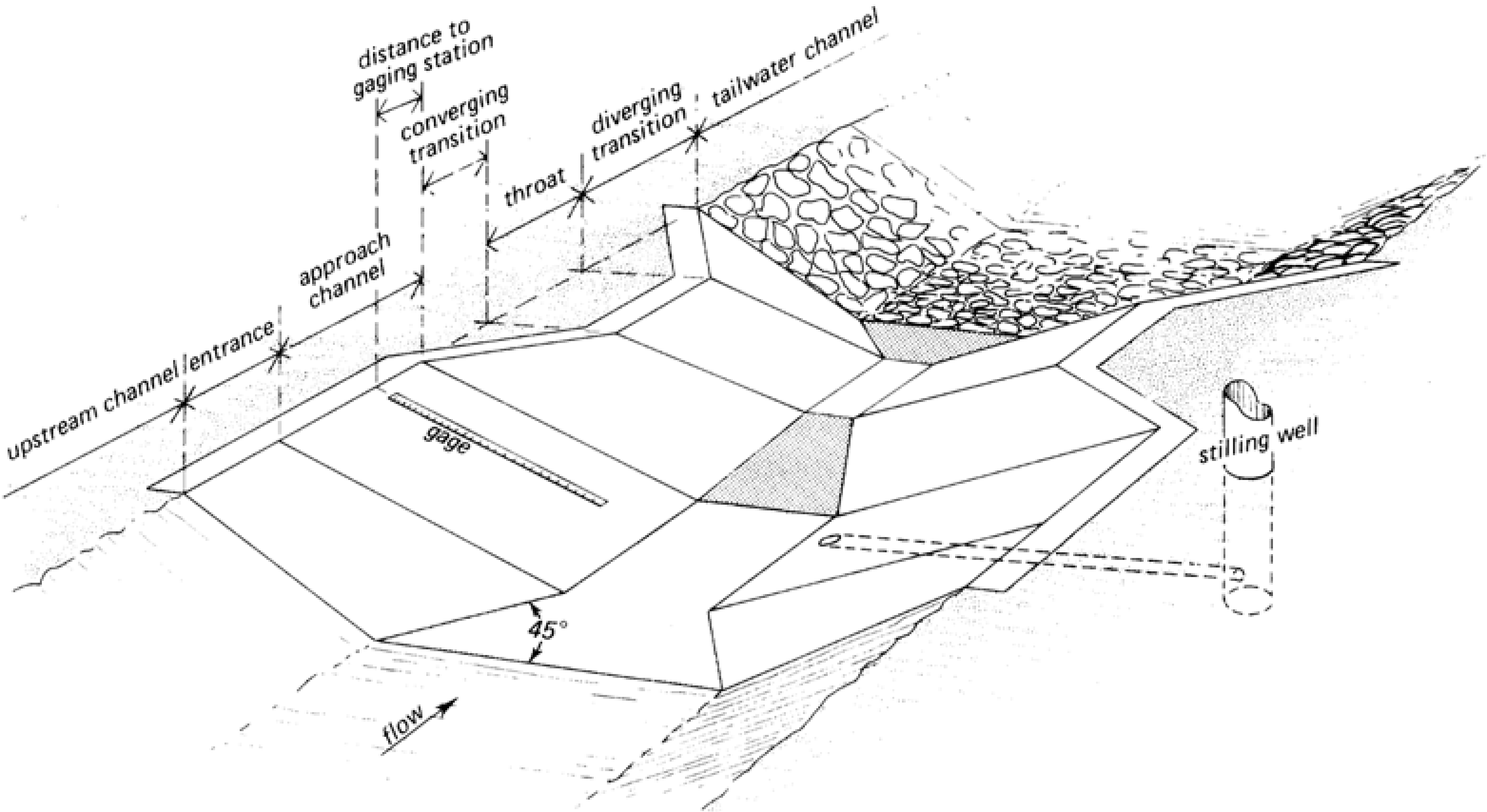
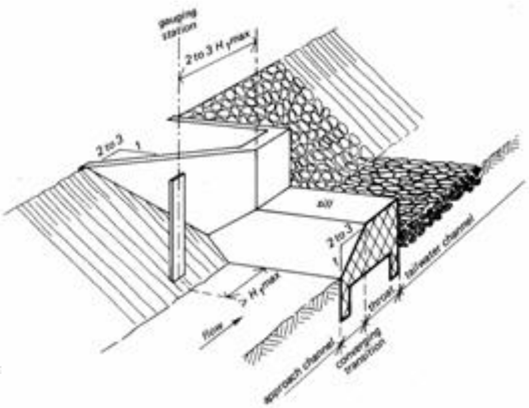
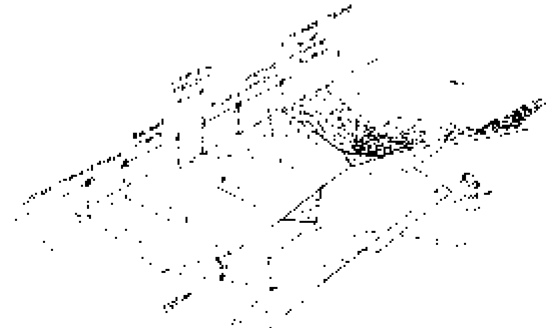
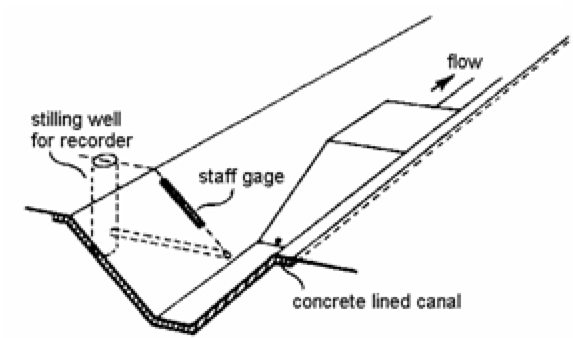
Introduction to Long-Throated Flumes (Ramp Flumes), Broad-Crested Weirs and WinFlume

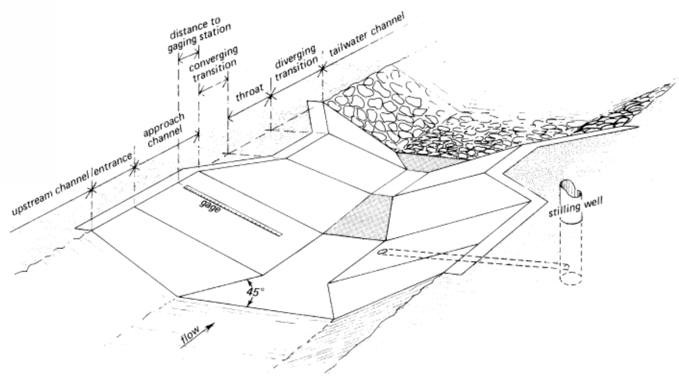


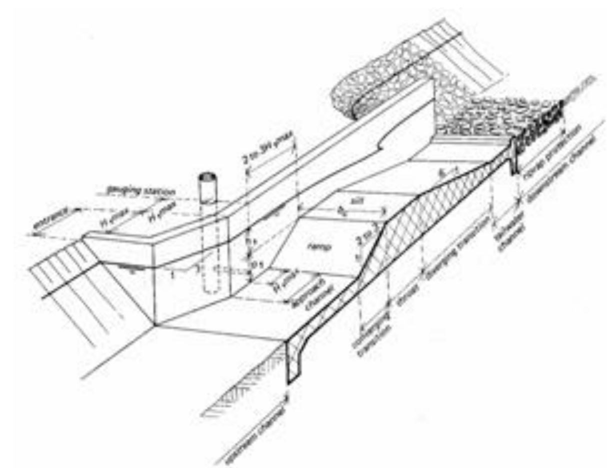
The term *long-throated flume* describes a broad class of critical-flow flumes and broad-crested weir devices used to measure flow in open channels.

