

Bonneville Adult Collection & Monitoring Facility (AFF)
Hydraulic Design Calculations

CENWP-EC-HD

Comp by

SJS	12/21/12
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Checked by

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Hydraulic Data Collection Oct 31, 2012

Elevations (NGVD): Ref: BDF-2 -18/9 and BDF-2--18/24

Lower Exit Channel Invert (grating) =	39 ft, NGVD
Upper Exit Channel Invert (concr.) =	42 ft, NGVD
Floor supporting Valve 15, 14	32 ft, NGVD
Work Platform Floor =	45 ft, NGVD
Grating Platform (about 1.5" higher) =	45.1 ft, NGVD

Valve Pipe OD (field checked)

Valve 14	36 in =	3.0 feet
Valve 15	30 in =	2.5 feet
CL Valve Elevations		
Valve 14		33.5 ft, NGVD
Valve 15 (Z-15)		33.25 ft, NGVD

Main Exit Channel at Trashrack

Flow depth =	4.9 ft	WS Elev =	43.9 ft
Width =	8 ft		

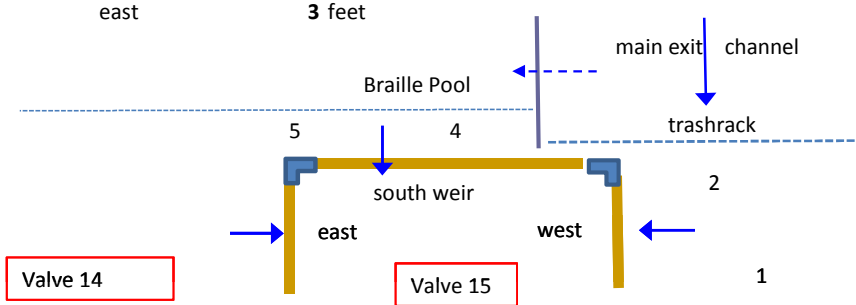
Current Valve Settings:		
Valve No.	14	15
% Open	0	75%

Weir Data

Distance from Top of Grating =	24.5 inches =	2.04 feet	Weir Elev =	43.04 ft
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Weir Lengths (open length between guides)

west	3 feet
south	6.5 feet
east	3 feet



Velocities Measured using Price Metter (single count setting)

Depth below WS (ft)	Lateral Location (looking U/s) in feet (Bi)					Integrated Average	Straight Average
	1	2.5	4	5.5	7		
0.5	2.85	3.31	3.44	2.60	2.06	2.81	2.85
1.5	3.15	3.12	2.20	1.81	1.89	2.44	2.44
2.5	2.00	2.04	1.01	1.32	1.41	1.57	1.56
3.5	1.37	0.76	0.68	0.60	0.96	0.91	0.87
4.3	0.64	0.51	0.62	0.49	0.90	0.65	0.63

	Integrated	Straight
Average Velocity (feet/sec) =	1.69	1.67
Computed Flow Rate (cfs) =	66.1	65.4

Integrated row average $V_j = \sum (B_{i+1} - B_i) * (V_i + V_{i+1})/2$ for $i = 0$ to n

$$V_0 = V_{1+} (V_2 - V_1) / (B_2 - B_1) * (B_1 - B_0) * \text{Edge coef}$$

$$V_n = V_{n-1+} (V_{n-2} - V_{n-1}) / (B_{n-2} - B_{n-1}) * (B_n - B_{n-1}) * \text{Edge coef}$$

Edge coeff = 0.5

B_n = total width

Total Integrated average $V = \sum (Y_{j+1} - Y_j) * (V_j + V_{j+1})/2$ for $j = 0$ to n

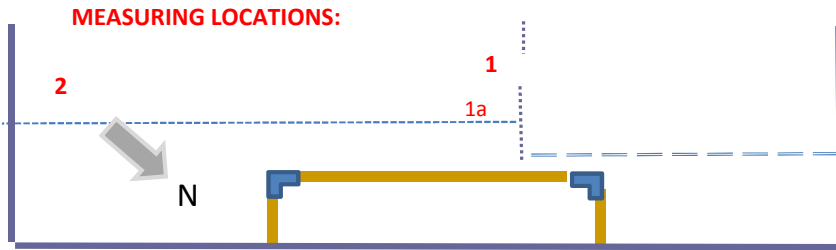
$$V_0 = V_1 \quad \text{Surface same as 0.5 ft down}$$

$$V_n = V_{n-1+} (V_{n-2} - V_{n-1}) / (Y_{n-2} - Y_{n-1}) * (Y_n - Y_{n-1}) * \text{Edge coef}$$

Y_n =m total depth

Braille Pools Data

Depth of Pool at North end = 4 feet



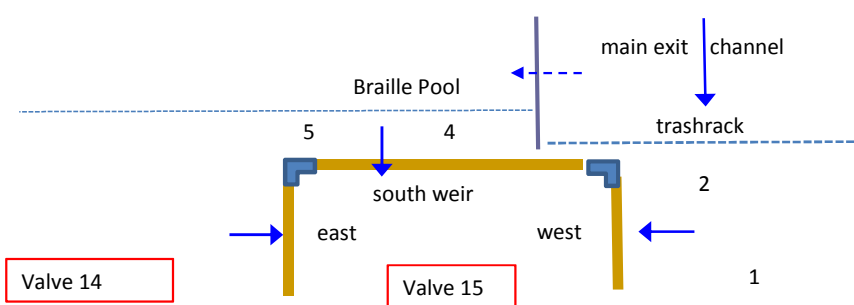
CURRENT Operation		Valve 15	75%
		Valve 14	0%
Depth Below Water (ft)	VELOCITIES (ft/s)		
	MEASURING LOCATION		
	1	1a	2
0.5	0.29	0.46	0.10
1.5	0.27	0.56	0.10
2.5	0.10		0.20
3.2	0.21		0.20
Average V	0.22	0.51	0.15
Average direction	↓	←	↙

Modified Operation		Valve 15	70%
		Valve 14	30%
Depth Below Water (ft)	VELOCITIES (ft/s)		
	MEASURING LOCATION		
	1	1a	2
0.5	0.29		0.00
1.5	0.23		0.19
2.5	0.19		0.22
3.2	0.17		0.29
Average V	0.22		0.18
Average direction	↓	←	↘

Centerline Velocities in Main Channel under Modified Operations

Depth Below Water (ft)	Current OP		Valve 15 70%		Valve 15 60%	
	Valve 15	Valve 14	Valve 15	Valve 14	Valve 15	Valve 14
	75%	0%	40%	50%	60%	50%
0.5	3.44		4.12		3.99	
1.5	2.20		2.63		2.60	
2.5	1.01		1.33		1.34	
3.5	0.68		0.67		1.01	
4.3	0.62		0.70		0.51	
Average Velocity (ft/s)	1.59		1.89		1.89	
Percent Above Normal	0.00		19%		19%	

Water Level Data upstream of Stop Log weirs



Location	Distance from top of grating (ft)	(H) Depth above weir (ft)	surface cond.	(q) Unit discharge rate (cfs/ft)	Surface Velocity (ft/s)	Ws Elevations
1	1.04	1.00	no flow	3.31	3.31	44.0
2	1.08	0.96	fast	3.11	3.24	44.0
4	1.25	0.79	moderate	2.33	2.95	43.8
5	1.33	0.71	slow	1.97	2.79	43.8
Average head =		0.83	Total Q =	30.8	cfs	

Table 5-3 of King & Brater, "Handbook of Hydraulics"

Broad crested weir coefficient = 3.31
 Edge contraction = 0.1 x H

		Weirs				
		West	South	East	Total	
ave H =	feet	0.98	0.82	0.71		
L =	feet	3	6.5	3	12.5	
L' =	feet	2.90	6.42	2.93	12.25	ave DH = (Qwr/L'/Cw)^0.67
Q weir =	cfs	9.3	15.8	5.8	30.8	ave DH = 0.83 feet

Weir Coeff. Factoring in Leakage = CWI = Qmeas/ Qcomp * 3.31 = 7.09 very high
 Weir coefficient using max head = 5.39

Estimated Bypass Flume Diameter

Pipe = 14 Inch Sch 40 steel pipe
 OD = 14.0 inches
 Th = 0.437 inches
 ID = 13.13 inches = 1.09 feet

Measured distances from walkway over exit channel to:

Bottom of channel raise 13.53 feet
 distance to top of flume pipe at exit = 7.93 feet
 depth in channel upstream of sill = 4.9 feet
 depth in d/s elevated channel = 1.9 feet
 distance to water surface elev = 11.63 feet
 distance to flume invert = 9.0 feet
 Height of flume invert above water = 2.6 feet

