

Design of Stream-Road Crossings for Aquatic Organism Passage in Vermont

Design tools

- Sediment sample form – English
- Sediment sample form – metric
- Stability / Mobility spreadsheet
- Corps of Engineers riprap design for key features
- Bed design worksheet – Weiss Cr example
- Baffled culvert hydraulics worksheet – Broad Brook example (incomplete)
- Stream simulation design data checklist (5 pages)
- Vermont hydraulic and low-slope design data checklist (4 pages)

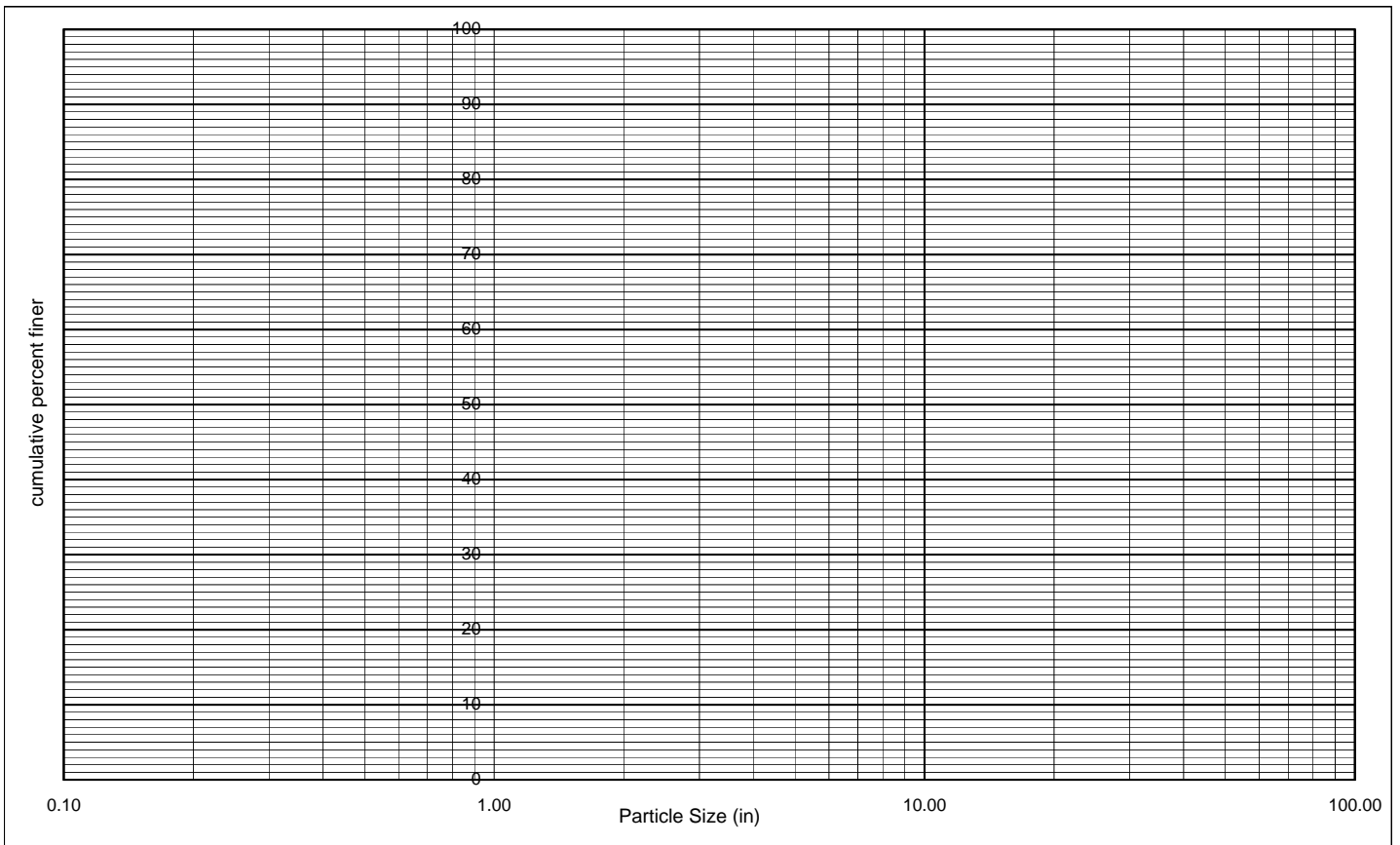
Stream / Location:

particle size interval name	size interval (inches)	finer than (inches)	tally	count	percent frequency	cumulative percent finer
Bedrock						100
medium boulders	20.2 - 28.5	20				
	14.3 - 20.2	14				
small boulders	10.1 - 14.3	10				
	7.1 - 10.1	7.1				
large cobbles	5.0 - 7.1	5.1				
	3.6 - 5.0	3.6				
small cobbles	2.5 - 3.6	2.5				
	1.8 - 2.5	1.8				
very coarse gravel	1.3 - 1.8	1.3				
	0.9 - 1.3	0.89				
coarse gravel	0.6 - 0.9	0.63				
	0.4 - 0.6	0.44				
medium gravel	0.3 - 0.4	0.32				
	0.2 - 0.3	0.22				
fine gravel	< 0.2	0.16				
very fine gravel						
sand, silt, or clay						
	Total count				100.00	

Project Name: Weiss Cr culvert replacement at Weiss Cr Rd	
Sample ID	
Sample Date	
Sampler Name	
Sample Locaton	
Sample Method	

Particle sizes from plotted data (inches)	
D95	
D84	
D50	
D16	
D5	

Sample site descriptions by observation	
Channel type	
D100 (inches)	
Colluvium	
Debris	
Other	



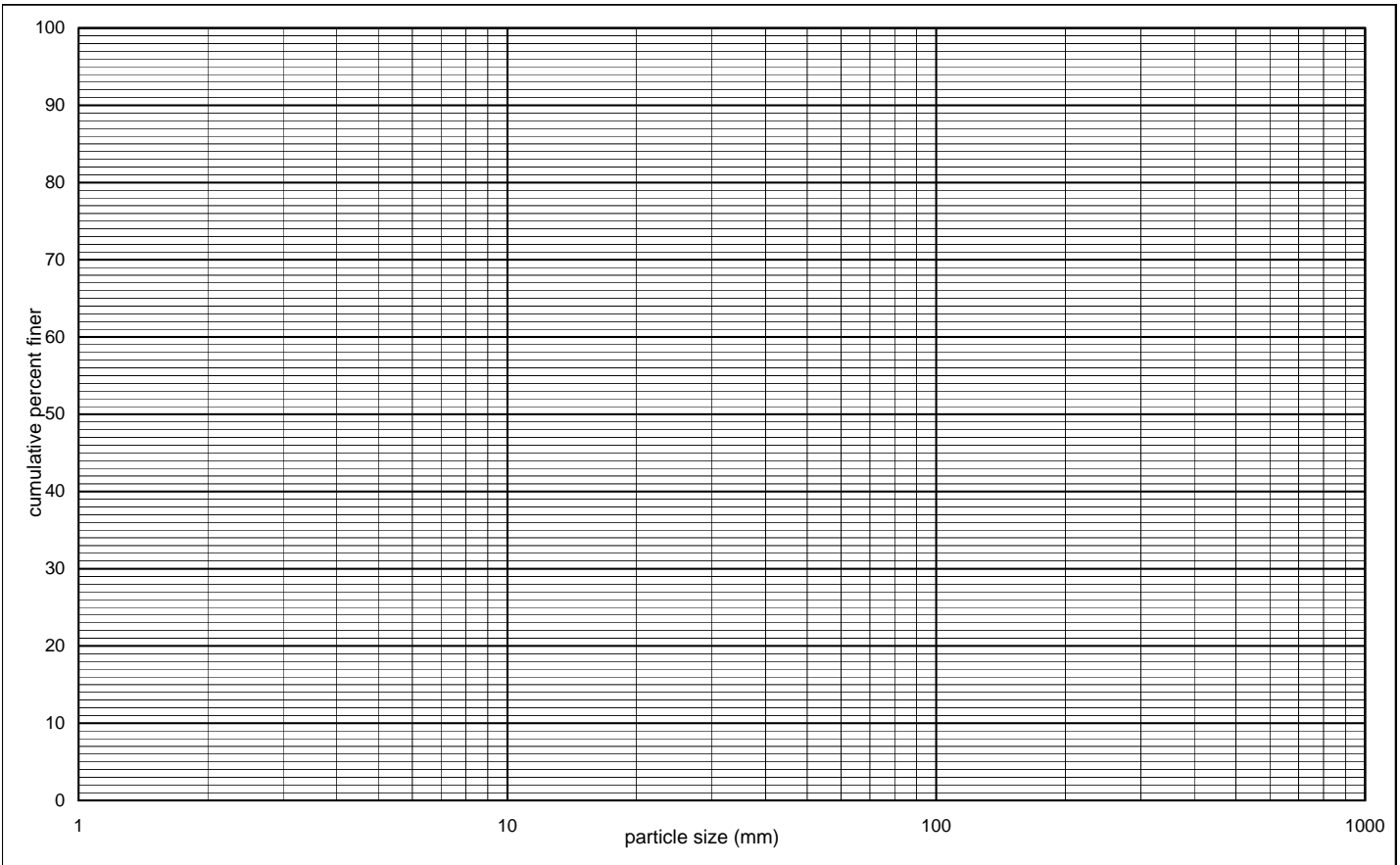
Stream / Location:

particle size interval name	size interval (mm)	tally	count	percent frequency	cumulative percent finer
Bedrock					
medium boulders	512 to 724				
	362 to 512				
small boulders	256 to 362				
	181 to 256				
large cobbles	128 to 181				
	90.5 to 128				
small cobbles	64.0 to 90.5				
	45.2 to 64.0				
very coarse gravel	32.0 to 45.2				
	22.6 to 32.0				
coarse gravel	16.0 to 22.6				
	11.3 to 16.0				
medium gravel	8.0 to 11.3				
	5.7 to 8.0				
fine gravel	4.0 to 5.7				
	2.8 to 4.0				
very fine gravel	2.0 to 2.8				
sand, silt, or clay	< 2				
	Total count			100.00	

Project Name:	
Sample ID	
Sample Date	
Sampler Name	
Sample Locaton	
Sample Method	

Particle sizes from plotted data (mm)	
D95	
D84	
D50	
D16	
D5	

Sample site descriptions by observation	
Channel type	
D100 (mm)	
Colluvium	
Debris	
Other	



Stream Simulation bed by Bathurst critical unit discharge

Reference channel

Stream sim channel

$$Q_{c84} = \left[\frac{0.15 g^{0.5} D_{50}^{1.5} \left(\frac{D_{84}}{D_{50}} \right)^b}{S^{1.12}} \right] w + Q_{FP}$$

equals

$$Q_{c84} = \left[\frac{0.15 g^{0.5} D_{50}^{1.5} \left(\frac{D_{84}}{D_{50}} \right)^b}{S^{1.12}} \right] w + Q_{FP}$$

$$b = 1.5 \left[\frac{D_{16}}{D_{84}} \right]$$

$$b = 1.5 \left[\frac{D_{16}}{D_{84}} \right]$$

Given

D95		in
D84		in
D50		in
D16		in
S		%
w		ft active channel width
Qfp		cfs active floodplain flow
g	32.2	ft/s/s

	Initial est	Multiplier	Resulting	
D95		1.00	0.0	in
D84			0.0	in
D50			0.0	in
D16			0.0	in
S				%
w				ft active channel width
Qfp	0			cfs active floodplain flow
g	32.2			ft/s/s

Compare Q _____ cms

_____ cfs

D = particle median diameter
 S = energy slope
 w = active channel width
 Qfp = floodplain flow

- Assumes D84 mobility equal in both channels
- Change variables to make total flow equal in both channels

CAUTION: Review Corps and Maynard references for limitations of source data

CAUTION: This analysis includes a simplification for demonstration purposes. Correct it before applying this spreadsheet.

Corps riprap design

Corps of Engineers EM 1110-2-1601, 1994

$$D_{30} = S_f C_s C_v C_T d \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{0.5} \frac{V}{\sqrt{K_1 g d}} \right]^{2.5}$$

V		fps
d		ft
g	32.2	ft/s/s
Sf	1.2	
Cv	1.2	improve with bend equation
CT	1.2	
Cs	0.375	
Gammaw	62.4	lb/ft cu
Gammas	160	lb/ft cu
alpha	100	horizontal to 1.0 vertical
phi	45	degrees
K1	0.98	
D30	#DIV/0!	inches
D90/D30	1.4	1.4 for Corps std riprap mix
D90	#DIV/0!	inches

Corps recommends limiting slope to max of 2.0%
Solution is iterative if rock affects velocity and depth

D = median particle diameter
V = vertical averaged velocity
d = depth of water
g = acceleration of gravity

Sf = Safety Factor
Cv = Vertical velocity distribution coefficient
= 1.0 straight channel (R/W > 26),
inside of bend
= 1.283 - 0.2 log(R/W)
CT = Thickness coefficient