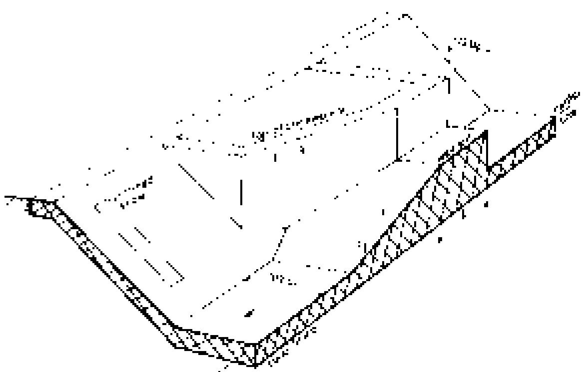

gauging station
2 to 3 H ymax
2 to 3
1
sill
2 to 3
> H ymax
flow
approach channel
converging transition
throat
tailwater channel

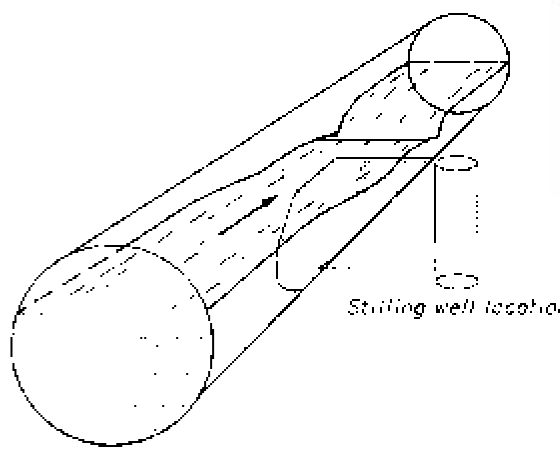



flow
stilling well
for recorder
staff gage
concrete lined canal


distance to
gaging station
converging
transition
diverging
transition
tailwater channel
throat
approach
channel
upstream channel/entrance
gage
stilling well
45°
flow


gauging station
entrance
sill
ramp
approach channel
upstream channel
converging transition
throat
diverging transition
tailwater channel

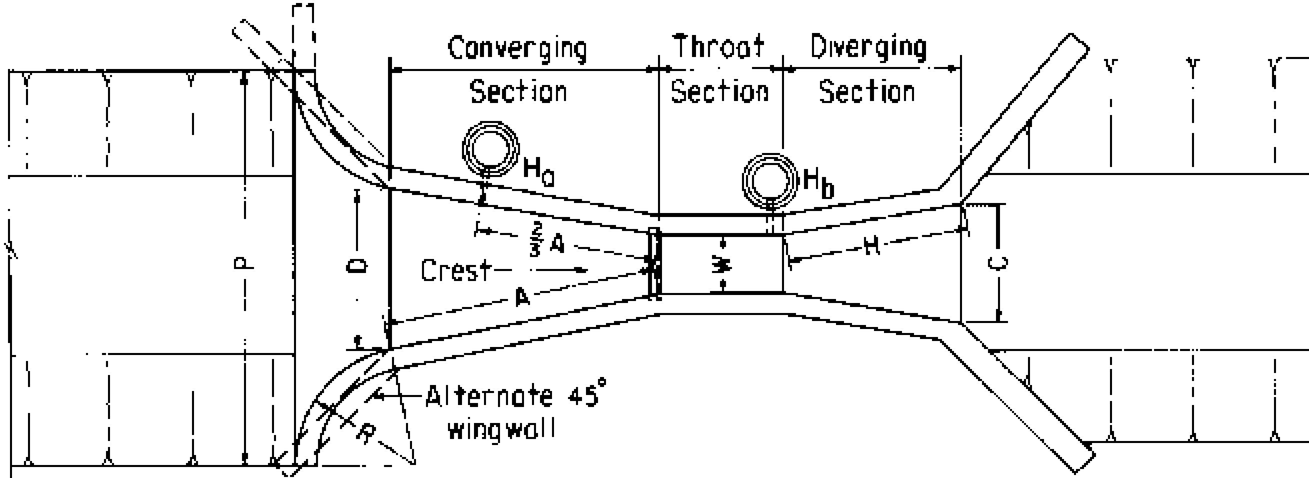



Stilling well location

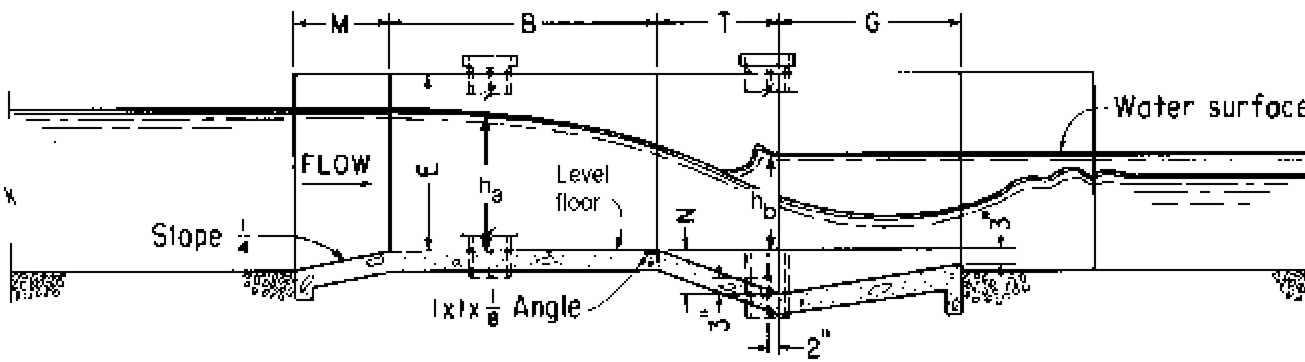
Traditional Critical-Flow Devices

- Traditional critical-flow devices have curved, three-dimensional flow fields in the control section
- All such devices require laboratory calibration
- Parshall flumes, cutthroat flumes, H-flumes, etc.
- V-notch weirs, Cipoletti weirs, rectangular weirs

Parshall Flume



PLAN



PROFILE

Long-Throated Flumes and Broad-Crested Weirs

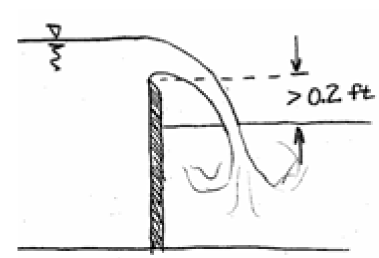
- Long-throated flumes have one-dimensional flow in the control section -- *Long-throated means long enough to eliminate lateral and vertical contraction of the flow at the control section…streamlines are essentially parallel*
  - Can be calibrated using well-established hydraulic theory
    - **No laboratory testing needed**
  - Calculations are iterative and tedious, so computer models that do the calculations have made long-throated flumes practical in recent years

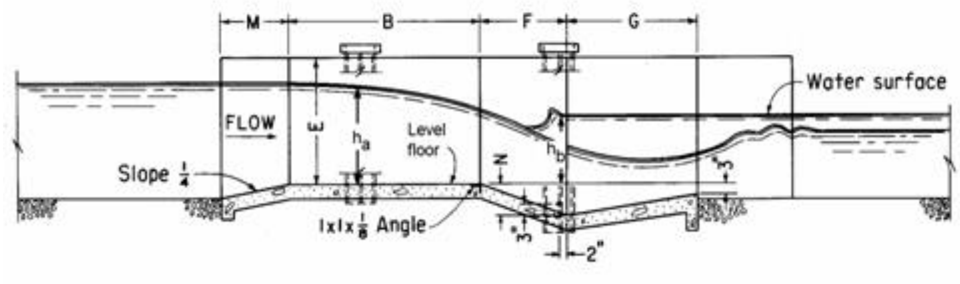
Advantages of Analytical Calibration

- Allows design of flumes customized to your site and needs
- Easy to calibrate using as-built dimensions
- Better measurement accuracy
  - ± 2% uncertainty vs. ± 3-5% uncertainty
- Can accurately predict tolerance for submergence