Elevation Difference in Pool Crest (DZ) = 1 foot
 Orifice sqr Dim = 18 inch
 Orifice Area (Ao) = 2.25 ft^2
 Orifice coeff (Cdo) = 0.67
 Weir Crest Length (Lw) = 5 ft
 Qo = Ao * Cdo * sqrt(2g * (DZ))

Ladder Flow

Normal Case

Shad flow

Ladder head (DH) =	1.0 feet	Ladder hd (DHs) =	1.3 feet
Weir coeff (CW) =	5.07	Weir coeff (CWs) =	5.25
Qw = L * CW * (DH)^1.5		Qw(shad) = L * CWs * (DsH)^1.5 * {1 - (DHs-1)/DHs}^1.5	0.385
Qo = Orifice flow =	12.1 cfs	Qo (shad) =	12.1 cfs
Qw = Weir Flow =	25.4 cfs	Qw (shad) =	37.2 cfs
Qt = Total Exit Ladder flow =	37.4 cfs	QT (shad) =	49.3 cfs
		Vp	
measured =	66.1 cfs		14.16
ladder =	37.4 cfs		
difference =	28.6 cfs		

Valve 15

Butterfly Valve CD (ref: Figure 4.3, "Hydraulics of Pipelines", Tullis (1989))

Valve Loss Coeff = (Kv) $Kv = 1/CD^2 - 1$

Operation case	Valve Opening	CD	Kv
Original Operation	55%	0.34	7.7
Current Operation	75%	0.50	3.0
Full open	100%	0.80	0.6
Intake loss coeff (Ki) =			0.15
OD-15 = Valve 15 Pipe diameter =		30 in =	2.5 ft
Wall thickness =		3/8 in =	typical pipe wall thickness assumed
ID - 15 = inside pipe Dia (vale 15) =		29.25 in =	2.44 ft
A15 = Valve 15 Pipe area =		4.67 ft ²	

Butterfly Discharge Coefficients

Valve Opening	CD
0%	0.00
10%	0.02
20%	0.07
30%	0.14
40%	0.22
50%	0.30
60%	0.38
70%	0.46
80%	0.54
90%	0.64
100%	0.80

HL = Estimated Headloss through Valve = $(Q/A)^2 / 2g (Kv + Ki)$

HGL = HL + Z-15	Valve OP	Q	Vp	VH	HL	HGL
Z-15 = 33.25	75% open	65	13.9	3.01	9.5	42.7
	55% open	41	8.8	1.20	9.4	42.6
	100% open	100	21.4	7.13	5.1	38.3

Measured 10/31/12
43.0 ft

Measured D/s of weir

below bottom of grating

10/24/12	19 inches >>	HGL =	43.4	Air bulking is factor
10/31/12	24 inches >>	HGL =	43.0	

Assume Valve HL is same $Q1 = Av CD1 * \sqrt{2gDH}$
 $Q2 = Av CD2 * \sqrt{2gDH}$

$Q1/Q2 = CD1/CD2 =$	0.68	
$Q2 =$	66.1 cfs	Vp (ft/s) 14.2
$Q1 = Q2 * CD1/CD2 =$	44.9 cfs	9.6
% Q reduction =	32%	

Size Porosity Plates for Design Flow

Design Flow = 38.0 cfs, or Design Ladder Flow

	Open Length of Porosity Plates			Remaining open length of Stop Log weirs	
	South	west	sum	Prev sum	Remainder sum
Perf. height	1.5	3	4.5 ft	12.5	7.5

CW with leakage estimated = 7.09
 Assume with reduce leakage CWr = 4
 Ave DH = 0.83 ft
Raise weirs 4 inches
 Revised DH = 0.50 ft
 Sum eff length $L' = L - 0.1 * DH * 2 =$ 7.40 feet

$Qwr = \text{New Weir Flow Rate} = CWr * L' * Ave DH^{1.5}$
 $Qwr =$ 10.5 cfs

$Qs = \text{Total Target Exit Discharge} =$ **38.0** cfs

$Qpp = \text{Net discharge through Porosity Plates} = Qs - Qwr$
 $Qpp =$ **27.5** cfs

Valve (Tullis) data reversed

CD	Valve Opening
0.00	0%
0.02	10%
0.07	20%
0.14	30%
0.22	40%
0.30	50%
0.38	60%
0.46	70%
0.54	80%
0.64	90%
0.80	100%

Average Channel Velocity
1.0 ft/s

Flow depth = 4.9 ft
 Assume differential = 2.5 ft Valve can be adjusted to attain this differential
 level d/s of weirs = 2.4 ft HGL = 41.4 ft
 Valve Head loss = 8.15 feet
 Required KV = 7.76 >> CD = 0.34 >>> Valve Opening = 55% open

Hole diameter (Do) = 3 inches Hole area(Ao) = 7.07 in^2 = 0.049 ft^2
 Discharge coeff (CDo) = 0.63
 Head diff = minimum(Flow depth - WS d/s of weir, flow depth - hole elev)

Assume square grid spacing Set Spacing at 6 inches Porosity = 20%
 Number of rows = 9
 Number of holes per row N Discharge = 27.4
 Height (ft) 4 9 check diff from target % diff = 0%
 Height (ft) 5 6

Row Discharge = $Q_r = CD * \Sigma A_o * \sqrt{2g * DH}$

$\Sigma A_o = N * A_o$

	Elev above floor (ft)	Area of Holes (ft^2)	Head diff (ft)	Discharge Rate (cfs)	Sum Q (cfs)
1 Row 1	0.25	0.442	2.50	3.53	3.53
2 Row 2	0.75	0.442	2.50	3.53	7.06
3 Row 3	1.25	0.442	2.50	3.53	10.59
4 Row 4	1.75	0.442	2.50	3.53	14.13
5 Row 5	2.25	0.442	2.50	3.53	17.66
6 Row 6	2.75	0.442	2.15	3.28	20.93
7 Row 7	3.25	0.442	1.65	2.87	23.80
8 Row 8	3.75	0.442	1.15	2.40	26.20
9 Row 9	4.25	0.295	0.65	1.20	27.40
10 Row 10					
11 Row 11					
12 Row 12					

Check Shad Condition (Weir Head = 1.3 feet)

Increased head = 0.3
 Flow depth = 5.2 ft
 Assume differential = 2.2 ft
 level d/s of weirs = 3 ft

Weirs
 Ave DH with normal Flow = 0.50 ft
 Revised DH with increase head 0.80
 Sum eff length $L' = L - 0.1 * DH * 2 = 7.34$ feet

$Q_{wr} = \text{New Weir Flow Rate} = C_{Wr} * L' * \text{Ave DH}^{1.5}$
 $Q_{wr} = 21.2$ cfs

$Q_s = \text{Total Target Exit Discharge} = 49.3$ cfs
 Average Channel Velocity 1.3 ft/s

$Q_{pp} = Q_s - Q_{wr} = 28.1$ cfs

Valve can be adjusted to attain this differential
 HGL = 42 ft
 Valve Head loss = 8.75 feet
 Required KV = 4.90 >> CD = 0.41 >>> Valve Opening = 64% open

Same square grid spacing (Shad Condition continued) 6 inches Porosity = 20%
 Number of rows = 10
 Number of holes per row N Discharge = 28.14 % diff = 0%
 Height 4 9
 Height 5 6

	Elev above floor (ft)	Area of Holes (ft ²)	Head diff (ft)	Discharge Rate (cfs)	Sum Q (cfs)
1 Row 1	0.25	0.442	2.20	3.31	3.31
2 Row 2	0.75	0.442	2.20	3.31	6.63
3 Row 3	1.25	0.442	2.20	3.31	9.94
4 Row 4	1.75	0.442	2.20	3.31	13.25
5 Row 5	2.25	0.442	2.20	3.31	16.56
6 Row 6	2.75	0.442	2.20	3.31	19.88
7 Row 7	3.25	0.442	1.95	3.12	23.00
8 Row 8	3.75	0.442	1.45	2.69	25.69
9 Row 9	4.25	0.295	0.95	1.45	27.14
10 Row 10	4.75	0.295	0.45	1.00	28.14
11 Row 11					
12 Row 12					

Check: No Flow Change Scenario

Increased head = 0.1 ft
 Flow depth = 5 ft
 Assume PP differential = 4.7 ft
 level d/s of weirs = 0.3 ft
 Weirs
 Remove 4" raise
 Ave DH with normal Flow = 0.83 ft
 Revised DH with increase head 0.93
 Sum eff length L' = L - 0.1 * DH * 2 = 7.31 feet

