40$

Always survey the elevation of the tailwater control. When you plan to use the Cross-Section Method, measure the channel or water-surface slope beginning at the tailwater control and ending at the first substantial break in channel or water surface slope.

Default Swim Speeds

FishXing contains a number of default swim speeds. They exist in two forms; regression equations and constant speeds.

Regression Equations

The regression equations for fish swim speeds were developed by Hunter and Mayor (1986) based on fish performance data collected in previous field and laboratory studies. Each regression equation applies to an individual species and uses fish length and swim time as variables. The general form of the equation is:

$$V = aL^b t^{-c}$$

where,

V = swim speed of the fish

L = length of the fish

t = time to exhaustion

a, b, c = regression constants

Each swim speed equation applies to a specific mode of swimming, burst or prolonged, and has a range of applicable fish lengths. Often the length range can be classified as falling within either the juvenile or adult size class, although some length ranges encompass both size classes.

FishXing calculates the swim speed equation based on the selected species, age class, and fish length. When *FishXing* applies the regression equations, the reference, **Hunter & Mayor, 1986**, will appear below the swim speeds. If no swim speed equation was developed for the selected fish then *FishXing* will provide a constant speed if it exists. If neither a regression equation nor a constant swim speed exists, a message will appear saying **Not Available**.

Note: If no swim speed equation is available, the fish length may be out of the applicable range. Try either switching the age class or adjusting the fish length.

For a list of all the swim speed coefficients, click here [»](#) .

Constant Swim Speeds

FishXing uses constant swim speeds when no swim speed equation is available. Constant swim speeds are dependent on the species and age class you select. Most of the constant swim speeds come from **Bell, 1991**. The values come from the middle range of speeds given by Bell. If no constants are available then **Not Available** appears and you can enter your own value.

For a list of the constant swim speeds used in *FishXing*, click here [»](#) .

Swim Speed Equations

Swim speed equations developed and presented by Larry A. Hunter and Lesley Mayor in their 1986 publication, *Analysis of Fish Swimming Performance Data, Volume 1* are used in *FishXing* for calculating default swim speeds of numerous species. The general form of the swim speed equation is,

$$V = aL^b t^{-c}$$

where;

V = swim speed of the fish

L = length of the fish

t = time to exhaustion

a, b, c = regression constants

FishXing uses a default time to exhaustion of 5 seconds for burst swim speeds and 30 minutes for prolonged swim speeds. The following tables lists the default coefficients (a , b , and c) and range of applicable fish lengths for juvenile and adult fish. The fish length range does not specifically define the age class. Some length ranges given include both adult and juvenile fish.

Juvenile Swim Speed Coefficients

| Species | <u>Burst Coefficients</u> | | | <u>Prolong Coefficients</u> | | | Min length | Max length |
|-----------------|---------------------------|------|------|-----------------------------|-------|------|------------|------------|
| | a | b | c | a | b | c | (mm) | (mm) |
| Arctic Char | 4.30 | 0.00 | 0.49 | 2.690 | 0.606 | 0.08 | 70 | 420 |
| Arctic Grayling | - | - | - | 1.670 | 0.193 | 0.10 | 60 | 400 |

| | | | | | | | | |
|--------------------|-------|------|------|--------|-------|------|-----|-----|
| Atlantic Salmon | - | - | - | 36.310 | 1.720 | 0.00 | 30 | 52 |
| Broad Whitefish | - | - | - | 1.460 | 0.450 | 0.10 | 50 | 400 |
| Brook Trout | - | - | - | 1.990 | 0.430 | 0.10 | 40 | 270 |
| Burbot | - | - | - | 2.230 | 0.070 | 0.26 | 100 | 700 |
| Chum | - | - | - | 93.590 | 1.890 | 0.00 | 38 | 48 |
| Coho | - | - | - | 3.020 | 0.520 | 0.10 | 40 | 178 |
| Flathead Chub | - | - | - | 2.660 | 0.670 | 0.10 | 150 | 350 |
| Goldfish | 5.37 | 0.66 | 0.22 | - | - | - | 67 | 213 |
| Humpback Whitefish | - | - | - | 1.730 | 0.350 | 0.10 | 60 | 600 |
| Inconnu | - | - | - | 1.290 | 0.175 | 0.10 | 70 | 800 |
| Longnose Sucker | - | - | - | 2.390 | 0.529 | 0.10 | 30 | 700 |
| Northern Pike | - | - | - | 1.170 | 0.550 | 0.10 | 100 | 800 |
| Rainbow Trout | 15.98 | 0.81 | 0.50 | 3.280 | 0.370 | 0.10 | 30 | 200 |
| Sea Lamprey | - | - | - | 2.570 | 0.360 | 0.26 | 145 | 508 |
| Sockeye | - | - | - | 4.420 | 0.500 | 0.10 | 77 | 200 |
| Steelhead | 15.98 | 0.81 | 0.50 | 3.280 | 0.370 | 0.10 | 30 | 200 |
| Striped Bass | - | - | - | 22.110 | 0.580 | 0.30 | 29 | 115 |
| Walleye | - | - | - | 2.600 | 0.510 | 0.10 | 70 | 400 |
| White Sucker | - | - | - | 2.480 | 0.552 | 0.10 | 105 | 400 |

