QUARTERLY PROGRESS REPORT

October, 1 2010 to December, 31 2010

No additional funding was received for the project in this reporting period. The total funding received for the TPF-5(164) study so far is $240,000.
In this reporting period FHWA and MD SHA updated the proposed work including tests and data analysis for the study.

A primary objective of this aspect of the fish passage study is to determine the local velocities and flow distributions in corrugated metal pipes and pipe arches. This information is proposed for use to supplement the guidance in the publication FHWA- NHI 01-020 Hydraulic Design of Highway Culverts, Hydraulic Design Series No. 5. Conventional open-channel culvert hydraulics provides the tools and software needed to compute the average velocity of flow at any culvert cross-section for higher flows, given the culvert shape, roughness, slope and boundary conditions. In order to more accurately evaluate the ability of fish to traverse corrugated metal culverts, it is desirable to look at the changes in the local average velocity of the flow adjacent to the culvert wall under low flow conditions. Other studies (1) have documented the tendency of fish to seek out a swimming location with the lowest velocity of flow. The location of lowest velocity can generally be found immediately adjacent to the culvert wall

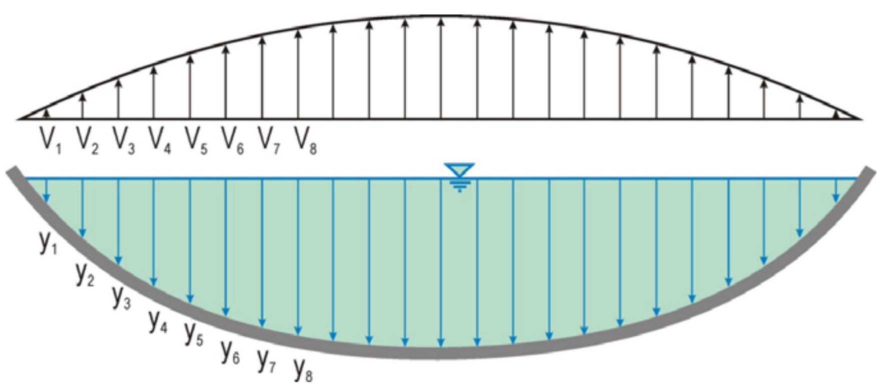

FIGURE 1
Variation of Flow Velocity and Depth in a Cross-Section of a Corrugated Metal Pipe

Figure 1 illustrates the information that will be measured in the flume and by the numerical modeling methods described below. At a given culvert cross-section, flow depth and flow discharge, the local depth-averaged velocities V_1, V_2, V_3, etc. will be measured at regular offsets from the culvert wall. Typically the local depth-averaged velocity will approach zero at the culvert wall and will be at a maximum near the center of the culvert. The tests runs will encompass a number of flow depths and velocities for each culvert. The minimum velocity in the flume to be tested is 0.71 feet/second (equals 1 feet/second in the prototype culvert) and then the velocities will be increased to 2.12 feet/second (equals 3 feet/second in the prototype culvert). The CFD modeling will test a velocity range from 1 to 4 feet/second. The relationship between the various local depth-averaged flow velocities, V_1, V_2, V_3, etc, and Vave will be determined.

In a similar manner, the local flow depths y_1, y_2, y_3 be measured at the same offsets from the wall that are used for the velocity readings. These depths can be related to the maximum flow depth y_{max} through the culvert geometry

TABLE 1A
GENERAL DESIGN REQUIREMENTS FOR FISH PASSAGE
STATE OF MARYLAND

GENERAL DESIGN REQUIREMENTS FOR FISH PASSAGE STATE OF MARYLAND		
	FLOW VELOCITY	MINIMUM FLOW DEPTH
NON-TROUT STREAMS	UP TO 1 FPS	4 TO 6 INCHES
TROUT STREAMS	UP TO 3 FPS	12 INCHES

TABLE 1 B
Fish-Passage Design Criteria for Culvert Installations
(Excerpted from FHWA Hydraulic Engineering Circular 26, First Edition, Culvert Design for Aquatic Organism Passage.)

	Adult Trout >6 in. (150 mm)	Adult Pink or Chum Salmon	Adult Chinook, Coho, Sockeye or Steelhead
(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.)			
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

Tables 1A and 1B depict current recommendations of design standards for fish passage. These values can be expected to vary from state to state depending on the fish species under consideration, local conditions and the agencies setting the standards. Other important considerations may include the sustained and prolonged speeds of the various species for which the fish passage is being designed.

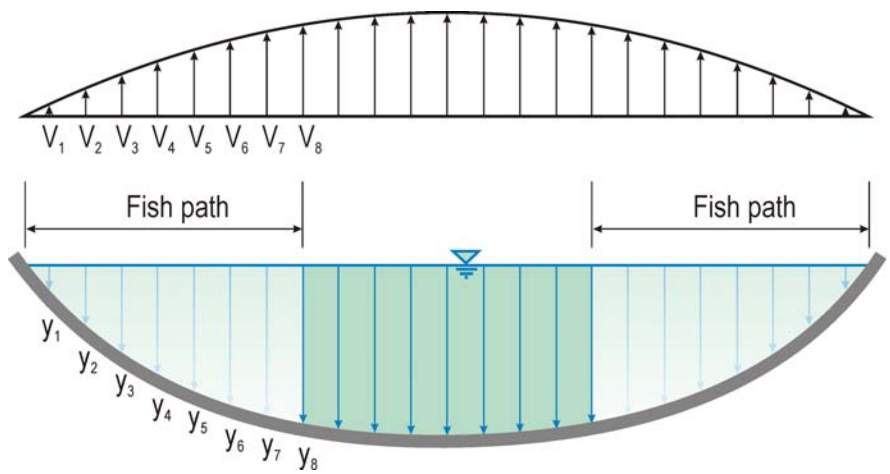

FIGURE 2
Computation of the Dimensions of the Flow Path for the Selected Fish Design Criteria of Velocity and Depth

The local depth-averaged velocity V and the local depth y of the flow at any point in the culvert cross-section can be determined by the procedure illustrated in Figure 1, The fish design criteria, can be provided by the appropriate environmental agency as noted in the discussion of Tables 1A and B.. . The next step is to define the path in the culvert available for fish passage for the given conditions.