Qwr = New Weir Flow Rate = CWr * L' * Ave DH^{1.5}
 Qwr = 26.7 cfs

Qs = Total Target Exit Discharge = 68.0 cfs
 Average Channel Velocity 1.7 ft/s
 Qpp = Qs - Qwr 41.3 cfs

Valve can be adjusted to attain this differential
 HGL = 39.3 ft
 Valve Head loss = 6.05 feet
 Required KV = 1.68 >> CD = 0.61 >>> Valve Opening = 87% open

Same square grid spacing (no Flow Change continued) 6 inches Porosity = 20%
 Number of rows = 10
 Number of holes per row Discharge = 41.97 % diff = -2%
 Height 4 9
 Height 5 6

	Elev above floor (ft)	Area of Holes (ft^2)	Head diff (ft)	Row Discharge Rate (cfs)	Sum Q (cfs)
1 Row 1	0.25	0.442	4.70	4.84	4.84
2 Row 2	0.75	0.442	4.70	4.84	9.68
3 Row 3	1.25	0.442	4.70	4.84	14.53
4 Row 4	1.75	0.442	4.70	4.84	19.37
5 Row 5	2.25	0.442	4.70	4.84	24.21
6 Row 6	2.75	0.442	4.70	4.84	29.05
7 Row 7	3.25	0.442	4.70	4.84	33.90
8 Row 8	3.75	0.442	4.70	4.84	38.74
9 Row 9	4.25	0.295	4.70	3.23	41.97
10 Row 10	4.75	0.295			41.97
11 Row 11					
12 Row 12					

Flood Scenario

Assume current discharge rounded up to nearest 10 cfs
 Assume all perforation are plugged
 All flow over top of weirs and Perf plates

Q = 70.0 cfs WS = 5.87 ft

Weir Length L (ft)	CW	Weir Ht Zwr (ft)	DH (ft)	eff length L' (ft)	Q (cfs)
4.5	3.3	5	0.87	4.3	11.6
8	4.0	4.33	1.54	7.7	58.6
sum					70.1 cfs
diff =					0.1

Required Flow for recovery boxes

1 gpm per 15 lbs of fish
 5% increase for every degree above 50 degrees

maximum water temp = 72 deg Base temp = 50 deg
 Average fish weight = 37 lbs
 number of fish/box = 1
 Nb = number of boxes = 4 = number of inflow pipes

Total water supply = 1 gpm/15 lbs * 4 boxes * 37 lbs * (1 + (72 - 50) * 5%)
 Total water supply = 20.72 gpm = 0.04616435 cfs

V = outlet velocity = $Qt/Np/(\pi) * D^2/4$

Pipe Diameter (inches)			Thick-ness	Velocity (ft/s)
Nominal	OD	ID		
1	1.32	1.05	0.133	1.9
1.25	1.66	1.38	0.140	1.1
1.5	1.90	1.61	0.145	0.8
2	2.38	2.07	0.154	0.5
2.5	2.88	2.47	0.203	0.3
3	3.50	3.07	0.216	0.2

Elevation Difference in Pool Crest (DZ) = 1
 Orifice sqr Dim = 18 inch
 Orifice Area (Ao) = 2.25 ft²
 Orifice coeff (Cdo) = 0.67 $Q_o = A_o * C_{do} * \sqrt{2g * (DZ)}$
 Weir Crest Length (Lw) = 5 ft

Ladder Flow

Normal Case

Ladder head (DH) =	1.0 feet	0.8	5.05	0.1
Weir coeff (CW) =	5.07	1	5.07	0.6
$Q_w = L * C_w * (DH)^{1.5}$		1.3	5.25	3.8
Qo = Orifice flow =	12.1 cfs	1.5	6.01	4.0
Qw = Weir Flow =	25.4 cfs	1.7	6.80	
Qt = Total Exit Ladder flow =	37.4 cfs			

Backwater Profile for Exit Ladder to Pool 49 assuming Current Conditions

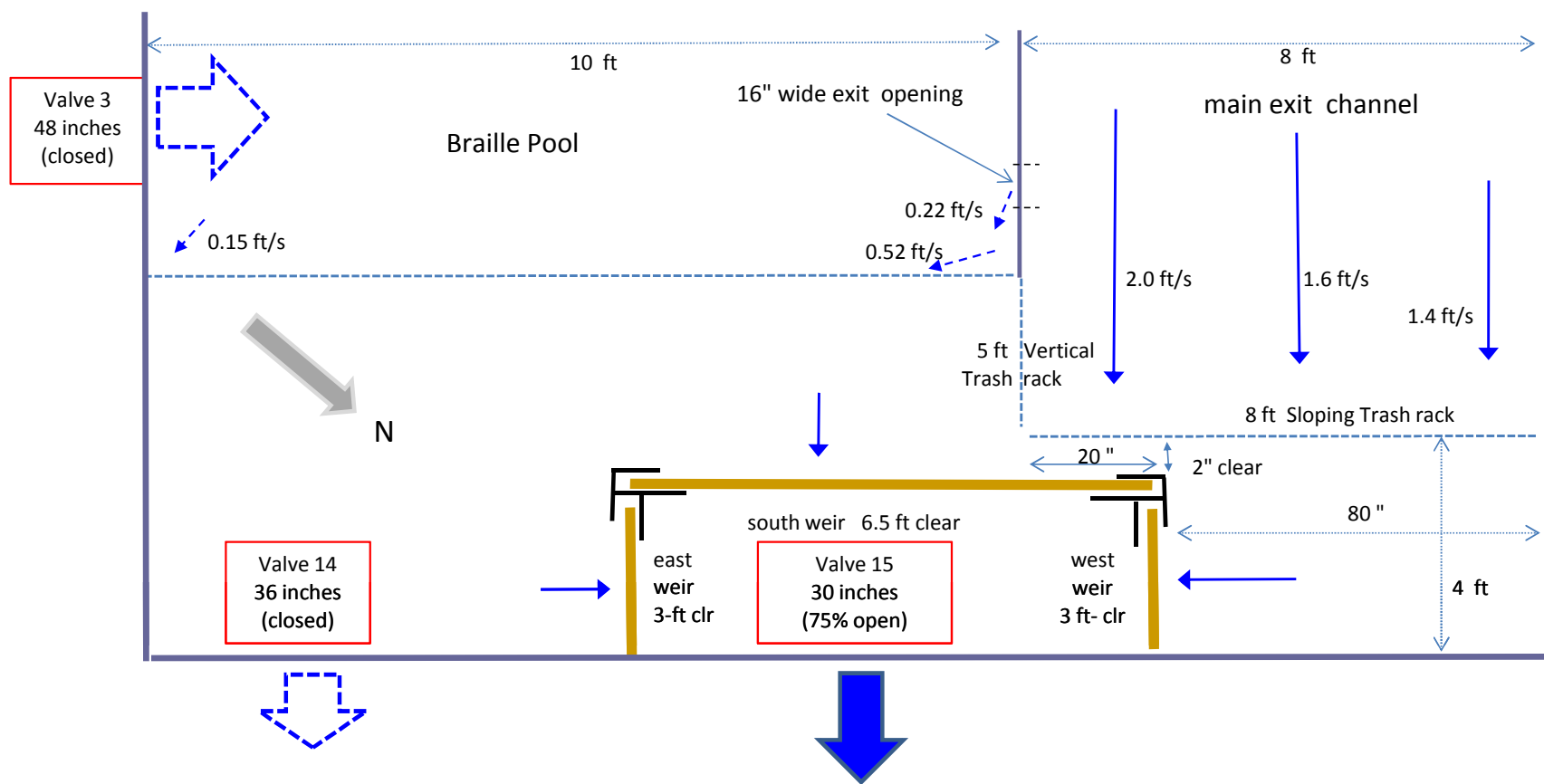
Q = 66.1 cfs
 D/s Depth = 4.9 ft WS EL = 43.9 ft

Weir	D/S WS EL	DH	U/S WS	Hu	DH	Qo	Hu	Cw	Qw
44	43.90		1.55	45.45		1	12.1	0.90	5.06 21.6
45	45.45		1.07	46.52		1.55	15.1	2.00	8.00 108.7
46	46.52		1.01	47.54		1.07	12.5	1.59	6.38 59.2
47	47.54		1.00	48.54		1.01	12.2	1.55	6.21 55.0
48	48.54		1.00	49.54		1.00	12.1	1.54	6.18 54.2
49	49.54		1.00	50.54	1.5	1.00	12.1	1.54	6.17 54.0