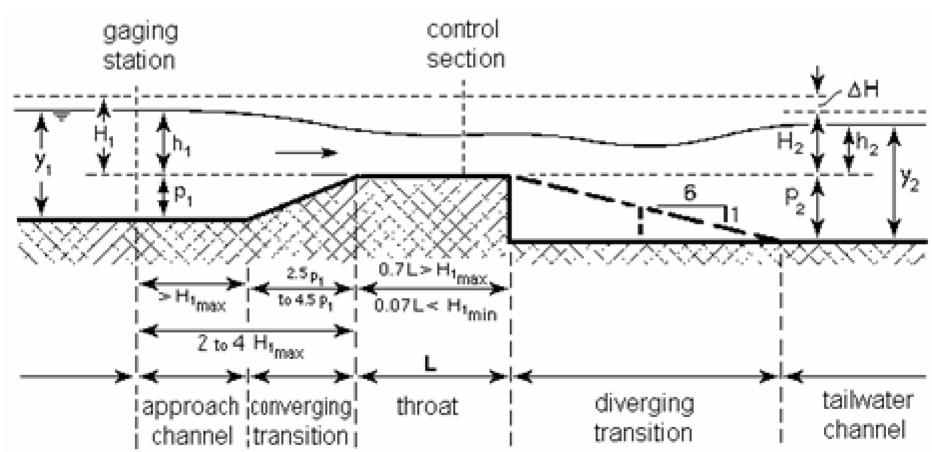
Submergence of Flumes and Weirs

- h_2/h_1 or h_b/h_a is the submergence ratio
- Sharp-crested weirs
  - NO SUBMERGENCE ALLOWED
- Parshall flume
  - Some submergence allowed, 50-80%
- Long-throated flume and broad-crested weir
  - Most submergence allowed, 80-95%