Cs = Stability coefficient
= 0.30 for angular rock
= 0.375 for rounded rock
 γ_s = unit wt of rock
 γ_w = unit wt of water
 θ = Bank slope
 ψ = Rock angle of repose

Weiss Stream Channel Design Mix Specification

Reference reach bed size distribution

Material size in inches

	Ref 1	Ref 2	Ref 3	Weighted	Ratios
weight of reference	1	0	0		
D100	19.2	0	0	19.2	
D95	10.0	0	0	10.0	
D84	6.0	0	0	6.0	3.2
D50	2.8	0	0	2.8	2.1
D16	1.2	0	0	1.2	2.3
D5	0.2	0	0	0.2	6.0

Design mix (inches)

FT		ratios		Weighted mix
0.45	0.7	FT=0.45	FT=0.70	
19.2	19.2			19.2 inches
10.0	10.0			10.0
6.0	6.0	3.2	3.2	6.0
2.8	2.8	2.1	2.1	2.8
0.22	0.55	12.6	5.1	0.4
0.02	0.10	13.3	5.3	0.1

Calculated final mix

% finer than	%	max inches	max mm	Manually adjust for final mix size	percent passing
100	5	19.2	488	20 inches	100
95	10	10.0	254	10 inches	95
84	35	6.0	152	6" square	84
50	35	2.8	71	3" square	50
16	10	0.39	10	US No 4	16
5	5	0.06	2	US No 20	5

FT

0.45

0.7

$$D16=0.32^{(1/n)} \times D50$$

$$D5=0.1^{(1/n)} \times D50$$

weight

0.5

0.5

Use with round rock. Tends toward excess fines

Use with fractured rock. Tends toward excess voids

For Reference

Standard Sieve Sizes

Particle Description	inches	mm	Equivalent Sieve
Bedrock	80	>2048	
Large – Very Large Boulders	40 – 80	1024 - 2048	
Medium Boulders	20 – 40	512 – 1024	
Small Boulders	10 – 20	256 - 512	
Large Cobbles	5 – 10	128 - 256	
Small Cobbles	2.5 – 5	64 - 128	5"
Very Coarse Gravels	1.26 – 2.5	32 – 64	2.5"
Coarse Gravels	.63 – 1.26	16 – 32	1.5"
Medium Gravels	.31 - .63	8 – 16	4
Fine Gravels	.16 - .31	4-8	6
Very Fine Gravels	.08 - .16	2-4	8
Very Coarse Sands	.04 - .08	1.0 - 2.0	14
Coarse Sands	.02 - .04	.50 - 1.0	20
Medium Sands	.01 - .02	.25 - .50	40
Fine Sands	.005 - .01	.125 - .25	100
Very Fine Sands	.002 - .005	.062 - .125	200
Silts/Clays	<.002	<.062	

WSDOT Borrow specs

Gravel borrow

Sieve size	percent passing
4" square	100
2" square	75-100
US No 4	50-80
US No 40	30 max
US No 200	7 max
sand equivalent	50 min

Select borrow

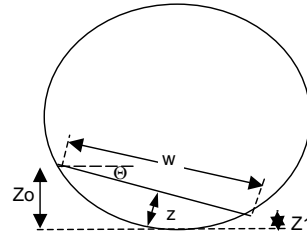
Sieve size	percent passing
6" square	100
3" square	75-100
US No 40	50 max
US No 200	10 max
sand equivalent	30 min

Calculate hydraulics of circular baffled culvert using Rajaratnam

1 Initial geometry

Culvert diameter D 22 ft
 Slope S 0.0086 ft/ft
 Flow Q 80 cfs fish passage design flow

Baffle height z 3 ft
 Baffle slope 0.5 ft across culvert
 Baffle spacing L 12 ft
 Min depth d1 floor 0.3 ft not used in calcs
 Min depth d2 weir 0.3 ft not used in calcs



2 Choose coefficients from Rajaratnam interpolated table

z/D 0.14
 L/D 0.55
 y/D 0.22
 C 2.2 from table
 a 2.33 from table

	Baffles Design Table - Circular and Box Culverts					Limits
	Zo/D	L/D	C	a	n (est)	
	0.20	0.6	2.2	2.33	0.13	
		1.2	4.2	2.88	0.11	
		1.8	5.7	3.19	0.09	
		2.4	7.4	3.5	0.07	
WB-1	0.15	0.6	5.4	2.43	0.11	0.25 $y_0/D < 0.8$
WB-2		1.2	6.6	2.62	0.09	0.35 $y_0/D < 0.8$
		1.8	7.5	2.81	0.07	
		2.4	8.5	3	0.05	
WB-3	0.10	0.6	8.6	2.53	0.08	0.35 $y_0/D < 0.8$
WB-4		1.2	9	2.36	0.07	0.20 $y_0/D < 0.8$
		1.8	9.3	2.43	0.06	
		2.4	9.6	2.5	0.05	
	0.05	0.6	10.7	2.63	0.07	
		1.2	11.1	2.1	0.06	
		1.8	11.4	2.05	0.05	
		2.4	11.8	2	0.04	