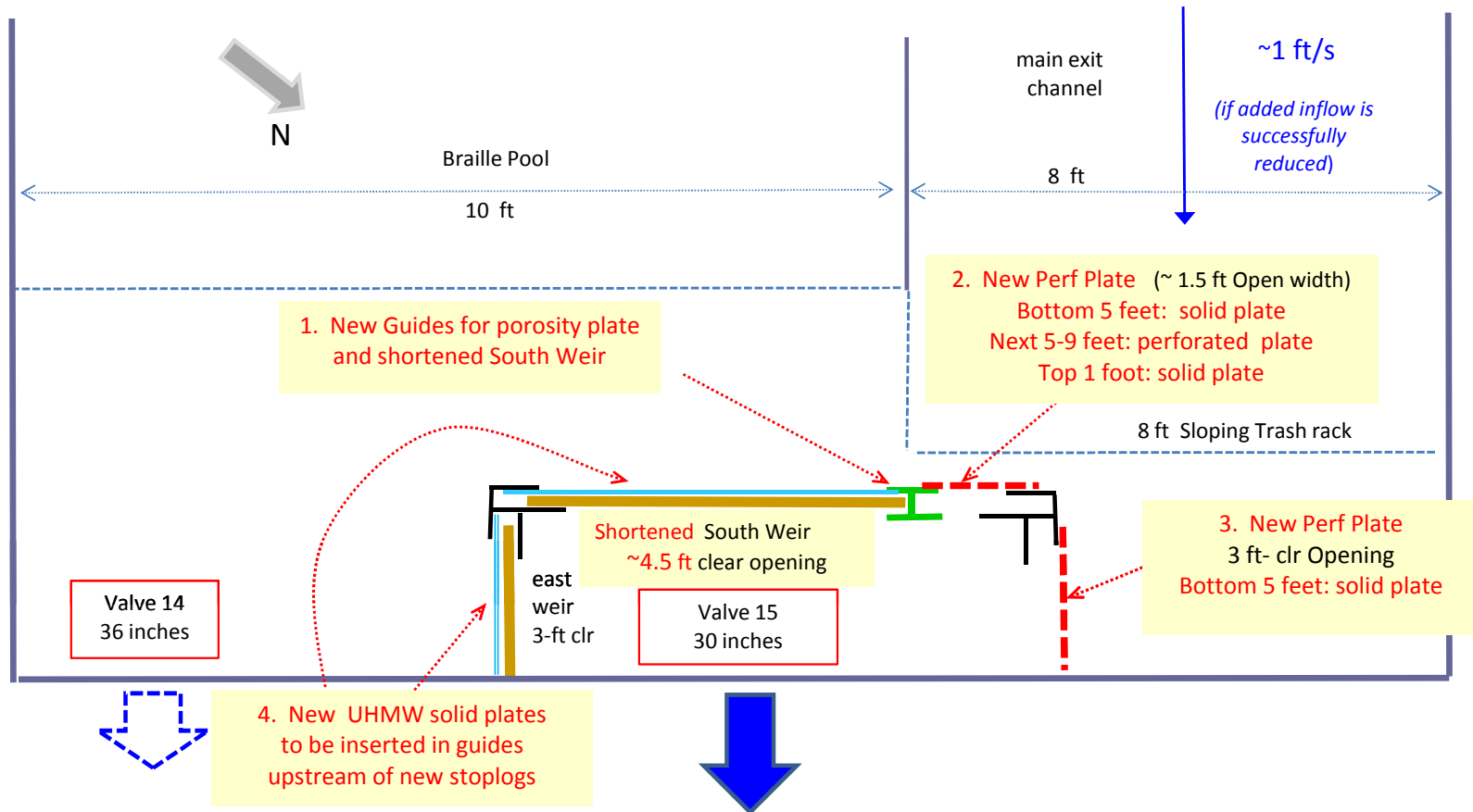
Average Exit Channel Velocities

Case	Flow Rate (cfs)	Channel Velocities (ft/s)	
		Deep Section	Shallow Section
Current OP	66	1.7	4.3
Design	38	1.0	2.5

EXISTING OPERATION WITH DIMENSIONS AND DEPTH AVERAGED VELOCITIES



PROPOSED REVISIONS



Bonneville AFF : Flume Calcs *INNER FLUME*

Assumptions
 Pipe thickness **0.437** inch **g =** **32.2 ft/s²**
 Pipe O.D. = **14** inches SDR 40 PVC
 Mannings n = **0.010** (PVC)

drop in pipe = 2.00 feet

Diameter = 13.13 inches = 1.1 ft
 Flow rate **110** gpm = 0.25 cfs

Nominal Flow Rate **Total L** **39.0** feet

Z(elevation)	Location	Slope
U/s Flume IE. Elev 49.0 ft	X 1 0 feet	interval 1 0.11
DS end bend 1 46.6 ft	X 2 21.5 feet	interval 2 0.12
US end Bend 2 44.5 ft	X 3 39.0 feet	

DEPTH	Velocity	Normal Depth
(ft)	(in)	(ft/s)
End of 1st Slope :	0.086 1.04	7.11 0.086 ft
End of 2nd Slope:	0.084 1.01	7.36 0.084 ft

minimum water depth:
 0.084 ft = 1.0 inches
 min. WS elevation = **43.90** ft Min FROUDE No. = 3.5 (d/s of 1rst 5 feet)

Jet Impact Velocity
 Beta = atan (slope) 0.120 radians = 6.9 degrees
 Total velocity (Vt) at end of flume = 7.36 ft/s
 vertical component (Vzi) = Vt * sin(beta) 0.88 ft/s
 horizontal comp (Vx) = Vt cos (beta) 7.30 ft/s

Vertical velocity (Vzi) at impact = sqrt(2g*(Z2-z3+y2/2) * Vz') 9.6 ft/s
 Total Impact Velocity (Vti) at Impact = sqrt(Vzi² + Vx²) = 12.1 ft/s
 βi = Angle of Impact with Respect to horizontal = 0.92 rads = 52.7 degrees

Vti = 12.1 ft/s OK, Vti is less than 25 ft/s

Normal Depth	X	Z elevation	Depth	Velocity	FR
Yn (in)	Locaton	(feet)	(feet)	(in)	(ft)
1.0	X 1	0	49.0	1.71	3.4 1.9
1.0	X 2	21.5	46.6	1.04	7.1 5.2
	X 3	39.0	44.5	1.01	7.4 5.43

RESULTS OF DIFFERENT FLOW CONDITIONS

Depth of Flow (in)	Discharge		Velocity (ft/s)		Impact Angle (deg)
	gpm	cfs	Exit	Impact	
0.5	25	0.06	4.7	9.1	59
1.0	110	0.25	7.4	12.1	53
1.5	240	0.53	9.3	14.4	50
2.0	450	1.00	11.0	16.7	49

EQUATIONS FOR FLUME CALCULATIONS

Equation for Water Depth

Reference: Henderson (1966), *Open Channel Flow*, Eq 7-52

$$\frac{dy}{dx} = \frac{S_o - S_f}{1 - Fr^2}$$

in which;

$\frac{dy}{dx}$	=	change in water depth with respect to channel length,
S_o	=	channel slope,
S_f	=	friction slope
	=	$\frac{Q^2 n^2}{C^2 A^2 Rh^{1.33}}$
Q	=	flow rate (cfs) in channel at location x,
g	=	gravity = 32.2 ft/s ²
A	=	cross-sectional flow area at location x (ft ²)
	=	$\frac{D^2 \cdot (\beta - \cos\beta \cdot \sin\beta)}{4}$
Fr ²	=	Froude number squared
	=	TQ^2 / gA^3

and:

y	=	flow depth (ft)
D	=	Inside Diameter of Pipe Flume (ft)
n	=	Manning roughness factor,
C	=	coefficient (1.486 for English units, 1 for metric units).
β	=	$\cos^{-1}\left(1 - \frac{2 \cdot y}{D}\right)$ (radians)
Rh	=	hydraulic radius (ft) = area/wetted perimeter,
	=	A/P
P	=	wetted perimeter (ft) = D * β
T	=	Top width of flow (ft)
	=	D * sin (β)

Computation Procedure Using 4th Order Runge-Kutta Methods

Assume initial depth $Y_1 = (Y_c + Y_n)/2$ due to energy of false weir at u/s end

Y_n = normal depth (ft) = depth at which $SF = S_o$

Y_c = critical depth (ft) = depth at which $FR^2 = 1$

Given: D, Q, Z, X, DX, S_o , g, n, C

From Y_1 , Compute β , A, V, P, Rh, $1 - FR^2$, SF and Dy/Dx based on above equations