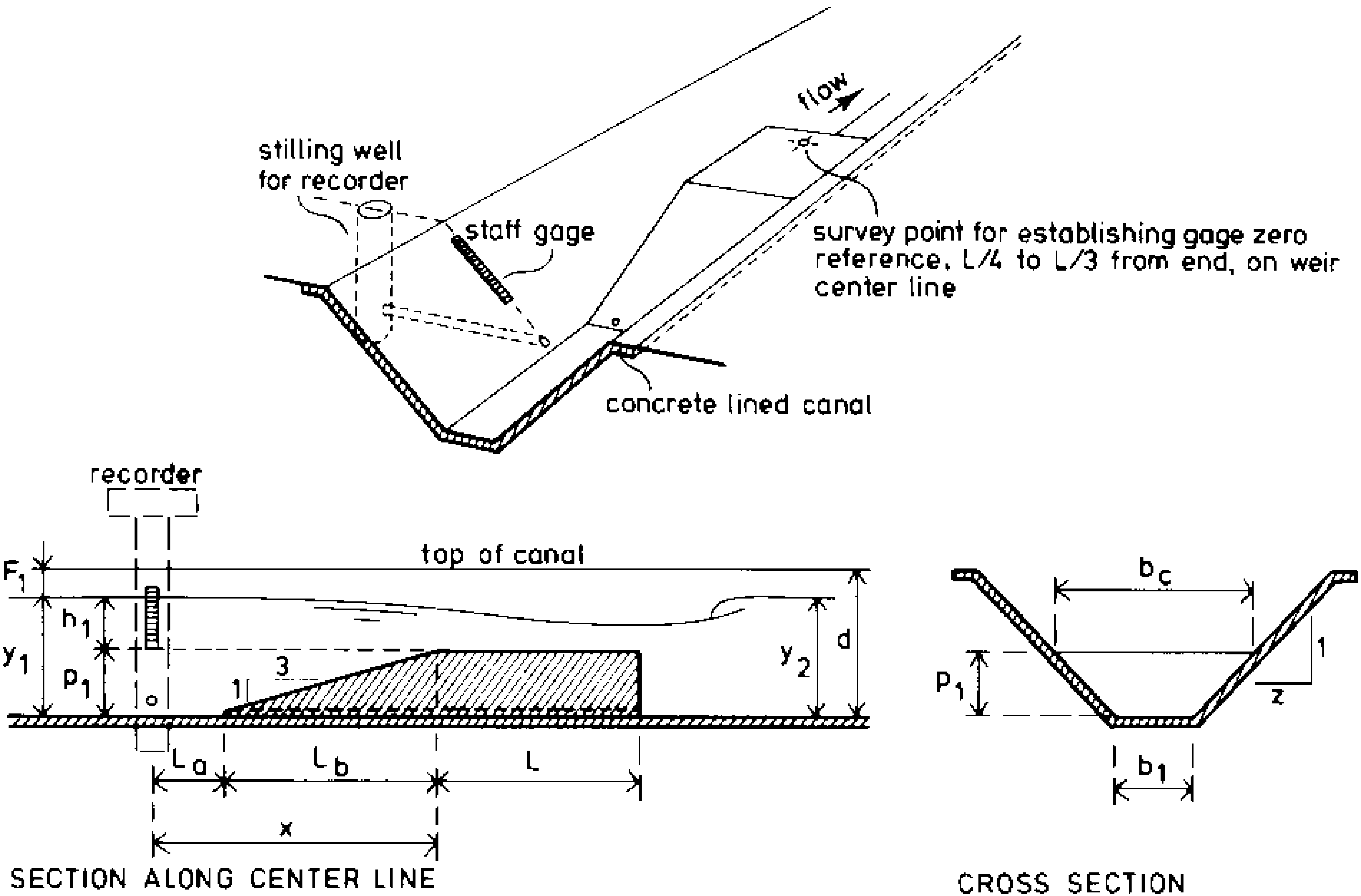
PROFILE

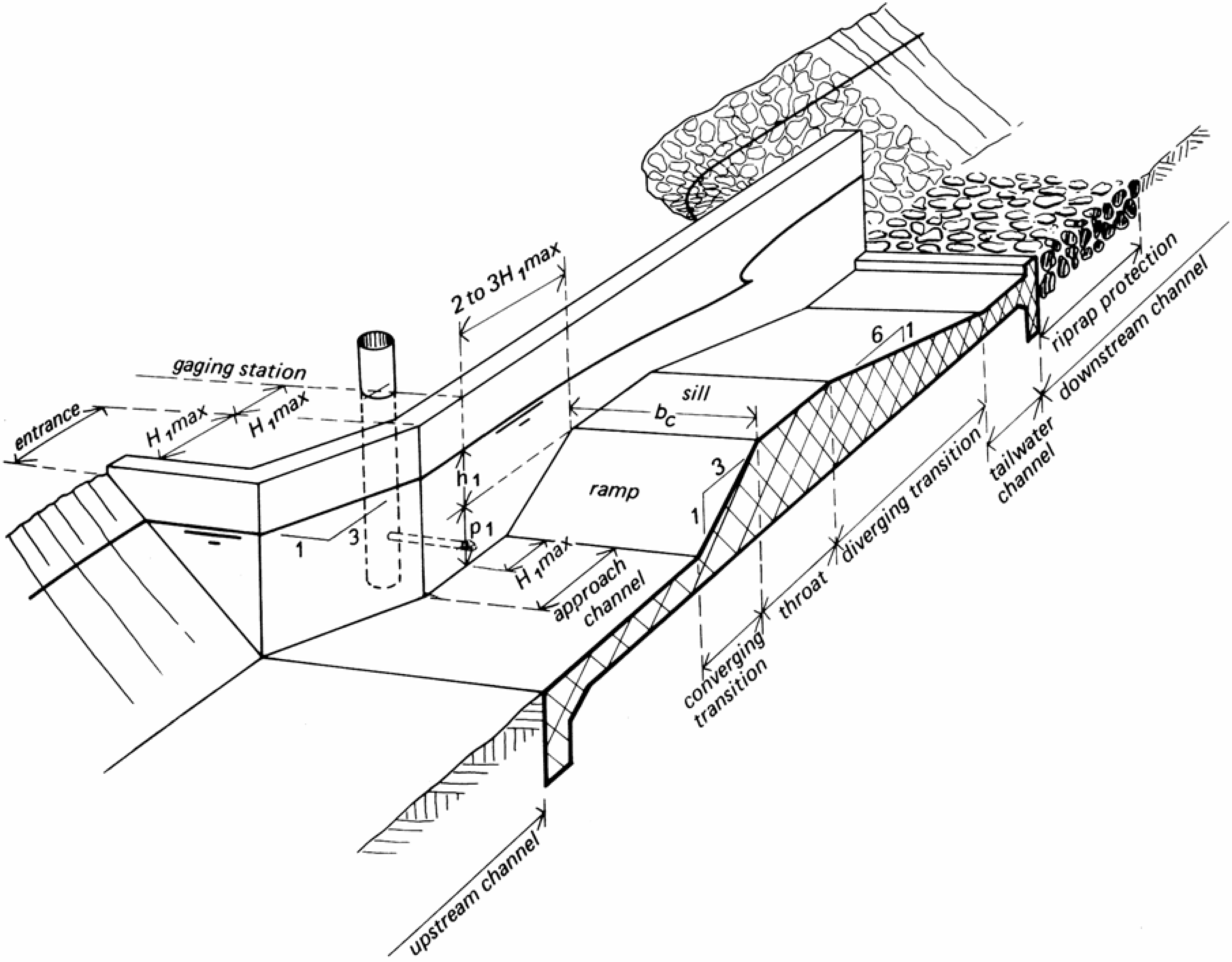


Throat Section Shape Selection

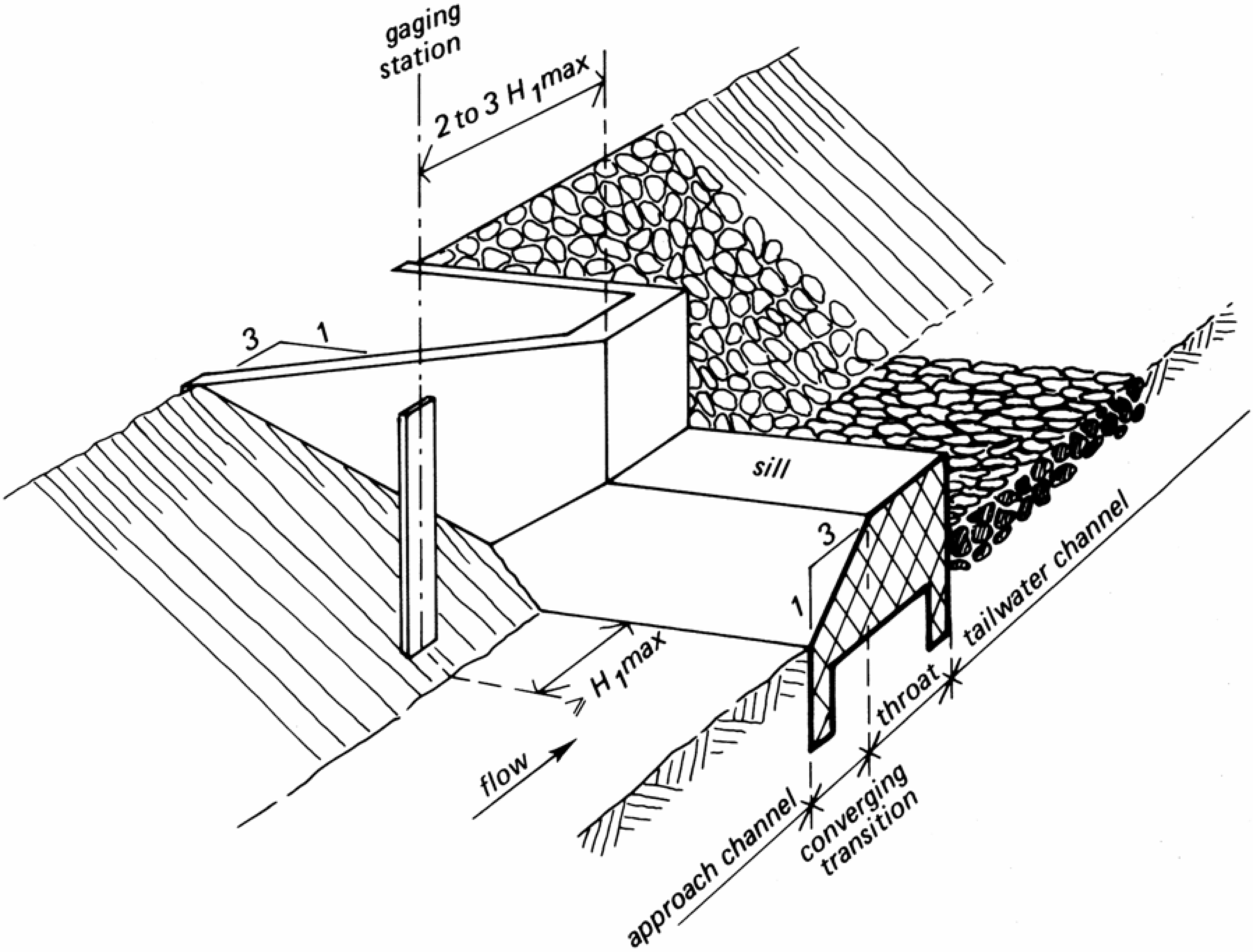
- Constructability
- Range of Flows to be Measured

Shape	Q_{max}/Q_{min} ±2% uncertainty	Q_{max}/Q_{min} ±4% uncertainty
Rectangular	35	100
Triangular	350	1970
Trapezoidal – wide at top	55	180
Trapezoidal – narrow at top	210	1080
Parabolic	105	440
Complex – wide at top	> 100	> 200
Complex – narrow at top	> 250	> 2000


flow
stilling well
for recorder
staff gage
survey point for establishing gage zero
reference, L/4 to L/3 from end, on weir
center line
concrete lined canal
recorder
top of canal
F_1
h_1
y_1
p_1
3
1
y_2
d
L_a
L_b
L
x
SECTION ALONG CENTER LINE
b_c
p_1
1
z
b_1
CROSS SECTION



2 to 3H 1max
gaging station
entrance
H 1max
H 1max
sill
b c
h 1
p 1
ramp
1
3
1
3
6
1
H 1max
approach channel
converging transition
throat
diverging transition
tailwater channel
downstream channel
riprap protection
upstream channel



gaging station
2 to 3 $H_1 max$
3
1
sill
3
1
$H_1 max$
flow
throat
tailwater channel
approach channel
converging transition