3 Calculate velocity

Depth 4.9 ft from Rajaratnam eq
 Theta 1.97 radians geometry
 A 63.4 sq ft geometry
 Velocity 1.3 fps

4 Vary culvert and baffle dimensions as needed to achieve target velocity in radians

5 Check EDF for streaming flow

min dh 0.10 ft Drop between baffles. Should be close to 0.2. Change slope or spacing.
 min z 2.5 ft approximate; average of d1 and Y
 EDF - streaming 0.7 ft-lb/sec/cuft

6 Check EDF at plunging to streaming transition

P-S coefficient 0.25
 P-S transition 7.7 cfs
 Chord at weir crest 15.1 ft
 Depth 3.3 ft approximate; horizontal weir formula without submergence and weir average elevation. Depth will be great
 Theta 1.59 radians geometry
 Area 35.8 sq ft geometry
 Velocity 0.4 fps
 EDF - plunging 0.03 ft-lb/sec/cuft $16Qh/A/L$

7 Check minimum depth

Stream Simulation Design Data Checklist

This is a guide and summary for design and review of a stream simulation road / stream crossing. Data is summarized to show design milestones, assumptions, and conclusions. This isn't necessarily all of the data required for a design. This isn't necessarily all of the data required for a complete design.

A plan view sketch and a long profile should be attached to this design data form. See the design guide for background for all data and details recommended on sketches.

Describe any additional details necessary for the design on additional sheets.

Project

Project name and ID		
Stream		
Road, location		
Lat / Long (d/m/s)		
ID Team members		
Date		

Brief description of project _____

Project type; chose one: New - Retrofit - Replacement

Does final design satisfy stream simulation design criteria? Explain deviations and limitations.

Y / N _____

Site characteristics (LS)

Is there an existing Culvert(s)? Y / N

Existing culvert perched? Y / N Height of perch _____

Downstream channel incised? Y / N Depth of incision _____

Evidence of incision _____

Upstream backwater deposition Y / N

Evidence and extent _____

2 - BASIS OF DESIGN

Proposed Project Profile and Alignment

Proposed new channel within crossing. Slope _____ Length _____

Upstream channel within project Slope _____ Length _____

Downstream channel within project Slope _____ Length _____

Show proposed project profile on long profile plot.

Channel elevations at ends of proposed culvert:

	Downstream end	Upstream end
At low potential profile		
At high potential profile		
At proposed constructed profile		

Reference Reach

Description of reference reach

Location of reference reach (e.g.; "150' upstream from crossing)

Show location of reference reach on plan view sketch and profile.

Length of reference reach _____

Reference reach channel types (e.g.; 75% pool-riffle, 25% plane bed)

Key bed features, function, and spacing (debris, steps, bends, etc)

Bed mobility and how it was determined

Key bank features and frequency

3 - BASIS OF DESIGN

Reference reach cross sections

Cross section labels and locations			
Bankfull width			
Bankfull depth			
Floodprone width			
Depth to high water mark			

Reference reach slope

Average _____

Range _____

Reference reach bed material

	Particle size (inches or mm)	How was particle size determined?
D95		
D84		
D50		
D16		
D5		
Fines		

	Size (inches or mm)	Function	Spacing	dh	Permanence, mobility, condition
Debris and live wood					
Colluvium					
Bedrock					
Steps, clusters					

Function: Profile control, Roughness, Confinement, Bank stability

4 - DESIGN

Mobility / stability analysis

Design flows

Design Flows	Return period (years)	Flow (cfs)	How was flow estimated, certainty
Floodplain contraction			
Stability of key features			
Flood capacity			
Headwater depth			

Stream simulation bed material

	Particle size (inches or mm)	How was particle size determined? (what model, observations)
D95		
D84		
D50		
D16		
D5		

Additional features if included in the design

	Particle size (inches or mm)	Frequency, spacing	How identified, designed
Bands			
Banklines			
Key features			

5 - DESIGN

High flow hydraulics

Event	Flow (cfs)	Tailwater elevation	Roughness (n)	Water surface elevation upstream	HW depth (HW/culvert rise)
Q2					
Q100					

Describe methods and sources of data high flow hydraulic calculations. _____

Road and Alignment

Height of fill on upstream face: _____ ft.