$X + DX$ = next X location for depth computation (ft)

Fourth Order Runge- Kutta Calculation for Y at $X + DX$:

DY_1 = 1st estimate of change in Y over DX; $DY_1 = DX * (Dy/DX)_1$

DY_2 = 2nd estimate of change in Y over DX; $DY_2 = DX * (Dy/DX)_2$

DY_3 = 3rd estimate of change in Y over DX; $DY_3 = DX * (Dy/DX)_3$

DY_4 = 4th estimate of change in Y over DX; $DY_4 = DX * (Dy/DX)_4$

$DY = (DY_1 + 2 * DY_2 + 2 * DY_3 + DY_4) / 6$

$Y_{i+1} = Y_i + DY$

DY/DX_1 based on Y_i at X

DY/DX_2 based on $Y_i + DY_1/2$ at $X + DX/2$

DY/DX_3 based on $Y_i + DY_2/2$ at $X + DX/2$

DY/DX_4 based on $Y_i + DY_3$ at $X + DX$

LEG 1 SUPERCRITICAL FLOW COMPUTATIONS

Existing Pipe

X1 = 0.0 ft D = 1.094 ft
 X2 = 21.5 ft Q = 0.245 cfs z1 = 49.0 ft
 Length = 21.5 ft z2 = 46.6 ft
 Yc = 0.1984 So = 0.1100
 Y1 = 0.14 Yn = 0.0860
 Dx = 0.22 ft
 n = 0.01 g = 32.2 ρ = 1.94
 C = 1.486 2g = 64.4 γ = 62.40

Critical depth for Circular channels

g = 32.2 ft/sec² Tolerance
 D = 1.094 ft 1E-08

Critical Depth supercrit	Q	Yc	Critical flow area	Critical velocity	Top width	error
	0.245	0.198	0.116	2.11	0.84	0
Normal Depth supercrit	Q	Yn	Dia	slope	n	
	0.245	0.086	1.094	11%	0.01	

end: 0.0863 0.245 7.11

x (ft)	Z (ft)	y (ft)	Q (cfs)	beta (rads)	area (ft ²)	V (ft/s)	WS EL (ft)	EGL (ft)	T	FR	1-FR ²	P (ft)	Rh (ft)	SF	dY1/dx	DY (ft)
0.00	48.97	0.142	0.245	0.738	0.0718	3.41	49.11	49.29	0.736	1.93	-2.712	0.807	0.089	0.013	-0.036	0.000
0.22	48.94	0.136	0.245	0.721	0.0674	3.64	49.08	49.28	0.722	2.10	-3.408	0.789	0.085	0.016	-0.028	-0.006
0.43	48.92	0.131	0.245	0.706	0.0636	3.86	49.05	49.28	0.710	2.27	-4.154	0.773	0.082	0.019	-0.022	-0.005
0.65	48.90	0.127	0.245	0.694	0.0606	4.05	49.02	49.28	0.700	2.42	-4.879	0.759	0.080	0.022	-0.018	-0.004
0.86	48.87	0.123	0.245	0.684	0.0581	4.22	48.99	49.27	0.691	2.57	-5.585	0.748	0.078	0.024	-0.015	-0.003
1.08	48.85	0.120	0.245	0.675	0.0560	4.38	48.97	49.27	0.683	2.70	-6.275	0.738	0.076	0.027	-0.013	-0.003
1.29	48.82	0.117	0.245	0.667	0.0542	4.53	48.94	49.26	0.677	2.82	-6.949	0.730	0.074	0.030	-0.012	-0.002
1.51	48.80	0.115	0.245	0.660	0.0526	4.66	48.92	49.25	0.671	2.93	-7.607	0.722	0.073	0.032	-0.010	-0.002
1.72	48.78	0.113	0.245	0.654	0.0512	4.79	48.89	49.25	0.665	3.04	-8.250	0.715	0.072	0.035	-0.009	-0.002
1.94	48.75	0.111	0.245	0.648	0.0500	4.90	48.86	49.24	0.661	3.14	-8.877	0.709	0.070	0.037	-0.008	-0.002
2.15	48.73	0.109	0.245	0.643	0.0489	5.02	48.84	49.23	0.656	3.24	-9.488	0.704	0.069	0.040	-0.007	-0.002
2.37	48.71	0.108	0.245	0.639	0.0479	5.12	48.81	49.22	0.652	3.33	-10.083	0.699	0.069	0.042	-0.007	-0.001
2.58	48.68	0.106	0.245	0.634	0.0470	5.22	48.79	49.21	0.648	3.42	-10.663	0.694	0.068	0.045	-0.006	-0.001
2.80	48.66	0.105	0.245	0.631	0.0462	5.31	48.76	49.20	0.645	3.50	-11.227	0.690	0.067	0.047	-0.006	-0.001
3.01	48.64	0.104	0.245	0.627	0.0454	5.40	48.74	49.19	0.642	3.57	-11.775	0.686	0.066	0.049	-0.005	-0.001
3.23	48.61	0.103	0.245	0.624	0.0447	5.48	48.71	49.18	0.639	3.65	-12.307	0.682	0.066	0.051	-0.005	-0.001
3.44	48.59	0.102	0.245	0.621	0.0441	5.56	48.69	49.17	0.636	3.72	-12.823	0.679	0.065	0.054	-0.004	-0.001
3.66	48.56	0.101	0.245	0.618	0.0435	5.63	48.67	49.16	0.633	3.78	-13.324	0.676	0.064	0.056	-0.004	-0.001
3.87	48.54	0.100	0.245	0.615	0.0430	5.70	48.64	49.15	0.631	3.85	-13.810	0.673	0.064	0.058	-0.004	-0.001
4.09	48.52	0.099	0.245	0.612	0.0425	5.77	48.62	49.13	0.629	3.91	-14.280	0.670	0.063	0.060	-0.004	-0.001
4.30	48.49	0.099	0.245	0.610	0.0420	5.83	48.59	49.12	0.627	3.97	-14.736	0.667	0.063	0.061	-0.003	-0.001
4.52	48.47	0.098	0.245	0.608	0.0416	5.89	48.57	49.11	0.625	4.02	-15.177	0.665	0.063	0.063	-0.003	-0.001
4.73	48.45	0.097	0.245	0.606	0.0412	5.95	48.54	49.09	0.623	4.07	-15.603	0.663	0.062	0.065	-0.003	-0.001
4.95	48.42	0.097	0.245	0.604	0.0408	6.00	48.52	49.08	0.621	4.12	-16.015	0.661	0.062	0.067	-0.003	-0.001

Internal row calculations not shown for brevity

20.00	46.77	0.086	0.245	0.570	0.0345	7.09	46.85	47.63	0.590	5.17	-25.697	0.623	0.055	0.108	0.000	0.000
20.21	46.74	0.086	0.245	0.570	0.0345	7.10	46.83	47.61	0.590	5.17	-25.719	0.623	0.055	0.108	0.000	0.000
20.43	46.72	0.086	0.245	0.570	0.0345	7.10	46.81	47.59	0.590	5.17	-25.740	0.623	0.055	0.108	0.000	0.000
20.64	46.70	0.086	0.245	0.569	0.0345	7.10	46.78	47.57	0.590	5.17	-25.760	0.623	0.055	0.108	0.000	0.000
20.86	46.67	0.086	0.245	0.569	0.0345	7.10	46.76	47.54	0.590	5.17	-25.779	0.623	0.055	0.108	0.000	0.000
21.07	46.65	0.086	0.245	0.569	0.0345	7.10	46.74	47.52	0.590	5.18	-25.797	0.623	0.055	0.108	0.000	0.000
21.29	46.63	0.086	0.245	0.569	0.0345	7.11	46.71	47.50	0.590	5.18	-25.814	0.623	0.055	0.108	0.000	0.000
21.50	46.60	0.086	0.245	0.569	0.0345	7.11	46.69	47.47	0.590	5.18	-25.831	0.623	0.055	0.108	0.000	0.000

LEG 2 SUPERCRITICAL FLOW COMPUTATIONS

New Pipe Extension

X2 = 21.5 ft D = 1.094 ft
 X3 = 39.0 ft Q = 0.245 cfs Z2= 46.6 ft
 Length = 17.5 ft Z3= 44.5 ft
 20 So = 0.1200
 Y1 = 0.09 Yc = 0.1984
 Dx = 0.88 ft Yn = 0.0842
 n = 0.01 g = 32.2 ρ = 1.94
 C = 1.486 Zg = 64.4 γ = 62.40