In Figure 2, one end of the path is defined by the culvert wall. The other end of the path, towards the center of the culvert, is defined by the point where the local depth-averaged flow velocity V is equal to the maximum fish velocity, V_F , as defined by the appropriate standard. In this example $V_8 = V_F$ The area (A) and quantity (Q) of the flow within the limits of the fish path can be computed, and the average velocity of the flow within the fish path can be computed as illustrated below in Figures 5 through 7.

This study will develop design aids for determining the limits of the fish path and the average velocity of flow within the fish path for varying conditions. The information needed by the designer will be (1) the culvert geometry and Manning “n” value, bed condition and slope, (2) the range of low flows under consideration for fish passage, and (3) the standards to be met regarding limiting fish velocities and minimum flow depths.

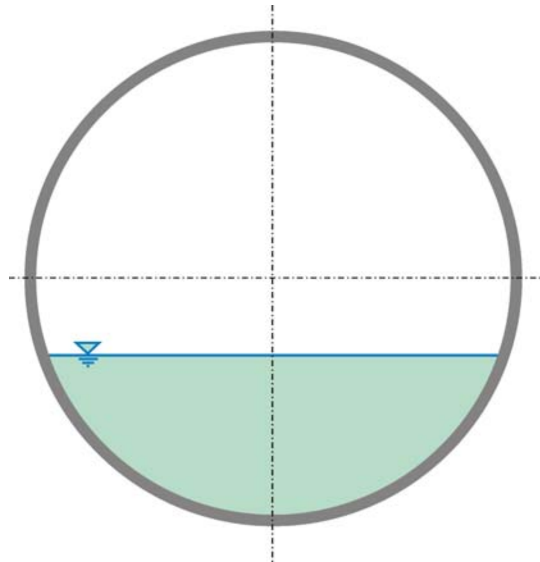

FIGURE 3
Culvert Water Surface at Low Flow

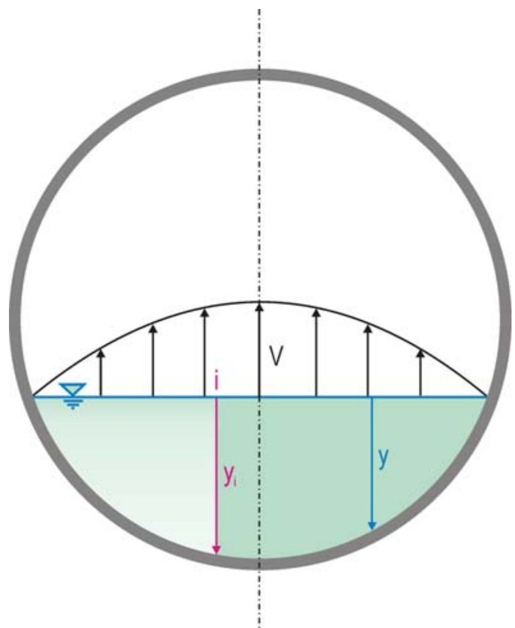

FIGURE 4
Determine Flow Depth and Velocity Distribution from Lab and CFD Tests

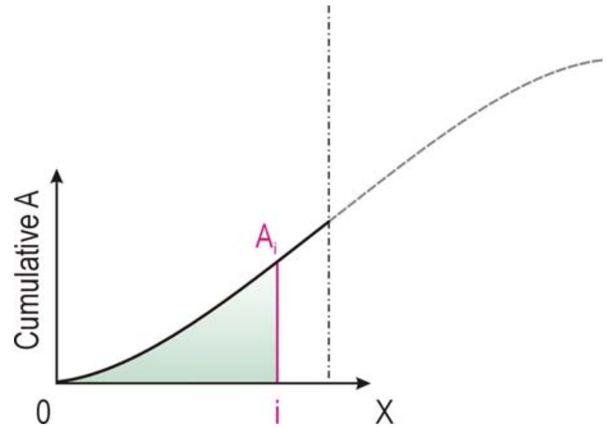

FIGURE 5
Determine the Cumulative Area from the Wall to the Centerline

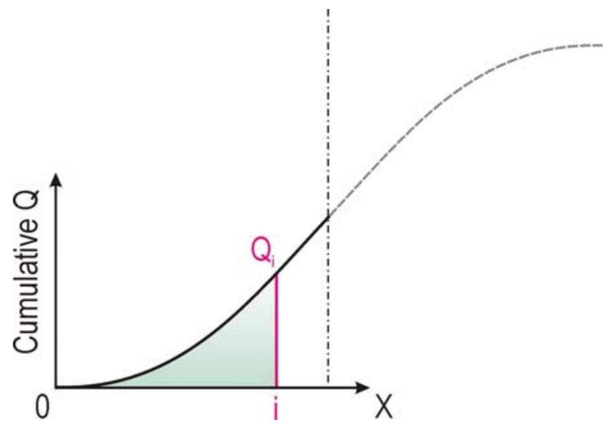

FIGURE 6
Determine the Cumulative Discharge from the Wall to the Centerline

Use equation 1 to determine the average velocity:

$$(V_{AVG})_i = \frac{Q_i}{A_i} \tag{1}$$

The recommended method for selecting design flows for evaluating fish passage is presented in the FHWA Hydraulic Engineering Circular 26, First Edition, Culvert Design for Aquatic Organism Passage. Two discharges are recommended:

- High passage flow Q_{H1}. representing the upper bound of discharge at which fish are believed to be moving within the stream. This value can be compared with the limiting discharge for fish passage computed for the culvert. If the proposed culvert has a limiting discharge significantly lower than the high passage flow Q_{H1} , then it may be feasible to redesign the culvert so as to improve its capability for fish passage.