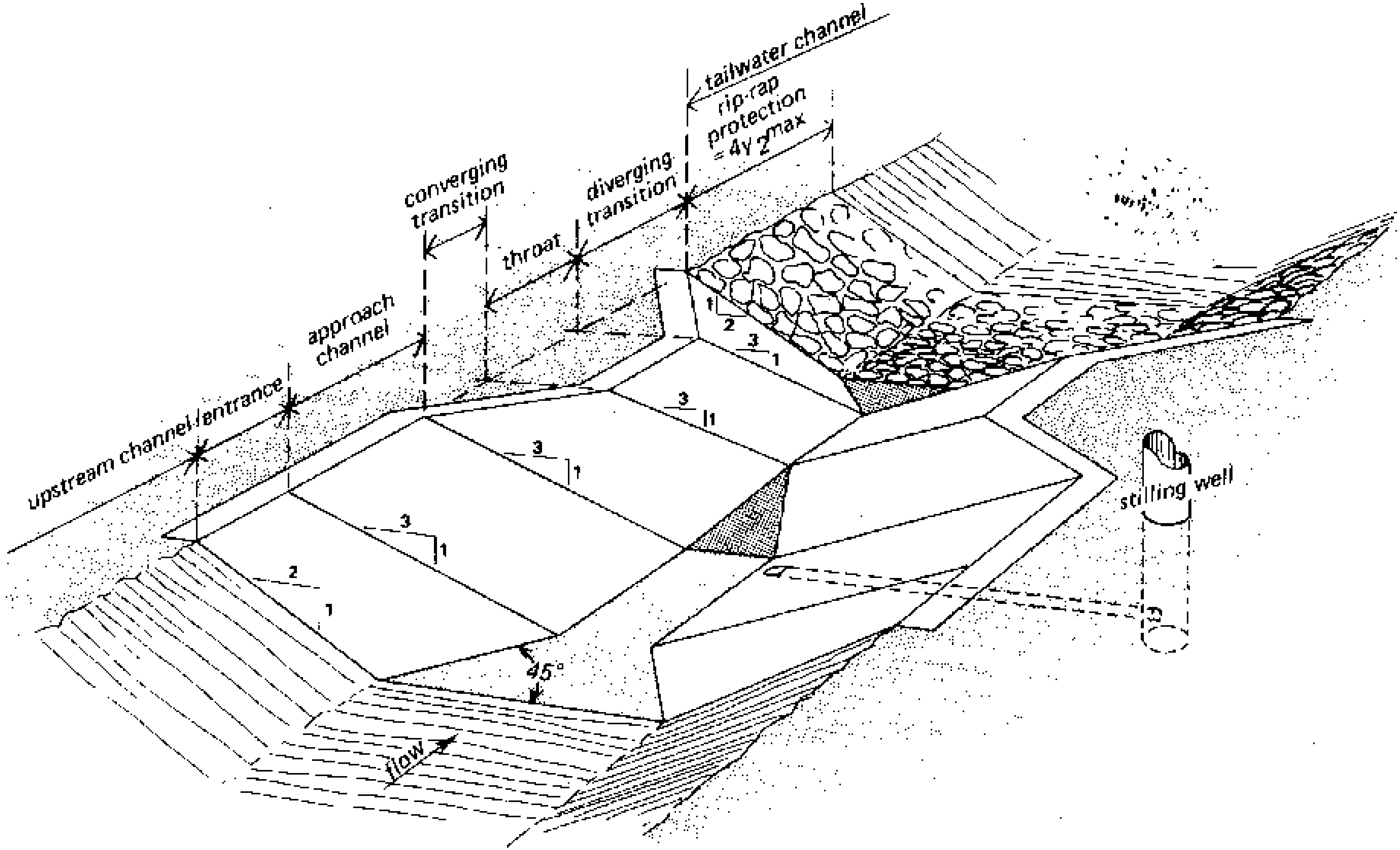


Figure 4.12. Triangular-throated flume.

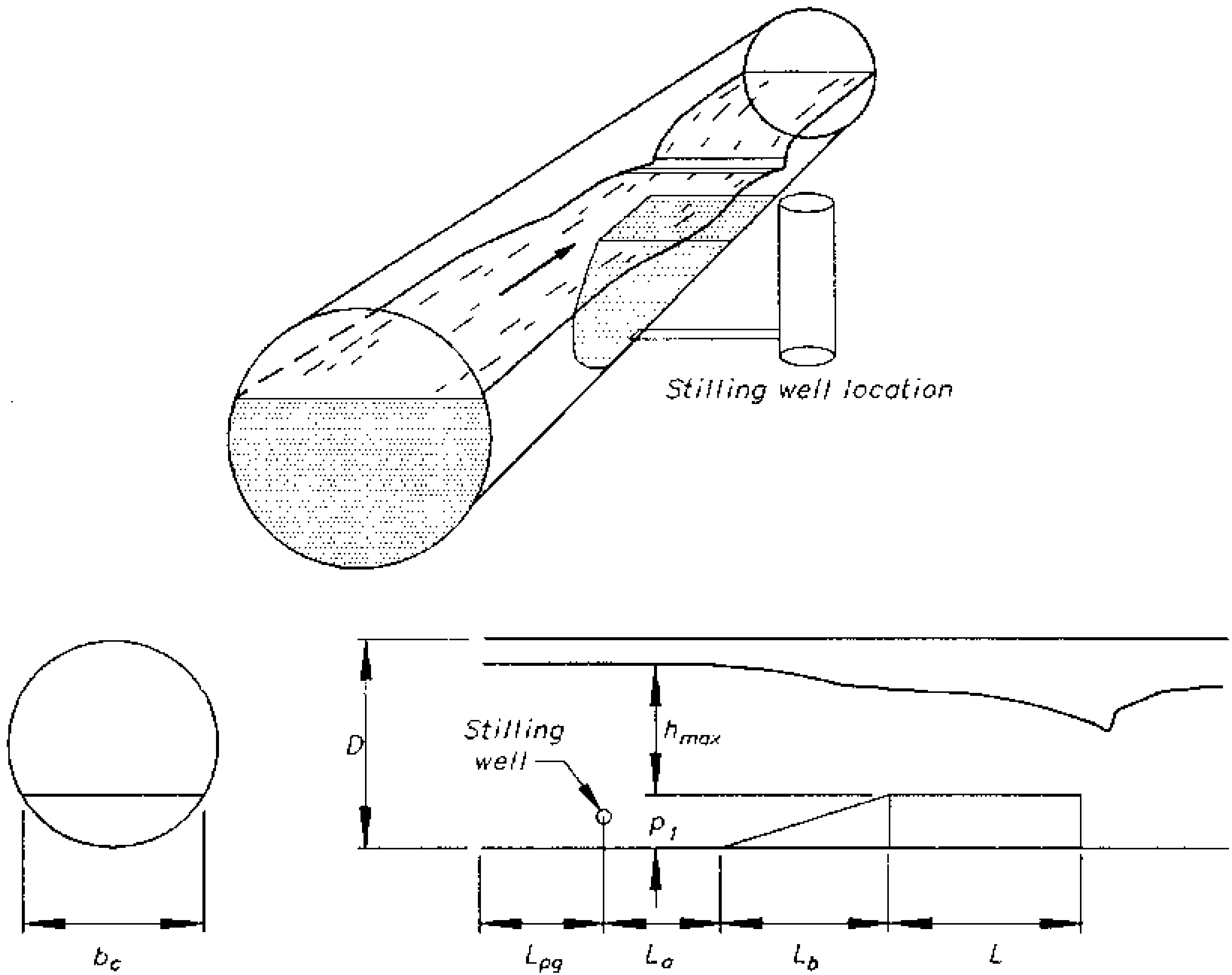


Figure 8-7.—Long-throated flume in a partially filled circular conduit.