Critical depth for Circular channels

g = 32.2 ft/sec² Tolerance
 D = 1.094 ft 1E-08

Critical Depth supercrit	Q	Yc	Critical flow area	Critical velocity	Top width	error	0
0.245	0.198	0.116	2.11	0.84			
Normal Depth supercrit	Q	Yn	Dia	slope	n		
0.245	0.084	1.094	12%	0.01			

End: 0.0843 0.245 7.36

x	Z	y (ft)	Q	beta (rads)	area	V	ws	EGL	T	FR	1-FR ²	P	Rh	SF	dY1/dx	DY
21.50	46.60	0.086	0.245	0.569	0.0345	7.11	46.69	47.47	0.590	5.18	-25.831	0.623	0.055	0.108	0.000	0.000
21.50	46.60	0.086	0.245	0.569	0.0345	7.11	46.69	47.47	0.590	5.18	-25.834	0.623	0.055	0.108	0.000	0.000
21.51	46.60	0.086	0.245	0.569	0.0345	7.11	46.69	47.47	0.590	5.18	-25.837	0.623	0.055	0.108	0.000	0.000
21.51	46.60	0.086	0.245	0.569	0.0345	7.11	46.69	47.47	0.590	5.18	-25.839	0.623	0.055	0.108	0.000	0.000
21.52	46.60	0.086	0.245	0.569	0.0345	7.11	46.68	47.47	0.590	5.18	-25.842	0.623	0.055	0.108	0.000	0.000
21.52	46.60	0.086	0.245	0.569	0.0345	7.11	46.68	47.47	0.590	5.18	-25.845	0.623	0.055	0.108	0.000	0.000
21.61	46.59	0.086	0.245	0.569	0.0345	7.11	46.67	47.46	0.590	5.18	-25.845	0.623	0.055	0.108	0.000	0.000
21.70	46.58	0.086	0.245	0.569	0.0345	7.11	46.66	47.45	0.589	5.19	-25.892	0.623	0.055	0.109	0.000	0.000
21.79	46.57	0.086	0.245	0.569	0.0344	7.12	46.65	47.44	0.589	5.19	-25.939	0.622	0.055	0.109	0.000	0.000
21.87	46.56	0.086	0.245	0.569	0.0344	7.12	46.64	47.43	0.589	5.19	-25.985	0.622	0.055	0.109	0.000	0.000
21.96	46.55	0.086	0.245	0.569	0.0344	7.13	46.63	47.42	0.589	5.20	-26.031	0.622	0.055	0.109	0.000	0.000
22.05	46.54	0.086	0.245	0.569	0.0344	7.13	46.62	47.41	0.589	5.20	-26.075	0.622	0.055	0.109	0.000	0.000
22.14	46.53	0.086	0.245	0.569	0.0343	7.14	46.61	47.40	0.589	5.21	-26.119	0.622	0.055	0.110	0.000	0.000
22.22	46.51	0.086	0.245	0.568	0.0343	7.14	46.60	47.39	0.589	5.21	-26.162	0.622	0.055	0.110	0.000	0.000
22.31	46.50	0.086	0.245	0.568	0.0343	7.14	46.59	47.38	0.589	5.22	-26.204	0.622	0.055	0.110	0.000	0.000
23.19	46.40	0.086	0.245	0.567	0.0341	7.18	46.48	47.29	0.588	5.25	-26.588	0.620	0.055	0.112	0.000	0.000
24.06	46.29	0.085	0.245	0.566	0.0340	7.21	46.38	47.19	0.587	5.28	-26.908	0.620	0.055	0.113	0.000	0.000
24.94	46.19	0.085	0.245	0.566	0.0339	7.24	46.27	47.09	0.586	5.31	-27.176	0.619	0.055	0.114	0.000	0.000
25.81	46.08	0.085	0.245	0.565	0.0338	7.26	46.17	46.99	0.586	5.33	-27.400	0.618	0.055	0.115	0.000	0.000
26.69	45.98	0.085	0.245	0.565	0.0337	7.28	46.06	46.89	0.585	5.35	-27.586	0.618	0.055	0.116	0.000	0.000
27.56	45.87	0.085	0.245	0.564	0.0336	7.29	45.96	46.78	0.585	5.36	-27.741	0.617	0.054	0.117	0.000	0.000
28.44	45.77	0.085	0.245	0.564	0.0336	7.30	45.85	46.68	0.585	5.37	-27.871	0.617	0.054	0.117	0.000	0.000
29.32	45.66	0.085	0.245	0.564	0.0335	7.31	45.75	46.58	0.584	5.38	-27.979	0.617	0.054	0.118	0.000	0.000
30.19	45.56	0.085	0.245	0.563	0.0335	7.32	45.64	46.48	0.584	5.39	-28.068	0.616	0.054	0.118	0.000	0.000
31.07	45.45	0.084	0.245	0.563	0.0334	7.33	45.54	46.37	0.584	5.40	-28.143	0.616	0.054	0.118	0.000	0.000
31.94	45.35	0.084	0.245	0.563	0.0334	7.34	45.43	46.27	0.584	5.40	-28.205	0.616	0.054	0.119	0.000	0.000
32.82	45.24	0.084	0.245	0.563	0.0334	7.34	45.33	46.16	0.584	5.41	-28.257	0.616	0.054	0.119	0.000	0.000
33.69	45.14	0.084	0.245	0.563	0.0334	7.34	45.22	46.06	0.584	5.41	-28.300	0.616	0.054	0.119	0.000	0.000
34.57	45.03	0.084	0.245	0.563	0.0334	7.35	45.12	45.96	0.584	5.42	-28.335	0.616	0.054	0.119	0.000	0.000
35.44	44.93	0.084	0.245	0.563	0.0333	7.35	45.01	45.85	0.584	5.42	-28.365	0.615	0.054	0.119	0.000	0.000
36.32	44.82	0.084	0.245	0.563	0.0333	7.35	44.91	45.75	0.583	5.42	-28.390	0.615	0.054	0.119	0.000	0.000
37.19	44.72	0.084	0.245	0.563	0.0333	7.35	44.80	45.64	0.583	5.42	-28.410	0.615	0.054	0.120	0.000	0.000
38.07	44.61	0.084	0.245	0.563	0.0333	7.36	44.70	45.54	0.583	5.42	-28.427	0.615	0.054	0.120	0.000	0.000
38.94	44.51	0.084	0.245	0.562	0.0333	7.36	44.59	45.43	0.583	5.43	-28.441	0.615	0.054	0.120	0.000	0.000

Bonneville AFF : Flume Calcs *OUTER FLUME*

Assumptions
 Pipe thickness **0.437** inch **g = 32.2** ft/s²
 Pipe O.D. = **14** inches SDR 40 PVC
 Mannings n = **0.010** (PVC)

Drop in pipe = 2.00 feet

Diameter = 13.13 inches = 1.1 ft
 Flow rate **20** gpm = 0.04 cfs

Nominal Flow Rate **Total L 51.8** feet

Z(elevation)	Location	Slope
U/s Flume IE. Elev 49.4 ft	X 1 0 feet	interval 1 0.11
DS end bend 1 46.6 ft	X 2 25.4 feet	interval 2 0.08
US end Bend 2 44.5 ft	X 3 51.8 feet	

DEPTH	Velocity	Normal Depth
(ft)	(in)	(ft/s)
End of 1st Slope :	0.039 0.46	4.25 0.039 ft
End of 2nd Slope:	0.042 0.50	3.80 0.042 ft

minimum water depth:
 0.039 ft = 0.5 inches
 min. WS elevation **43.90** ft Min FROUDE No. = 4.0 (d/s of 1rst 5 feet)

Jet Impact Velocity
 Beta = atan (slope) 0.080 radians = 4.6 degrees
 Total velocity (Vt) at end of flume = 3.80 ft/s
 vertical component (Vzi) = Vt * sin(beta) 0.30 ft/s
 horizontal comp (Vx) = Vt cos (beta) 3.79 ft/s

Vertical velocity (Vzi) at impact = sqrt(2g*(Z2-z3+y2/2)) * Vz' 7.3 ft/s
 Total Impact Velocity (Vti) at Impact = sqrt(Vzi^2 + Vx^2) = 8.2 ft/s
 βi = Angle of Impact with Respect to horizontal = 1.09 rads = **62.5** degrees

Vti = 8.2 ft/s OK, Vti is less than 25 ft/s

Normal Depth	X	Z elevation	Depth	Velocity	FR
Yn (in)	Locaton	(feet)	(feet)	(ft)	
0.5	X 1	0	49.4	0.73	2.1
0.5	X 2	25.4	46.6	0.46	4.3
	X 3	51.8	44.5	0.50	3.8