- Low passage flow Q_L the lowest discharge for which fish passage is required. The recommended approach for computing the minimum discharge in the culvert for fish passage is as follows:
  - Use a minimum depth in the range of 6 inches to12 inches, depending on the standards being used for the stream (See examples Table 1A or 1B).
  - Calculate the flow depth in the culvert at the centerline required to provide a hydraulic radius equal to the minimum depth
  - Calculate the flow area for the computed hydraulic radius.
  - Calculated the Manning "n" value for the computed area and hydraulic radius
  - Determine the culvert slope, S
  - Calculate the low passage flow as:

$$Q_L = \frac{1.486 \times A \times R^{2/3} \times S^{1/2}}{n} \tag{2}$$

  Design aids will be provided to simplify the computations discussed above. An example of a table that can be used to compute the area and hydraulic radius for partial flow in a circular culvert is presented in Table 3 below

In order for the forgoing design approach to succeed, certain boundary conditions at the culvert outlet and inlet must be met. Satisfying these conditions should be a part of the HEC-RAS study as well as the stream morphology study. For the design discharges for evaluating fish passage:

- The channel width and depth at the culvert outlet should provide a flow path and a flow depth deep enough to facilitate the entry of fish into the culvert. The culvert invert should be at or below the elevation of the bed of the outlet channel.
- The channel width and depth upstream of the culvert should transition to the width of the culvert entrance in a manner that avoids any significant contraction, drawdown of the flow, or critical flow at the culvert entrance.

Table 2
Determining the Area and Hydraulic Radius for a Culvert Flowing Part Full
(Excerpted from King's Handbook)

Table 84. For Determining the Area a of the Cross Section of a Circular Conduit Flowing Part Full

Let $\frac{\text{depth of water}}{\text{diameter of channel}} = \frac{D}{d}$ and c = the tabulated value. Then $a = cd^2$.

$\frac{D}{d}$	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.0000	.0013	.0037	.0069	.0105	.0147	.0192	.0242	.0294	.0350
.1	.0409	.0470	.0534	.0600	.0668	.0739	.0811	.0885	.0961	.1039
.2	.1118	.1199	.1281	.1365	.1449	.1535	.1623	.1711	.1800	.1890
.3	.1982	.2074	.2167	.2260	.2355	.2450	.2546	.2642	.2739	.2836
.4	.2934	.3032	.3130	.3229	.3328	.3428	.3527	.3627	.3727	.3827
.5	.393	.403	.413	.423	.433	.443	.453	.462	.472	.482
.6	.492	.502	.512	.521	.531	.540	.550	.559	.569	.578
.7	.587	.596	.605	.614	.623	.632	.640	.649	.657	.666
.8	.674	.681	.689	.697	.704	.712	.719	.725	.732	.738
.9	.745	.750	.756	.761	.766	.771	.775	.779	.782	.784

Table 85. For Determining the Hydraulic Radius r of the Cross Section of a Circular Conduit Flowing Part Full

Let $\frac{\text{depth of water}}{\text{diameter of channel}} = \frac{D}{d}$ and c = the tabulated value. Then $r = cd$.

$\frac{D}{d}$	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.000	.007	.013	.020	.026	.033	.039	.045	.051	.057
.1	.063	.070	.075	.081	.087	.093	.099	.104	.110	.115
.2	.121	.126	.131	.136	.142	.147	.152	.157	.161	.166
.3	.171	.176	.180	.185	.189	.193	.198	.202	.206	.210
.4	.214	.218	.222	.226	.229	.233	.236	.240	.243	.247
.5	.250	.253	.256	.259	.262	.265	.268	.270	.273	.275
.6	.278	.280	.282	.284	.286	.288	.290	.292	.293	.295
.7	.296	.298	.299	.300	.301	.302	.302	.303	.304	.304
.8	.304	.304	.304	.304	.304	.303	.303	.302	.301	.299
.9	.298	.296	.294	.292	.289	.286	.283	.279	.274	.267

The following approach will be used in testing the corrugated metal culverts

Phase 1

- Run flume tests of selected annular round corrugated pipes up to about 30 inches in diameter. Determine the local velocities and flow distributions within the culvert cross-section. Conduct multiple runs for each culvert, varying velocities and depths.
- Use the computer fluid dynamics program (CFD) to run mathematical simulations on the round pipe culverts with annular corrugations selected for the study. Determine the local velocities and flow distribution within each culvert cross-section. Conduct multiple runs for each culvert, varying velocity and flow depth.
- Use of Froude Number Similitude Criteria
  The experimental data from the flume runs will be used to test the CFD's accuracy and sensitivity to parameters such as shape, size and corrugation dimensions. Since the flow is open channel flow with relatively large values of roughness, it will be in a fully turbulent condition. Froude Number Similitude criteria will be used to correlate flume tests and field conditions. That is, the field hydraulic condition is considered to be similar to that of the model tests if both flows have same Froude numbers. For example, if a 24" diameter culvert is used for modeling a 96" Structural Plate Pipe culvert, the linear scale ratio of prototype to model will be 4. The velocity scale ratio then becomes the square root of 4 or 2. Using this approach, the velocity of 3 ft/s measured in the laboratory flume corresponds to a flow velocity of 6 ft/s for the 96" structural plate pipe culvert.
- Develop a table, set of curves or mathematical expressions to facilitate the computation of the fish pathways
- Test Matrix (See Table 3 to Table 9 in section Test schedule for flume and CFD tests)