Proposed culvert skew (parallel is 0 degrees)

Culvert to channel _____ degrees Road to culvert _____ degrees

Proposed alignment, transition changes _____

Describe permanent benchmark and elevation _____

Other special considerations, recommendations _____

Vermont Fish Passage Design Data Checklist

Hydraulic and Low-Slope Designs

This is a summary for design and review of a road / stream crossing using the Hydraulic or Low-Slope design methods for fish passage at culverts. Data is summarized to show design milestones, assumptions, and conclusions. This isn't necessarily all of the data required for a complete design. All parts of the data sheet are normally needed for a Hydraulic Design. Those marked with "(LS)" are normally needed for a Low-Slope Design.

A plan view sketch and a long profile should be attached to this design data form. See the design guide for background for all data and details recommended on sketches.

Describe any additional details necessary for the design on additional sheets.

Project (LS)

Project name and ID		
Stream		
Road, location		
Lat / Long (d/m/s)		
ID Team members		
Date		

Brief description of project _____

Project type (new, retrofit, replacement) _____

Design method: (hydraulic or low-slope) _____

Does this design satisfy design method criteria? If not, explain deviations and limitations.

Y / N _____

Site characteristics (LS)

Is there an existing Culvert(s)? Y / N

Existing culvert perched? Y / N Height of perch _____

Downstream channel incised? Y / N Depth of incision _____

Evidence of incision _____

Upstream backwater deposition Y / N

Evidence and extent _____

2 - BASIS OF DESIGN

Target Species

Species	Age class (Juv, Adult)	Fish length (in)	Movement seasons (months)	Hydraulic criteria		
				Max velocity (fps)	Swim mode	Min depth (ft)

Describe data sources _____

Hydrology

Watershed characteristics (LS)

Area _____ sq miles Mean elevation _____ ft above sea level

Mean annual precipitation _____ inches

Other hydrologic or flow characteristics (hydrologic province, area of lakes, northing, etc.) (LS)

Peak design flows (LS)	Derived flow (cfs)	Standard error (%)	Design flow (cfs)
2 - yr event			
25 - yr event			
100 - yr event			

Fish passage design flows

Species	Age class	High design flow (cfs)	Q7L2 (cfs)

Describe how hydrology was calculated and any assumptions (e.g. future conditions) made. (LS)

3 - DESIGN

Channel (LS)

	Downstream	Upstream
Average slope	%	%
Average bankfull width	ft	ft
Bed Elevation - low potential profile		
Bed Elevation - high potential profile		
Description of channel		
Channel roughness (n)		
Bed Elevation - project profile		
Elevation of downstream control		

How is profile controlled? _____

Culvert Description (LS)

Dimensions, Elevations

	Existing Culvert	Proposed Culvert
Span	ft	
Rise	ft	ft
Upstream Invert Elevation		
Downstream Invert Elevation		
Culvert Length	ft	ft
Slope	%	%

Note: for bottomless structures, report elevations of tops of footings.

Description of proposed culvert; Chose one or more in each line

Shape: Round - Arch - Box

Material: Corrugated metal - Smooth metal - Concrete

Corrugation dimensions: _____

Style Full pipe - Bottomless

4 - DESIGN

Fish Passage Hydraulics

Flow (cfs)	Tailwater elev	Roughness (n)	Velocity (fps)	Depth (ft)	EDF (ft-lb/sec/cuft)	Passability (%)

Describe roughness (corrugation dimensions, bed material or roughened channel description, baffle geometry, etc)

Describe methods and sources of data for fish passage hydraulic calculations.

High flow hydraulics (LS)

Event	Flow (cfs)	Tailwater elevation	Roughness (n)	Water surface elevation upstream	Headwater (HW/culvert rise)

Describe methods and sources of data high flow hydraulic calculations.

Road and Alignment (LS)

Height of fill on upstream face: _____ ft.

Proposed culvert skew (parallel is 0 degrees)

Culvert to channel _____ degrees

Road to culvert _____ degrees

Proposed alignment, transition changes

Describe permanent benchmark and elevation