RESULTS OF DIFFERENT FLOW CONDITIONS

Depth of Flow (in)	Discharge		Velocity (ft/s)		Impact Angle (deg)
	gpm	cfs	Exit	Impact	
0.5	20	0.04	3.8	8.2	62
1.0	100	0.22	6.2	10.7	55
1.5	210	0.47	7.8	12.6	52
2.0	400	0.89	9.5	14.7	50

EQUATIONS FOR FLUME CALCULATIONS

Equation for Water Depth

Reference: Henderson (1966), *Open Channel Flow*, Eq 7-52

$$\frac{dy}{dx} = \frac{S_o - S_f}{1 - Fr^2}$$

in which;

$\frac{dy}{dx}$	=	change in water depth with respect to channel length,
S_o	=	channel slope,
S_f	=	friction slope
	=	$\frac{Q^2 n^2}{C^2 A^2 R_h^{1.33}}$
Q	=	flow rate (cfs) in channel at location x,
g	=	gravity = 32.2 ft/s ²
A	=	cross-sectional flow area at location x (ft ²)
	=	$\frac{D^2 \cdot (\beta - \cos\beta \cdot \sin\beta)}{4}$
Fr ²	=	Froude number squared
	=	TQ^2 / gA^3

and:

y	=	flow depth (ft)
D	=	Inside Diameter of Pipe Flume (ft)
n	=	Manning roughness factor,
C	=	coefficient (1.486 for English units, 1 for metric units).
β	=	$\cos^{-1}\left(1 - \frac{2 \cdot y}{D}\right)$ (radians)
Rh	=	hydraulic radius (ft) = area/wetted perimeter,
	=	A/P
P	=	wetted perimeter (ft) = D * β
T	=	Top width of flow (ft)
	=	D * sin (β)

Computation Procedure Using 4th Order Runge-Kutta Methods

Assume initial depth $Y_1 = (Y_c + Y_n)/2$ due to energy of false weir at u/s end

Y_n = normal depth (ft) = depth at which $SF = S_o$

Y_c = critical depth (ft) = depth at which $FR^2 = 1$

Given: D, Q, Z, X, DX, S_o , g, n, C

From Y_1 , Compute β , A, V, P, Rh, $1 - FR^2$, SF and Dy/Dx based on above equations

$X + DX$ = next X location for depth computation (ft)

Fourth Order Runge- Kutta Calculation for Y at $X + DX$:

DY_1 = 1st estimate of change in Y over DX; $DY_1 = DX * (Dy/DX)_1$

DY_2 = 2nd estimate of change in Y over DX; $DY_2 = DX * (Dy/DX)_2$

DY_3 = 3rd estimate of change in Y over DX; $DY_3 = DX * (Dy/DX)_3$

DY_4 = 4th estimate of change in Y over DX; $DY_4 = DX * (Dy/DX)_4$

$DY = (DY_1 + 2 * DY_2 + 2 * DY_3 + DY_4) / 6$

$Y_{i+1} = Y_i + DY$

DY/DX_1 based on Y_i at X

DY/DX_2 based on $Y_i + DY_1/2$ at $X + DX/2$

DY/DX_3 based on $Y_i + DY_2/2$ at $X + DX/2$

DY/DX_4 based on $Y_i + DY_3$ at $X + DX$

LEG 1 SUPERCRITICAL FLOW COMPUTATIONS

Existing Pipe

X1 =	0.0 ft	D =	1.094 ft	z1 =	49.4 ft
X2 =	25.4 ft	Q =	0.045 cfs	Z2 =	46.6 ft
Length =	25.4 ft	Yc =	0.0837	So =	0.1100
Y1 =	0.06	Yn =	0.0387		
Dx =	0.25 ft				
n =	0.01	g =	32.2	ρ =	1.94
C =	1.486	2g =	64.4	γ =	62.40

Critical depth for Circular channels

g =	32.2 ft/sec ²	Tolerance	
D =	1.094 ft		1E-08
Critical Depth	Q	Yc	Critical flow area
supercrit	0.045	0.084	0.033
			Critical velocity
			1.35
			Top width
			0.58
			error
			-2.22E-15
Normal Depth	Q	Yn	Dia
supercrit	0.045	0.039	1.094
			slope
			11%
			n
			0.01

end: 0.0386 0.045 4.25

x (ft)	Z (ft)	y (ft)	Q (cfs)	beta (rads)	area (ft^2)	V (ft/s)	WS EL (ft)	EGL (ft)	T	FR	1-FR^2	P (ft)	Rh (ft)	SF	dY1/dx	DY (ft)
0.00	49.39	0.061	0.045	0.478	0.0207	2.15	49.46	49.53	0.503	1.86	-2.473	0.522	0.040	0.015	-0.038	0.000
0.25	49.37	0.055	0.045	0.452	0.0177	2.52	49.42	49.52	0.478	2.31	-4.318	0.495	0.036	0.024	-0.020	-0.005
0.51	49.34	0.051	0.045	0.435	0.0158	2.81	49.39	49.51	0.461	2.68	-6.166	0.476	0.033	0.034	-0.012	-0.003
0.76	49.31	0.048	0.045	0.424	0.0146	3.04	49.36	49.50	0.450	2.97	-7.847	0.463	0.032	0.042	-0.009	-0.002
1.02	49.28	0.046	0.045	0.415	0.0138	3.23	49.33	49.49	0.441	3.22	-9.371	0.454	0.030	0.050	-0.006	-0.002
1.27	49.26	0.045	0.045	0.409	0.0132	3.38	49.30	49.48	0.435	3.43	-10.745	0.447	0.029	0.057	-0.005	-0.001
1.52	49.23	0.044	0.045	0.404	0.0127	3.51	49.27	49.46	0.430	3.60	-11.975	0.441	0.029	0.063	-0.004	-0.001
1.78	49.20	0.043	0.045	0.399	0.0123	3.62	49.24	49.45	0.425	3.75	-13.070	0.437	0.028	0.069	-0.003	-0.001
2.03	49.17	0.042	0.045	0.396	0.0120	3.71	49.21	49.43	0.422	3.88	-14.040	0.433	0.028	0.074	-0.003	-0.001
2.29	49.14	0.042	0.045	0.393	0.0118	3.79	49.19	49.41	0.419	3.99	-14.897	0.430	0.027	0.079	-0.002	-0.001
2.54	49.12	0.041	0.045	0.391	0.0116	3.86	49.16	49.39	0.417	4.08	-15.649	0.428	0.027	0.083	-0.002	0.000
2.79	49.09	0.041	0.045	0.389	0.0114	3.91	49.13	49.37	0.415	4.16	-16.309	0.426	0.027	0.087	-0.001	0.000
3.05	49.06	0.041	0.045	0.387	0.0113	3.96	49.10	49.34	0.413	4.23	-16.886	0.424	0.027	0.090	-0.001	0.000
3.30	49.03	0.040	0.045	0.386	0.0111	4.00	49.07	49.32	0.412	4.29	-17.389	0.422	0.026	0.092	-0.001	0.000
3.56	49.00	0.040	0.045	0.385	0.0110	4.04	49.04	49.30	0.411	4.34	-17.827	0.421	0.026	0.095	-0.001	0.000
3.81	48.98	0.040	0.045	0.384	0.0110	4.07	49.02	49.27	0.410	4.38	-18.207	0.420	0.026	0.097	-0.001	0.000
4.06	48.95	0.040	0.045	0.383	0.0109	4.09	48.99	49.25	0.409	4.42	-18.537	0.419	0.026	0.099	-0.001	0.000
4.32	48.92	0.040	0.045	0.382	0.0108	4.12	48.96	49.22	0.408	4.45	-18.823	0.418	0.026	0.100	-0.001	0.000
4.57	48.89	0.039	0.045	0.382	0.0108	4.13	48.93	49.20	0.408	4.48	-19.071	0.418	0.026	0.101	0.000	0.000
4.83	48.86	0.039	0.045	0.381	0.0107	4.15	48.90	49.17	0.407	4.50	-19.286	0.417	0.026	0.103	0.000	0.000
5.08	48.84	0.039	0.045	0.381	0.0107	4.16	48.88	49.15	0.407	4.52	-19.471	0.417	0.026	0.104	0.000	0.000
5.33	48.81	0.039	0.045	0.380	0.0107	4.18	48.85	49.12	0.406	4.54	-19.631	0.416	0.026	0.105	0.000	0.000
5.59	48.78	0.039	0.045	0.380	0.0106	4.19	48.82	49.09	0.406	4.56	-19.769	0.416	0.026	0.105	0.000	0.000
5.84	48.75	0.039	0.045	0.380	0.0106	4.20	48.79	49.07	0.406	4.57	-19.889	0.415	0.026	0.106	0.000	0.000