  1. Flume Culvert Model (Model Scale 1:2), only the symmetrical half of the culvert will be tested.
     Flume Culvert Model Diameter: D = 36"
     Flume Culvert Model Corrugations 1 inches corrugation heights, with spacing of 3 inches This is equivalent to a 6x2 corrugation.
  2. CFD Model "Scale Validation" Culvert Diameter: D = 6ft
     CFD Culvert Corrugations 2 inches corrugation heights, with spacing of 6 inches
  3. CFD Prototype Culvert Diameter: D =8ft
     CFD Culvert Corrugations 2 inches corrugation heights, with spacing of 6 inches
  4. Bed Elevation: (How deep the culvert is buried below the channel bed?) Bottom of culvert (culvert bottom is flush with bed elevation Bed elevation at 0 x D, 0.15 x D and 0.3 x D (culvert is not 0 x D, and culvert is buried at 0.15 x D and 0.30 x D) (See Figures 7, 8 and 9)
  5. Flow condition to be tested:
     Flow depth: Increment of 1/18 culvert diameter starting from bed elevation. (3 combinations)

Flow velocity: Will be determined based on high and low flows (discharges) consistent with high and low velocities acceptable for fish passage.

6. Aquatic Organism Passage (AOP): CFD tests will be conducted to test the effect of an AOP pathway on velocity distributions (See Figures 10, 11 and 12):
   The AOP pathway width is 2ft.
   CFD Culvert Diameter: D = 8ft
   CFD Culvert Corrugations 2 inches corrugation heights, with spacing of 6 inches
   .

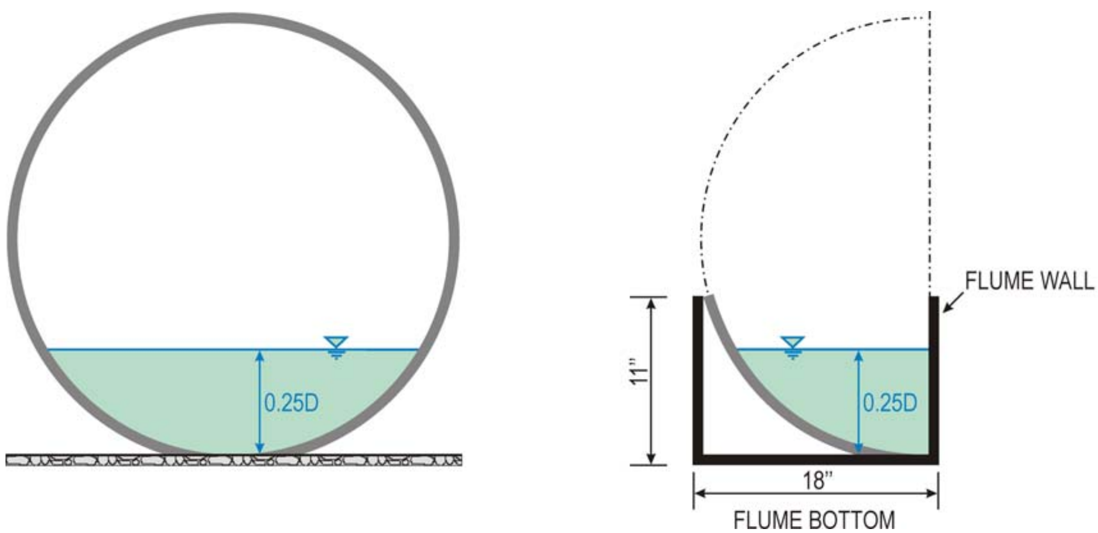

FIGURE 7
Bed Elevation at 0 culvert diameter and symmetrical half of Flume Culvert Model

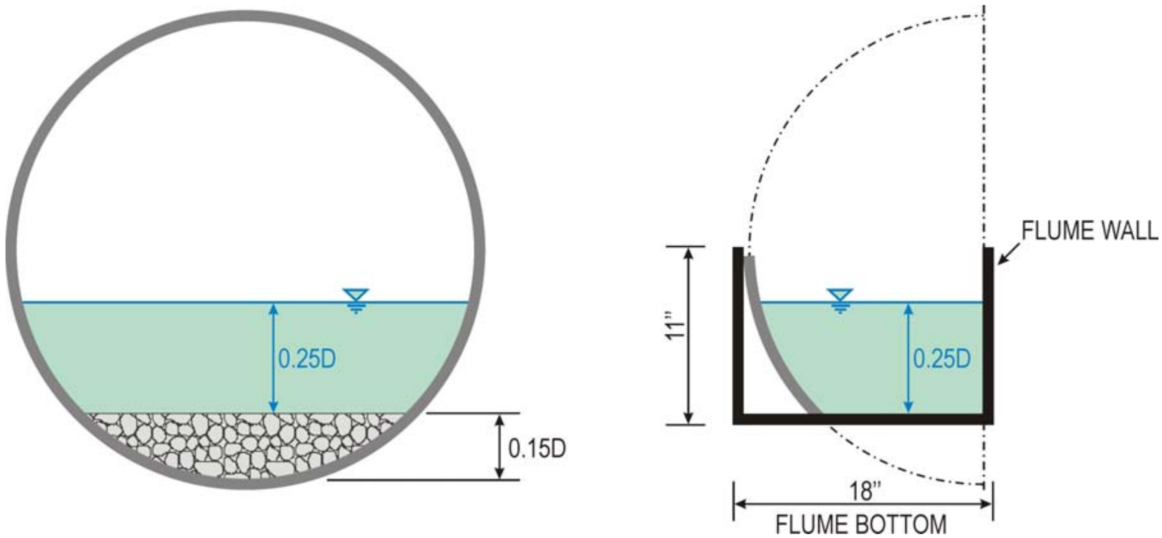

FIGURE 8
Bed Elevation at 0.15 culvert diameter and symmetrical half of Flume Culvert Model