Adult Swim Speed Coefficients

| Species | Burst Coefficients | | | Prolong Coefficients | | | Min length | Max length |
|--------------------|---------------------------|----------|----------|-----------------------------|----------|----------|------------|------------|
| | a | b | c | a | b | c | (mm) | (mm) |
| Arctic Char | 4.30 | 0.00 | 0.49 | 2.690 | 0.606 | 0.08 | 70 | 420 |
| Arctic Grayling | - | - | - | 1.670 | 0.193 | 0.10 | 60 | 400 |
| Atlantic Salmon | 11.34 | 0.88 | 0.50 | 0.173 | 0.680 | 0.50 | 52 | 500 |
| Broad Whitefish | - | - | - | 1.460 | 0.450 | 0.10 | 50 | 400 |
| Brook Trout | - | - | - | 1.990 | 0.430 | 0.10 | 40 | 270 |
| Burbot | - | - | - | 2.230 | 0.070 | 0.26 | 100 | 700 |
| Chinook | 11.49 | 0.32 | 0.50 | - | - | - | 508 | 965 |
| Coho | 13.30 | 0.52 | 0.65 | - | - | - | 256 | 610 |
| Dace | 12.37 | 0.65 | 0.50 | - | - | - | 30 | 250 |
| Flathead Chub | - | - | - | 2.660 | 0.670 | 0.10 | 150 | 350 |
| Goldfish | 5.37 | 0.66 | 0.22 | - | - | - | 67 | 213 |
| Humpback Whitefish | - | - | - | 1.730 | 0.350 | 0.10 | 60 | 600 |
| Inconnu | - | - | - | 1.290 | 0.175 | 0.10 | 70 | 800 |
| Longnose Sucker | - | - | - | 2.390 | 0.529 | 0.10 | 30 | 700 |
| Northern Pike | - | - | - | 1.170 | 0.550 | 0.10 | 100 | 800 |
| Pink Salmon | - | - | - | 4.080 | 0.550 | 0.08 | 494 | 607 |
| Rainbow Trout | 12.80 | 1.07 | 0.48 | - | - | - | 103 | 813 |
| Sea Lamprey | - | - | - | 2.570 | 0.360 | 0.26 | 145 | 508 |
| Sockeye | - | - | - | 5.470 | 0.890 | 0.07 | 126 | 611 |
| Steelhead | 12.81 | 1.07 | 0.48 | - | - | - | 103 | 813 |

| | | | | | |
|--------------|-------|-------|------|-----|-----|
| Walleye | 2.600 | 0.510 | 0.10 | 70 | 400 |
| White Sucker | 2.480 | 0.552 | 0.10 | 105 | 400 |

WSP Results Table

The table contains the water depth and velocity through the culvert for the flow shown above. The other columns list the water surface curve type and the swimming mode being used by the fish.

Dist Down Culvert - The first column lists the distance *traveling downstream* from the inlet to the outlet.

Depth – The water depth at the corresponding location within the culvert.

Velocity – The average cross-sectional water velocity at the corresponding location in the culvert. This is not the reduced velocity. If you selected reduction factors less than 1, the average velocity listed here will be multiplied by the reduction factor to obtain the water velocity the fish must swim through.

Curve – The water surface slope-type.

Swim Mode – This column lists the mode of swimming used being by the fish.

Burst is when the fish is swimming at burst speed,

Prolonged is when the fish swims at prolonged speed,

Exhausted appears at the point in the culvert that the fish has swam past its time to exhaustion, in either burst or prolonged mode,

Barrier is displayed at the first point encountered by the fish that the water velocity is greater than the swimming abilities of the fish, and

N/A appears at points upstream of where the fish was able to swim. The fish either encountered velocities greater than its swimming abilities or became exhausted at a downstream location in the culvert.

WSP Summary Table

The side table reports hydraulic conditions and the swimming performance of the selected fish for that flow.

Normal Depth – reports the **normal depth of flow**.

Critical Depth – reports the **critical depth**.

Headwater Depth – The water depth at the upstream side of the culvert, assuming the flow is outlet controlled. The water depth is the difference between the headwater elevation and the inlet bottom elevation and is partially determined by the magnitude of the **inlet head-loss coefficient**.

Inlet Velocity – The approximated water velocity in the inlet zone. The **inlet velocity** is greater than the average cross-sectional velocity.

Tailwater Depth – The water depth at the culvert outlet, measured from the outlet bottom.

Tailwater Depths are negative for perched culverts

Burst Swim Time – Displays the number of seconds the fish swam at **burst speed**. When the fish has reached its time to exhaustion, the calculations are ended regardless if the fish reached the end of the culvert. The burst swim time will be 0 if you have selected prolong swim speed only or if you selected both swim speeds but burst was not required.

Prolonged Swim Time - Displays the number of seconds the fish swam at **prolonged speed**. *FishXing* uses prolonged swim speed when possible. When the fish has reached its time to exhaustion, the calculations are ended. The prolonged swim time will be 0 if you have selected burst swim speed only or if you selected both swim speeds but water velocities strictly required burst.

Barrier Code - The barrier code notifies you if the water velocity in the culvert is a barrier. Water velocity can be a barrier if:

- **V** – The fish has encountered a water velocity that is greater than its swimming abilities (strict velocity barrier).
- **EB** – The fish has swam at burst speed for longer than its time to exhaustion (fish exhausted at burst speed).
- **L** – The fish has swam at prolonged speed for longer than its time to exhaustion. This almost always occurs when culverts are too long (fish exhausted at prolong speed, culvert too long).
- **Depth** – The water depth is less than the minimum required depth for the selected fish for more than half the culvert length.
- **Leap** – Excessive leap. Culvert is perched too high. Check Uniform Flow Results for details.
- **None** – Velocities are acceptable for upstream passage of your selected fish.

Note: Always check to see if the depth throughout the culvert is sufficient. If the outlet is perched, also check to see if the leap is excessive.

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