Internal row calculations not shown for brevity

23.62	46.80	0.039	0.045	0.378	0.0105	4.25	46.84	47.12	0.404	4.65	-20.632	0.414	0.025	0.110	0.000	0.000
23.88	46.77	0.039	0.045	0.378	0.0105	4.25	46.81	47.09	0.404	4.65	-20.632	0.414	0.025	0.110	0.000	0.000
24.13	46.74	0.039	0.045	0.378	0.0105	4.25	46.78	47.06	0.404	4.65	-20.632	0.414	0.025	0.110	0.000	0.000
24.38	46.71	0.039	0.045	0.378	0.0105	4.25	46.75	47.03	0.404	4.65	-20.632	0.414	0.025	0.110	0.000	0.000
24.64	46.69	0.039	0.045	0.378	0.0105	4.25	46.72	47.00	0.404	4.65	-20.632	0.414	0.025	0.110	0.000	0.000
24.89	46.66	0.039	0.045	0.378	0.0105	4.25	46.70	46.98	0.404	4.65	-20.632	0.414	0.025	0.110	0.000	0.000
25.15	46.63	0.039	0.045	0.378	0.0105	4.25	46.67	46.95	0.404	4.65	-20.632	0.414	0.025	0.110	0.000	0.000
25.40	46.60	0.039	0.045	0.378	0.0105	4.25	46.64	46.92	0.404	4.65	-20.632	0.414	0.025	0.110	0.000	0.000

LEG 2 SUPERCRITICAL FLOW COMPUTATIONS

New Pipe Extension

X2 = 25.4 ft D = 1.094 ft
 X3 = 51.8 ft Q = 0.045 cfs Z2= 46.6 ft
 Length = 26.4 ft Z3= 44.5 ft
 20 Yc = 0.0837 So = 0.0797
 Y1 = 0.04 Yn = 0.0417
 Dx = 1.32 ft
 n = 0.01 g = 32.2 ρ = 1.94
 C = 1.486 2g = 64.4 γ = 62.40

Critical depth for Circular channels

g = 32.2 ft/sec² Tolerance
 D = 1.094 ft 1E-08

Critical Depth supercrit	Q	Yc	Critical flow area	Critical velocity	Top width	error
	0.045	0.084	0.033	1.35	0.58	-2.22E-15
Normal Depth supercrit	Q	Yn	Dia	slope	n	
	0.045	0.042	1.094	8%	0.01	

End: 0.0417 0.045 3.80

x	Z	y (ft)	Q	beta (rads)	area	V	ws	EGL	T	FR	1-FR ²	P	Rh	SF	dY1/dx	DY
25.40	46.60	0.039	0.045	0.378	0.0105	4.25	46.64	46.92	0.404	4.65	-20.632	0.414	0.025	0.110	0.001	0.000
25.41	46.60	0.039	0.045	0.378	0.0105	4.25	46.64	46.92	0.404	4.65	-20.608	0.414	0.025	0.110	0.001	0.000
25.41	46.60	0.039	0.045	0.378	0.0105	4.25	46.64	46.92	0.404	4.65	-20.584	0.414	0.025	0.110	0.001	0.000
25.42	46.60	0.039	0.045	0.378	0.0105	4.25	46.64	46.92	0.404	4.64	-20.560	0.414	0.025	0.110	0.001	0.000
25.43	46.60	0.039	0.045	0.378	0.0105	4.24	46.64	46.92	0.404	4.64	-20.537	0.414	0.025	0.109	0.001	0.000
25.44	46.60	0.039	0.045	0.378	0.0105	4.24	46.64	46.92	0.404	4.64	-20.513	0.414	0.025	0.109	0.001	0.000
25.57	46.59	0.039	0.045	0.378	0.0105	4.24	46.63	46.91	0.404	4.64	-20.513	0.414	0.025	0.109	0.001	0.000
25.70	46.58	0.039	0.045	0.379	0.0106	4.21	46.62	46.89	0.405	4.59	-20.108	0.415	0.025	0.107	0.001	0.000
25.83	46.57	0.039	0.045	0.380	0.0106	4.18	46.61	46.88	0.406	4.55	-19.735	0.416	0.026	0.105	0.001	0.000
25.96	46.56	0.039	0.045	0.381	0.0107	4.16	46.60	46.86	0.407	4.52	-19.391	0.417	0.026	0.103	0.001	0.000
26.10	46.55	0.039	0.045	0.382	0.0108	4.13	46.59	46.85	0.408	4.48	-19.073	0.418	0.026	0.101	0.001	0.000
26.23	46.54	0.040	0.045	0.382	0.0108	4.11	46.58	46.84	0.408	4.45	-18.779	0.418	0.026	0.100	0.001	0.000
26.36	46.53	0.040	0.045	0.383	0.0109	4.09	46.56	46.82	0.409	4.42	-18.508	0.419	0.026	0.098	0.001	0.000
26.49	46.51	0.040	0.045	0.384	0.0109	4.07	46.55	46.81	0.410	4.39	-18.257	0.420	0.026	0.097	0.001	0.000
26.62	46.50	0.040	0.045	0.384	0.0110	4.05	46.54	46.80	0.410	4.36	-18.025	0.420	0.026	0.096	0.001	0.001
27.94	46.40	0.041	0.045	0.389	0.0114	3.93	46.44	46.68	0.414	4.18	-16.467	0.425	0.027	0.087	0.000	0.001
29.26	46.29	0.041	0.045	0.391	0.0115	3.86	46.34	46.57	0.417	4.09	-15.730	0.427	0.027	0.083	0.000	0.000
30.58	46.19	0.041	0.045	0.392	0.0116	3.83	46.23	46.46	0.418	4.05	-15.375	0.429	0.027	0.082	0.000	0.000
31.89	46.08	0.042	0.045	0.392	0.0117	3.82	46.13	46.35	0.418	4.03	-15.202	0.429	0.027	0.081	0.000	0.000
33.21	45.98	0.042	0.045	0.393	0.0117	3.81	46.02	46.25	0.418	4.01	-15.118	0.429	0.027	0.080	0.000	0.000
34.53	45.87	0.042	0.045	0.393	0.0117	3.81	45.92	46.14	0.419	4.01	-15.077	0.430	0.027	0.080	0.000	0.000
35.85	45.77	0.042	0.045	0.393	0.0117	3.80	45.81	46.04	0.419	4.01	-15.057	0.430	0.027	0.080	0.000	0.000
37.16	45.66	0.042	0.045	0.393	0.0117	3.80	45.71	45.93	0.419	4.01	-15.048	0.430	0.027	0.080	0.000	0.000
38.48	45.56	0.042	0.045	0.393	0.0117	3.80	45.60	45.82	0.419	4.01	-15.043	0.430	0.027	0.080	0.000	0.000
39.80	45.45	0.042	0.045	0.393	0.0117	3.80	45.50	45.72	0.419	4.01	-15.041	0.430	0.027	0.080	0.000	0.000
41.12	45.35	0.042	0.045	0.393	0.0117	3.80	45.39	45.61	0.419	4.00	-15.039	0.430	0.027	0.080	0.000	0.000
42.43	45.24	0.042	0.045	0.393	0.0117	3.80	45.29	45.51	0.419	4.00	-15.039	0.430	0.027	0.080	0.000	0.000
43.75	45.14	0.042	0.045	0.393	0.0117	3.80	45.18	45.40	0.419	4.00	-15.039	0.430	0.027	0.080	0.000	0.000
45.07	45.03	0.042	0.045	0.393	0.0117	3.80	45.08	45.30	0.419	4.00	-15.038	0.430	0.027	0.080	0.000	0.000
46.39	44.93	0.042	0.045	0.393	0.0117	3.80	44.97	45.19	0.419	4.00	-15.038	0.430	0.027	0.080	0.000	0.000
47.70	44.82	0.042	0.045	0.393	0.0117	3.80	44.86	45.09	0.419	4.00	-15.038	0.430	0.027	0.080	0.000	0.000
49.02	44.72	0.042	0.045	0.393	0.0117	3.80	44.76	44.98	0.419	4.00	-15.038	0.430	0.027	0.080	0.000	0.000
50.34	44.61	0.042	0.045	0.393	0.0117	3.80	44.65	44.88	0.419	4.00	-15.038	0.430	0.027	0.080	0.000	0.000
51.66	44.51	0.042	0.045	0.393	0.0117	3.80	44.55	44.77	0.419	4.00	-15.038	0.430	0.027	0.080	0.000	0.000