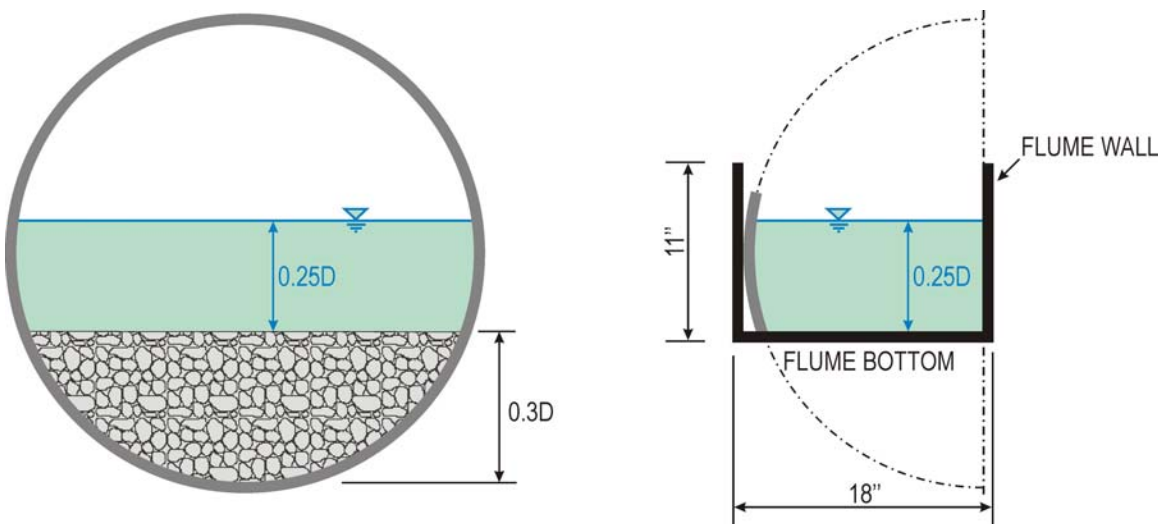

FIGURE 9
Bed Elevation at 0.30 culvert diameter and symmetrical half of Flume Culvert Model

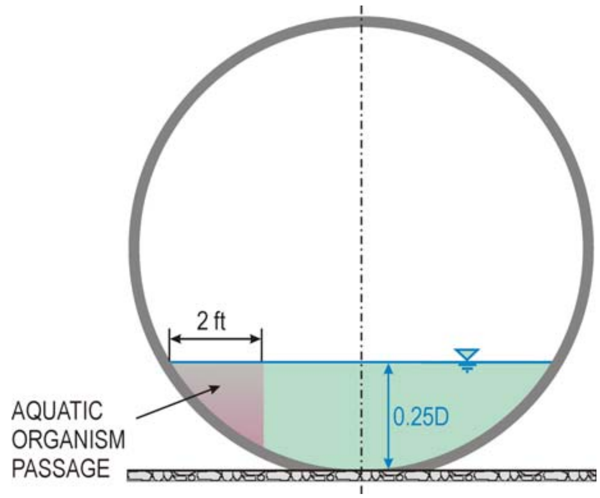

FIGURE 10
Bed Elevation at 0 culvert diameter and 2 ft AOP for CFD Tests only

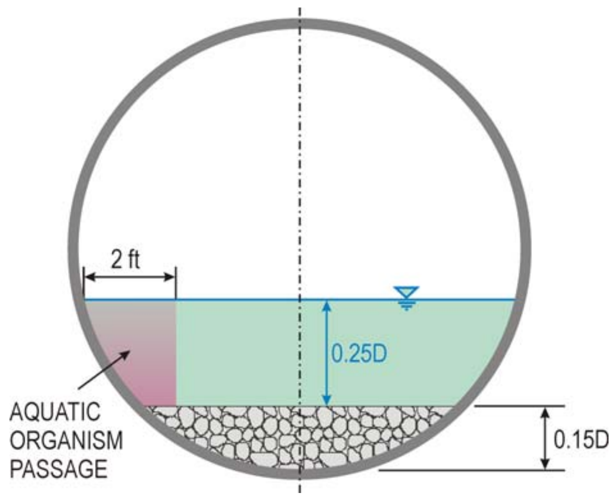

FIGURE 11
Bed Elevation at 0.15 culvert diameter and 2 ft AOP for CFD Tests

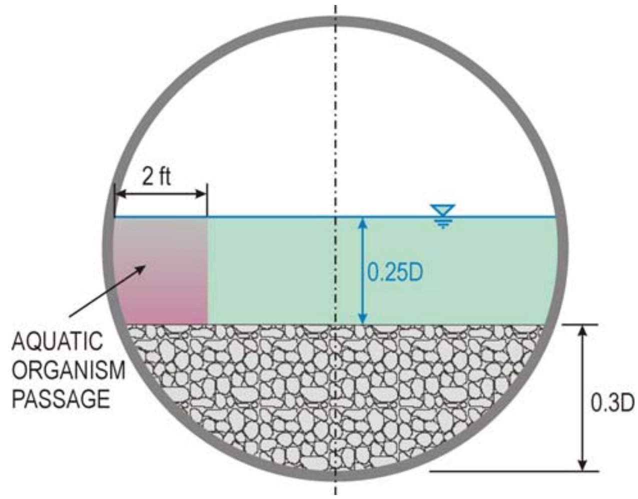

FIGURE 12
Bed Elevation at 0.30 culvert diameter and 2 ft AOP for CFD Tests

Phase 2

- Apply the computer fluid dynamics (CFD) program and process established for Phase 1 to other types of corrugated pipes and pipe arches. Evaluate corrugated pipes with helical corrugations.