Flume Design & Selection

- Pre-computed flume designs can be chosen using tables in the Water Measurement Manual
- Designs can be developed using the WinFlume computer program
  - Allows for customization
  - Provides best rating table accuracy
  - Simplifies checking of design

WinFlume

SOFTWARE FOR THE DESIGN AND CALIBRATION OF LONG-THROATED FLUMES AND BROAD-CRESTED WEIRS

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Water Resources Research Laboratory
Denver, Colorado

USDA ARS

U.S. Water Conservation Laboratory
Phoenix, Arizona

ILRI

International Institute for Land Reclamation & Improvement

Wageningen, The Netherlands

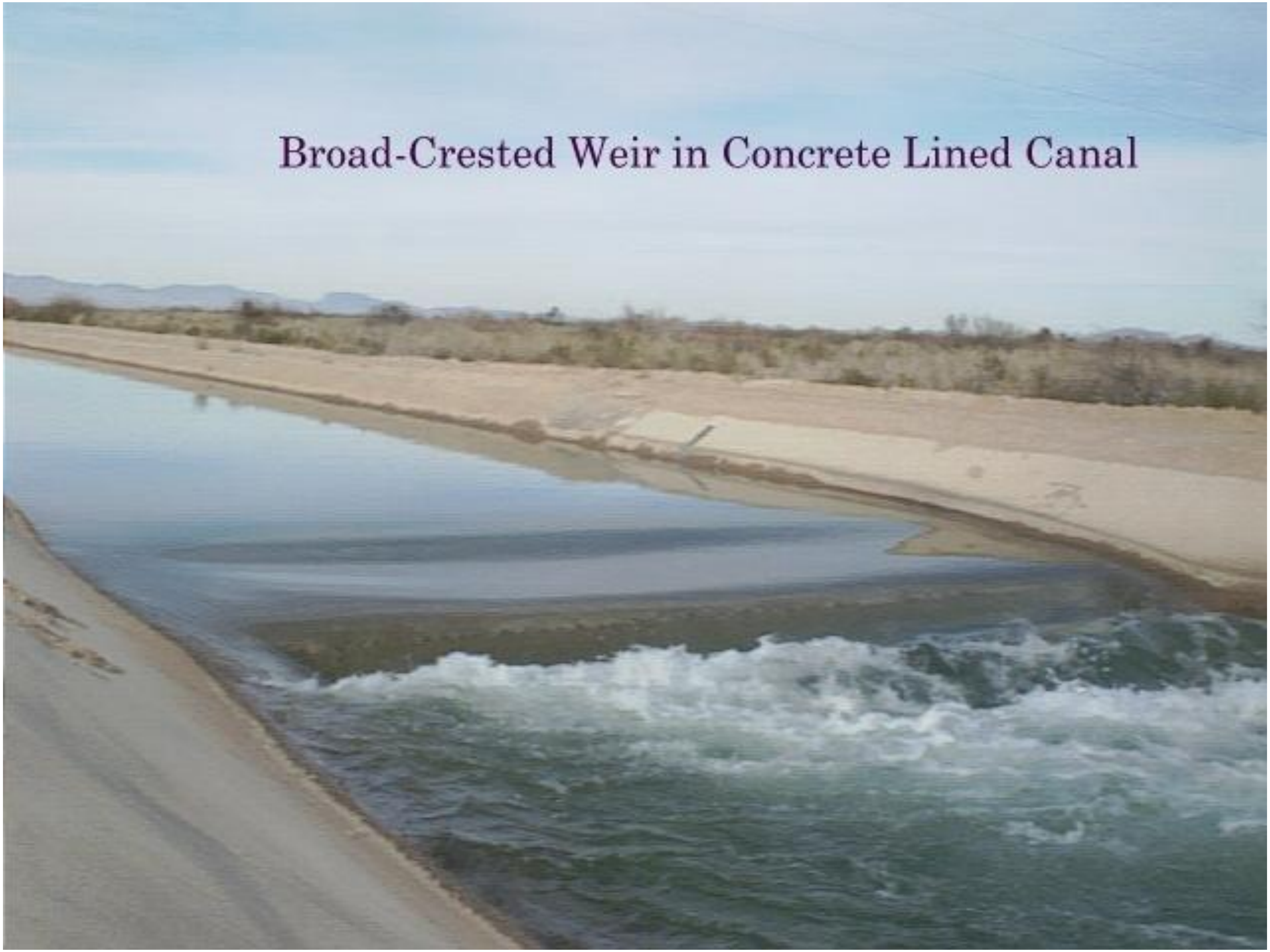
HOW TO OBTAIN WINFLUME

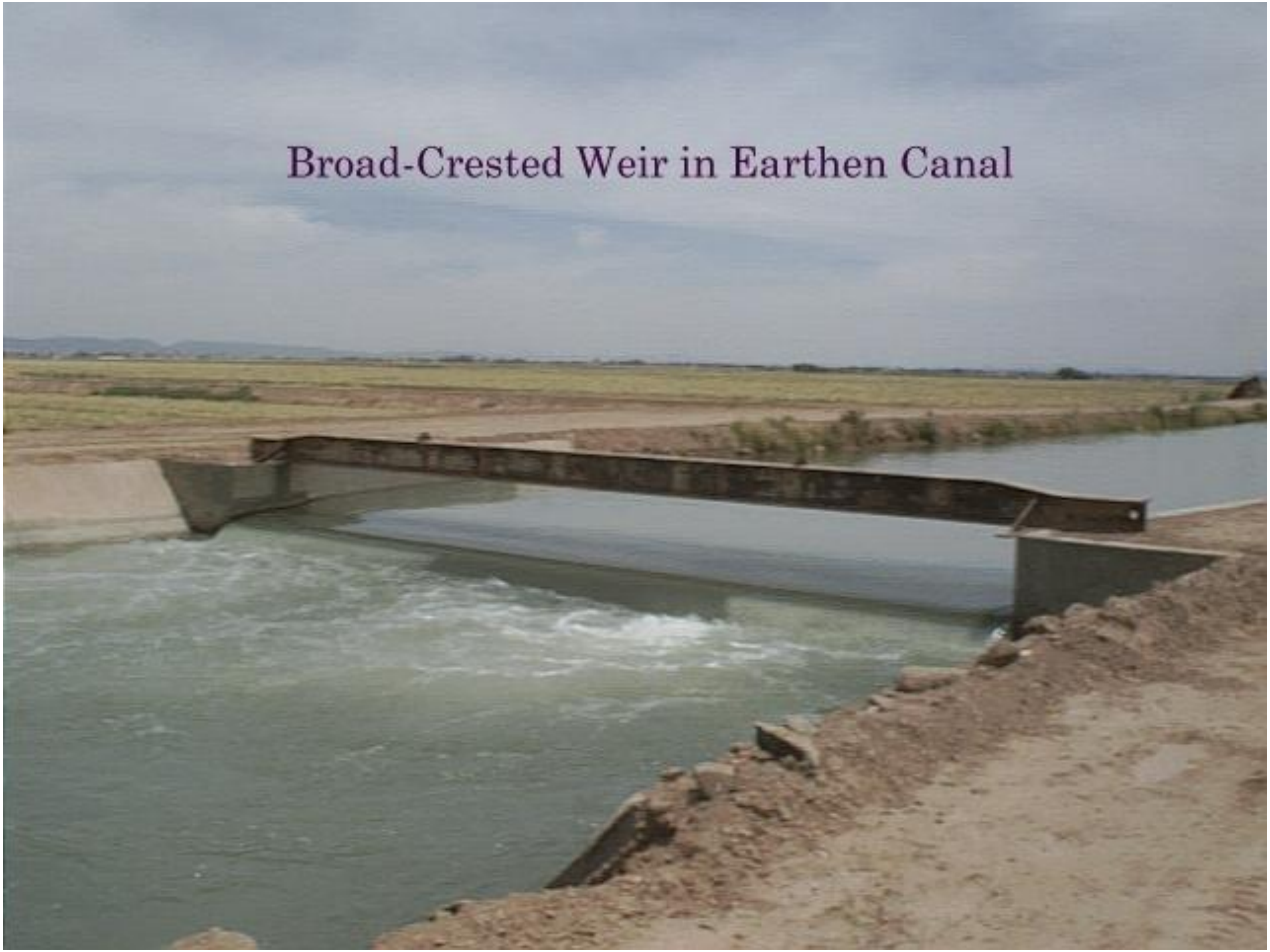
- The WinFlume program is available on the World Wide Web at:

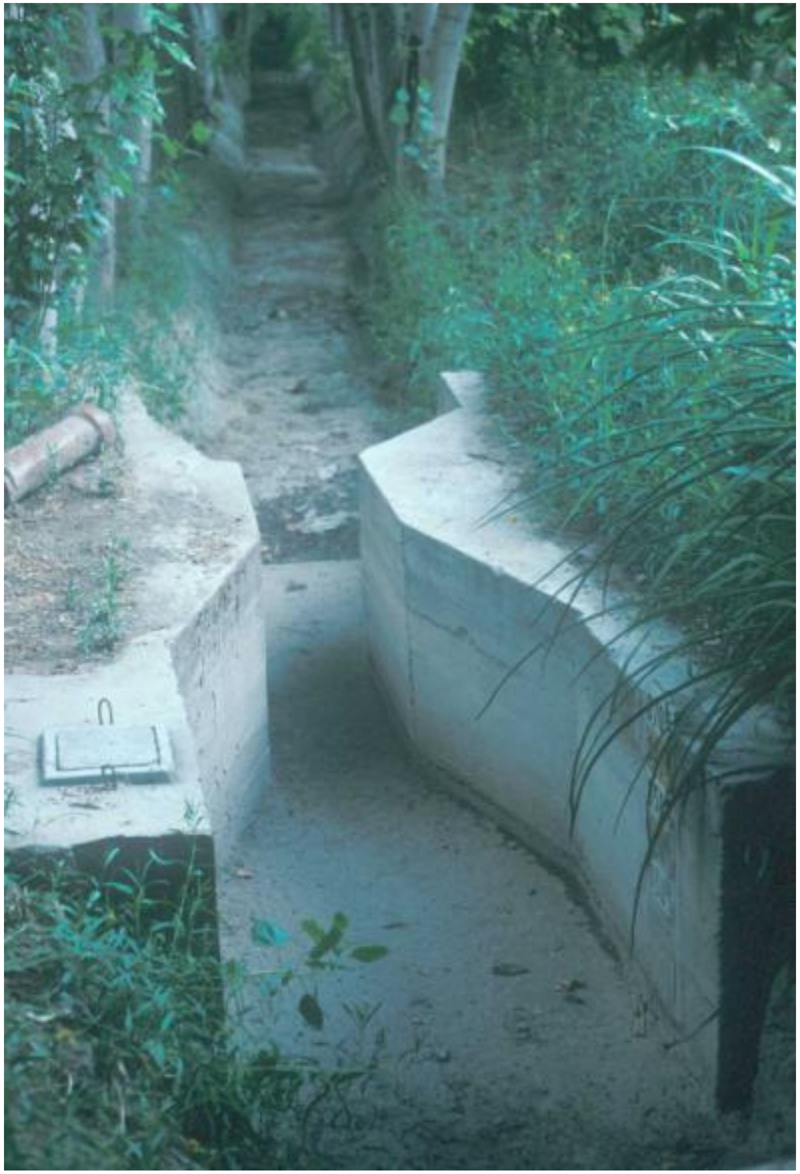
http://www.usbr.gov/pmts/hydraulics_lab/winflume

- There are 16-bit and 32-bit versions available that are appropriate for Windows 3.1x, Windows 95, Windows 98, and Windows NT systems.

This work has been funded by the U.S. Bureau of Reclamation's Water Conservation Field Services Program.


Broad-Crested Weir in Concrete Lined Canal


Broad-Crested Weir in Earthen Canal



Portable rectangular-throated flumes of fiberglass and metal


Portable plywood flumes for temporary measurements in larger ditches

12-inch Adjust-A-Flume in USBR lab

Large Adjust-A-Flume…portable if you have enough people

Temporary plywood flume in concrete-lined ditch





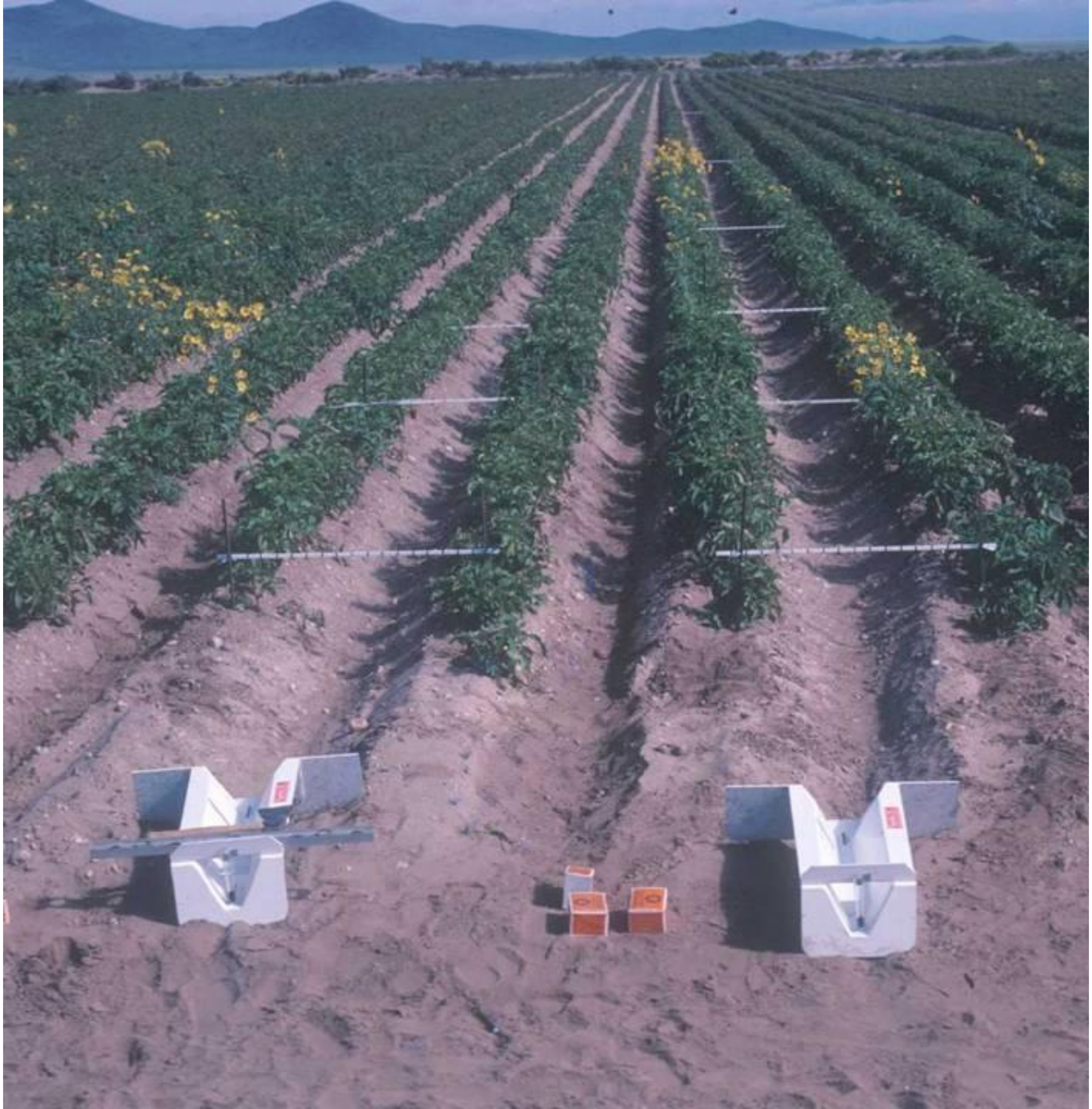
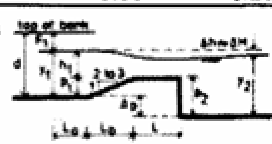



Table 8-2. — Long-throated flume sizes and discharge ranges for lined trapezoidal canals (English units)[a,e]