Phase 3

- Run limited flume tests and CFD tests on culverts with various bed thicknesses of sediment in the culvert invert; determine the effect of the sediment on (1) the average flow velocity in the pipe cross-section and (2) the average flow velocities for selected fish swimming paths.

Description of the FHWA Flume

The fish passage tilting flume is 30ft long and 4ft wide. The culvert section is 16.2 ft long and 18in wide. The flume can be tilted up to 3 degrees. 15 ultra sonic sensors measure the water surface profile. A 4cfs pump is used for pumping water into the culvert flume. The flume has a 2-dimensional robot to measure velocity flow fields in cross flow. 3 dimensional particle image Velocimetry is used to map boundary layer flows. (Figure 14)

FIGURE 13:
Fish Passage Culvert Flume

Description of the Computer Fluid Dynamics (CFD) Model

The simulation model used for this study is the commercial CFD software, STAR-CCM+, and the two-phase VOF model with water and air. Simulation results are compared with the experimental data obtained from TFHRC. The culvert in this study is half of the cross section of a culvert barrel having spiral corrugations as shown in Figure 5. This configuration is used in experimental evaluation of the culvert at TFHRC. The experimental setup of the flume is also shown in Figure 6.
Based on the dimensional details provided by TFHRC, a CAD model, as depicted in Figure 15 and 16, has been created in Pro-ENGINEER and imported to STAR-CCM+ in IGES (Initial Graphics Exchange Specification) file format. This CAD model consists of three parts: the intake (also called the inlet), the barrel (or the throat or the corrugated portion), and the diffuser (also called outlet). The barrel consists of spiral corrugations throughout its length.

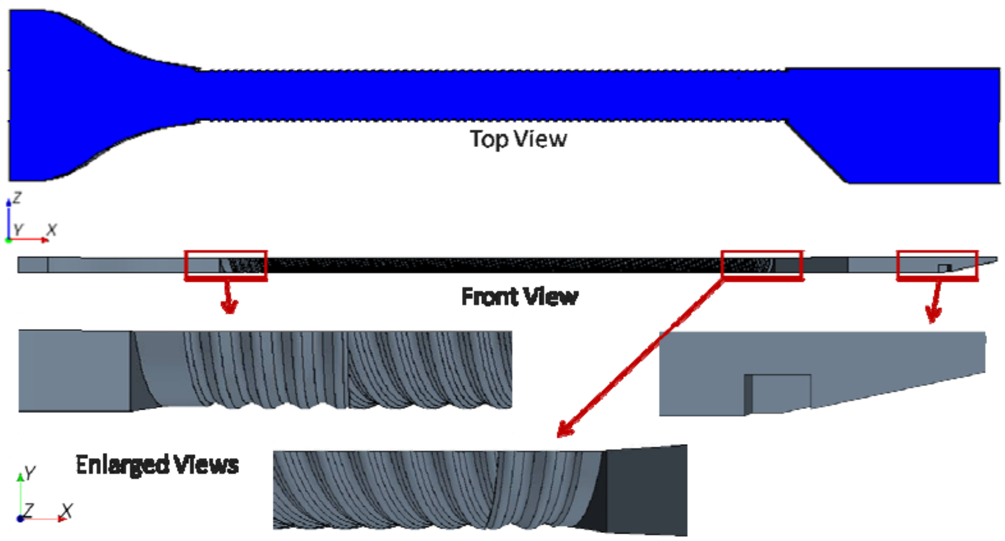

FIGURE 14
CAD model of culvert flume

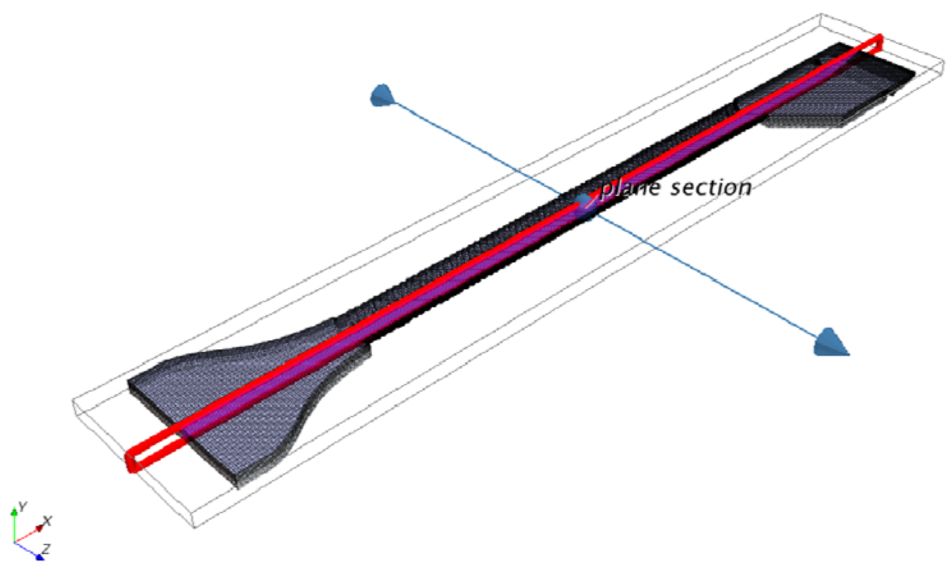

FIGURE 15
Isometric view of the mesh scene with a plane section passing through the center line.

TEST SCHEDULE for Flume Tests

Table 3
(Model Length Scale 1:2 and Model Velocity Scale 1:$(2)^{0.5}$
Adjust Slope of Flume to reach Uniform Flow and determine Manning's Roughness Values for all Tests

Model Culvert Diameter (Only symmetrical half will be tested) (inches)	Model Culvert Corrugations (inches)	Model Flow Depth (inches)	Model Bed Elevation (see Figures 8, 9 and 10) (inches)	Model Velocities (feet/second)
36	3 x 1	0.08 x D = 3	0	0.71
		0.16 x D = 6		
		0.25 x D = 9		
		0.08 x D = 3	0	2.12
		0.16 x D = 6		
		0.25 x D = 9		
		0.08 x D = 3	0.15 x D = 5.4	0.71
		0.16 x D = 6	Bed material coarse gravel D_{50} = 12 mm/(equals Manning's n = 0.023)	
		0.25 x D = 9		
		0.08 x D = 3	0.15 x D = 5.4	2.12
		0.16 x D = 6	Bed material coarse gravel D_{50} = 12 mm/(equals Manning's n = 0.023)	
		0.25 x D = 9		
		0.08 x D = 3	0.30 x D = 10.8	0.71
		0.16 x D = 6	Bed material coarse gravel D_{50} = 12 mm/(equals Manning's n = 0.023)	
		0.25 x D = 9		
		0.08 x D = 3	0.30 x D = 10.8	2.12
		0.16 x D = 6	Bed material coarse gravel D_{50} = 12 mm/(equals Manning's n = 0.023)	
		0.25 x D = 9		

TEST SCHEDULE for CFD Experiments

Table 4
Validation tests to compare velocity distributions of symmetrical half culvert with full size culvert. Use the roughness and slope determined in the flume tests.

Culvert Diameter (symmetrical half) (inches)	Culvert Corrugations (inches)	Flow Depth (inches)	Bed Elevation (see Figures 8) (inches)	Velocities (feet/second)
36	3 x 1	0.08 x D = 3	0	0.71
		0.16 x D = 6		
		0.25 x D = 9		
		0.08 x D = 3		2.12
		0.16 x D = 6		
		0.25 x D = 9		
Culvert Diameter (full size) (inches)	Culvert Corrugations (inches)	Flow Depth (inches)	Bed Elevation (see Figures 8) (inches)	Velocities (feet/second)
36	3 x 1	0.08 x D = 3	0	0.71
		0.16 x D = 6		
		0.25 x D = 9		
		0.08 x D = 3		2.12
		0.16 x D = 6		
		0.25 x D = 9		

Table 5
CFD tests to compare flume velocity distributions experiments with CFD modeling
Use the roughness and slope determined in the flume tests.

Culvert Diameter (symmetrical half) (inches)	Culvert Corrugations (inches)	Flow Depth (inches)	Bed Elevation (see Figures 8) (inches)	Velocities (feet/second)
36	3 x 1	0.08 x D = 3	0.15 x D = 5.4 Manning's n = 0.023 (equals D_{50} = 12 mm)	0.71
		0.16 x D = 6		
		0.25 x D = 9		
		0.08 x D = 3	0.15 x D = 5.4 Manning's n = 0.023 023 (equals D_{50} = 12 mm)	2.12
		0.16 x D = 6		
		0.25 x D = 9		
36	3 x 1	0.08 x D = 3	0.30 x D = 10.8 Manning's n = 0.023 023 (equals D_{50} = 12 mm)	0.71
		0.16 x D = 6		
		0.25 x D = 9		
		0.08 x D = 3	0.30 x D = 10.8 Manning's n = 0.023 023 (equals D_{50} = 12 mm)	2.12
		0.16 x D = 6		
		0.25 x D = 9		

Table 6
CFD experiments for "Model Scale Validation" (Culvert Diameter 6ft)
Consider scaled roughness and slope.

Culvert Diameter (feet)	Culvert Corrugations (inches)	Flow Depth (feet)	Bed Elevation (see Figures 8, 9 and 10) (feet)	Model Velocities (feet/seconds)
6	6 x 2	0.08 x D = 0.50	0	1
		0.16 x D = 1.00		
		0.25 x D = 1.50		
		0.08 x D = 0.50	0	3
		0.16 x D = 1.00		
		0.25 x D = 1.50		

Culvert Diameter (feet)	Culvert Corrugations (inches)	Flow Depth (feet)	Bed Elevation (see Figures 8, 9 and 10) (feet)	Model Velocities (feet/second)
6	6 x 2	0.08 x D = 0.50	0.15 x D = 0.96 Manning's n = 0.026 023 (equals D_{50} = 24 mm)	1
		0.16 x D = 1.00		
		0.25 x D = 1.50		
		0.08 x D = 0.50	0.15 x D = 0.96 Manning's n = 0.026 (equals D_{50} = 24 mm)	3
		0.16 x D = 1.00		
		0.25 x D = 1.50		

Culvert Diameter (feet)	Culvert Corrugations (inches)	Flow Depth (feet)	Bed Elevation (see Figures 8, 9 and 10) (feet)	Model Velocities (feet/second)
6	6 x 2	0.08 x D = 0.50	0.30 x D = 1.8 Manning's n = 0.026 (equals D_{50} = 24mm)	1
		0.16 x D = 1.00		
		0.25 x D = 1.50		
		0.08 x D = 0.50	0.30 x D = 1.8 Manning's n = 0.026 (equals D_{50} = 24 mm)	3
		0.16 x D = 1.00		
		0.25 x D = 1.50		

Table 7
CFD experiments for prototype culvert (Diameter 8ft)
Use uniform flow in the culvert.

Culvert Diameter (feet)	Culvert Corrugations (inches)	Flow Depth (feet)	Bed Elevation (see Figures 8, 9 and 10) (feet)	Model Velocities (feet/second)
8	6 x 2	0.08 x D = 0.64	0	1
		0.16 x D = 1.28		
		0.25 x D = 2.00		
		0.08 x D = 0.64	0	2
		0.16 x D = 1.28		
		0.25 x D = 2.00		
		0.08 x D = 0.64	0	3
		0.16 x D = 1.28		
		0.25 x D = 2.00		
		0.08 x D = 0.64	0	4
		0.16 x D = 1.28		
		0.25 x D = 2.00		

Culvert Diameter (feet)	Culvert Corrugations (inches)	Flow Depth (feet)	Bed Elevation (see Figures 8, 9 and 10) (feet) Run tests for 3 different roughness values	Model Velocities (feet/second)
8	6 x 2	0.08 x D = 0.64	0.15 x D = 1.2 Manning's n = 0.013, 0,018 and 0.026 (equals D_{50} = 0.32, 3.1 and 24 mm)	1
		0.16 x D = 1.28		
		0.25 x D = 2.00		
		0.08 x D = 0.64	0.15 x D = 1.2 Manning's n = 0.013, 0,018 and 0.026 (equals D_{50} = 0.32, 3.1 and 24 mm)	2
		0.16 x D = 1.28		
		0.25 x D = 2.00		
		0.08 x D = 0.64	0.15 x D = 1.2 Manning's n = 0.013, 0,018 and 0.026 (equals D_{50} = 0.32, 3.1 and 24 mm)	3
		0.16 x D = 1.28		
		0.25 x D = 2.00		
		0.08 x D = 0.64	0.15 x D = 1.2 Manning's n = 0.013, 0,018 and 0.026 (equals D_{50} = 0.32, 3.1 and 24 mm)	4
		0.16 x D = 1.28		
		0.25 x D = 2.00		

Table 7 (continued)
CFD experiments for prototype culvert (Diameter 8ft)

Culvert Diameter (feet)	Culvert Corrugations (inches)	Flow Depth (feet)	Bed Elevation (see Figures 8, 9 and 10) (feet). Run tests for 3 different roughness values	Model Velocities (feet/second)
8	6 x 2	0.08 x D = 0.64	0.30 x D = 2.4	1
		0.16 x D = 1.28	Manning's n = 0.013, 0,018 and 0.026 (equals D_{50} = 0.32, 3.1 and 24 mm)	
		0.25 x D = 2.00		
		0.08 x D = 0.64	0.30 x D = 2.4	2
		0.16 x D = 1.28	Manning's n = 0.013, 0,018 and 0.026 (equals D_{50} = 0.32, 3.1 and 24 mm)	
		0.25 x D = 2.00		
		0.08 x D = 0.64	0.30 x D = 2.4	3
		0.16 x D = 1.28	Manning's n = 0.013, 0,018 and 0.026 (equals D_{50} = 0.32, 3.1 and 24 mm)	
		0.25 x D = 2.00		
		0.08 x D = 0.64	0.30 x D = 2.4	4
		0.16 x D = 1.28	Manning's n = 0.013, 0,018 and 0.026 (equals D_{50} = 0.32, 3.1 and 24 mm)	
		0.25 x D = 2.00		

Table 8
CFD experiments for prototype culvert (Diameter 8ft) including Aquatic Organism Passage for metal passage

Culvert Diameter (feet)	Culvert Corrugations (inches)	Flow Depth (feet)	Bed Elevation (see Figures 11, 12 and 13) (feet). Run tests for 3 different roughness values	Model Velocities (feet/second)
8	6 x 2	0.08 x D = 0.64	0	1
		0.16 x D = 1.28		
		0.25 x D = 2.00		
		0.08 x D = 0.64	0.15 x D = 1.2	1
		0.16 x D = 1.28	Manning's n = 0.013, 0,018 and 0.026 (equals D_{50} = 0.32, 3.1 and 24 mm)	
		0.25 x D = 2.00		
		0.08 x D = 0.64	0.30 x D = 2.4	1
		0.16 x D = 1.28	Manning's n = 0.013, 0,018 and 0.026 (equals D_{50} = 0.32, 3.1 and 24 mm)	
		0.25 x D = 2.00		

Table 9
CFD experiments for prototype culvert (Diameter 8ft) including Aquatic Organism Passage for concrete passage

Culvert Diameter (feet)	Culvert Corrugations (inches)	Flow Depth (feet)	Bed Elevation (see Figures 11, 12 and 13) (feet). Run tests for 3 different roughness values	Model Velocities (feet/seconds)
8	6 x 2	0.08 x D = 0.64	0	1
		0.16 x D = 1.28		
		0.25 x D = 2.00		
		0.08 x D = 0.64	0.15 x D = 1.2	1
		0.16 x D = 1.28	Manning's n = 0.013, 0,018 and 0.026 (equals D_{50} = 0.32, 3.1 and 24 mm)	
		0.25 x D = 2.00		
		0.08 x D = 0.64	0.30 x D = 2.4	1
		0.16 x D = 1.28	Manning's n = 0.013, 0,018 and 0.026 (equals D_{50} = 0.32, 3.1 and 24 mm)	
		0.25 x D = 2.00		

TIME SCHEDULE:

Task	Month										
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Construct Model Pipe											
Flume Tests according to Test Matrix											
CFD Experiments according to Test Matrix											
Data Analysis and Recommendations for Implementation											
Preliminary Draft Report											
Final Report											

The Transportation Research Analysis and Computing Center (TRACC) at the Argonne National Laboratory continued performing computer modeling for the study. The current status of the high performance Computational Fluid Dynamics (CFD) modeling for the fish passage study is presented in the TRACC-CFD quarterly progress report.
In the period from 10-01-10 to 12-31-10 no TPF funds were spent.