Canal Shape		Maximum canal depth[b], d (ft)	Range of Canal Capacities		Weir selection (table 8-3)	Weir Dimensions		Minimum head loss, ΔH[a] (ft)
Side slope Z_1	Bottom width, b_1 (ft)		Q_{min}[c] (ft³/s)	Q_{max} (ft³/s)		Crest width, b_c (ft)	Sill height, p_1 (ft)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1.0	1.0	2.5	1.9	8[d]	A_e	2.0	0.50	0.06
			4.2	16[d]	B_e	2.5	0.75	0.08
			4.8	19	C_e	3.0	1.00	0.10
			5.6	15	D_e	3.5	1.25	0.12
			6.2	11	E_e	4.0	1.50	0.13
1.0	2.0	3.0	5.6	27[d]	D_e	3.5	0.75	0.10
			6.2	40	E_e	4.0	1.00	0.12
			6.8	33	F_e	4.5	1.25	0.14
			7.4	27	G_e	5.0	1.50	0.15
			8.2	22	H_e	5.5	1.75	0.16
1.25	1.0	3.0	5.0	19[d]	I_e	3.0	0.8	0.08
			6.4	35	J_e	4.0	1.2	0.11
			7.6	26	K_e	5.0	1.6	0.14
1.25	2.0	4.0	6.4	31[d]	J_e	4.0	0.8	0.10
			7.6	64[d]	K_e	5.0	1.2	0.13
			8.9	78	L_e	6.0	1.6	0.16
			10.1	62	M_e	7.0	2.0	0.18
			11.4	46	N_e	8.0	2.4	0.20
1.5	2.0	4.0	8.	49[d]	P_e	5.0	1.00	0.11
			9.	82[d]	Q_e	6.0	1.33	0.13
			11.	86	R_e	7.0	1.67	0.16
			12.	72	S_e	8.0	2.00	0.18
			13.	60	T_e	9.0	2.33	0.20
1.5	3.0	5.0	9.	66[d]	Q_e	6.0	1.00	0.12
			11.	108[d]	R_e	7.0	1.33	0.14
			12.	140[d]	S_e	8.0	1.67	0.17
			13.	160	T_e	9.0	2.00	0.20
			14.	140	U_e	10.0	2.33	0.22
			17.	98	V_e	12.0	3.00	0.25



NOTES:

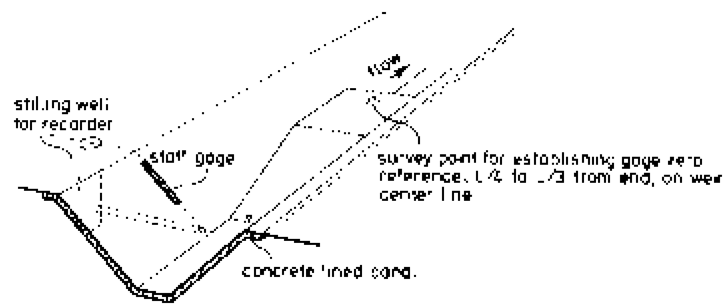
[a] $L_a \geq \Delta H_{1max}$; L_b=2 to 3p_1; $x=L_a+L_b$>2 to 3 H_{1max}
L>1.5 H_{1max}
d>1.2 $h_{1max}+p_1$
ΔH>0.1H_1

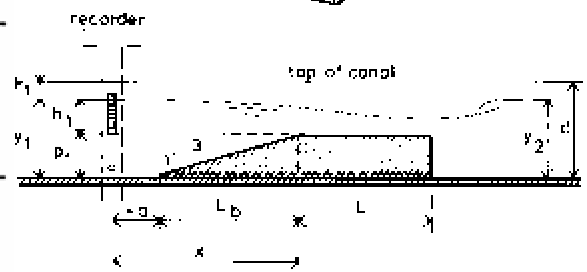
[b] Maximum recommended canal depth

[c] Limited by sensitivity

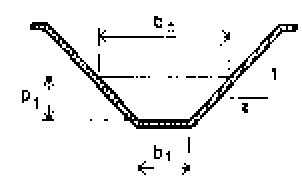
[d] Limited by Froude number; otherwise limited by canal depth

[e] Calibrations developed with WinFlume and the preceding computer models.





SECTION ALONG CENTER LINE



CROSS SECTION

Table 8-3. — Rating equation parameters and ranges of application for flat-crested, long-throated flumes in lined trapezoidal canals[a]

Parameters	Weir A_e	Weir B_e	Weir C_e	Weir D_e	Weir E_e	Weir F_e	Weir G_e
K_1	9.29	10.53	11.99	13.73	14.51	16.18	17.83
K_2	0.03	0.04	0.033	0.035	0.053	0.035	0.026
U	1.878	1.883	1.822	1.824	1.855	1.784	1.725
h_1, min.	0.12	0.14	0.125	0.13	0.19	0.175	0.16
h_1, max.	0.92	1.22	1.25	1.4	1.69	1.45	1.24
Q, min.	0.26	0.42	0.42	0.51	1.05	1.00	0.98
Q, max.	8.44	16.3	18.9	26.5	40.7	32.8	26.8

Parameters	Weir H_e	Weir I_e	Weir J_e	Weir K_e	Weir L_e	Weir M_e	Weir N_e
K_1	19.44	12.81	15.34	17.13	20.17	23.62	27.17
K_2	0.017	0.034	0.055	0.075	0.06	0.044	0.026
U	1.674	1.868	1.897	1.907	1.845	1.766	1.692
h_1, min.	0.15	0.125	0.185	0.254	0.228	0.205	0.19
h_1, max.	1.05	1.19	1.485	1.904	2.007	1.675	1.34
Q, min.	0.97	0.41	1.02	2.06	2.03	2.05	2.01
Q, max.	21.7	18.7	34.8	63.60	77.0	61.5	46.0

Parameters	Weir P_e	Weir Q_e	Weir R_e	Weir S_e	Weir T_e	Weir U_e	Weir V_e
K_1	18.95	20.96	23.94	25.61	28.13	31.29	38.44
K_2	0.05	0.07	0.056	0.072	0.072	0.062	0.034
U	1.874	1.906	1.856	1.866	1.841	1.8	1.709
h_1, min.	0.162	0.225	0.21	0.25	0.275	0.3	0.3
h_1, max.	1.6	2.0	2.2	2.5	2.5	2.25	1.7
Q, min.	1.0	2.0	2.1	3.1	4.0	5.0	5.9
Q, max.	48.4	83.9	108	149	160	141	98.5

[a] Calibrations developed with WinFlume and preceding computer models.

$$Q = K_1(h_1+K_2)^U$$

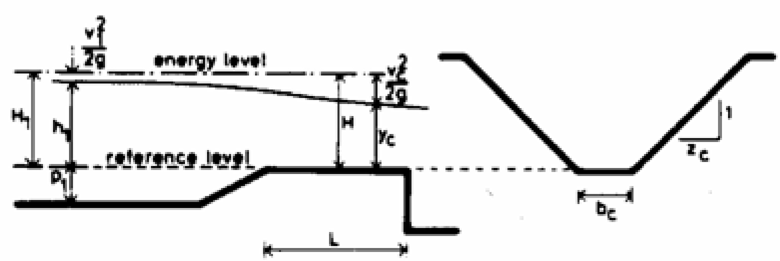


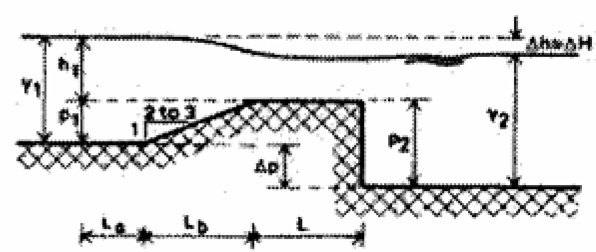
Table 8-4. — Rating equation parameters and ranges of application for flat-crested, long-throated flumes with rectangular throat sections (see Figure 8-6).

$q = K_1(h_1+K_2)^U$ where q is the unit discharge in cubic feet per second per foot of width of the throat.
$Q = qb_c$

Parameters	$0.35 \le b_c \le 0.65$ ft, L = 0.75 ft			$0.65 \le b_c \le 1.0$ ft, L = 1.0 ft			$1.0 \le b_c \le 1.5$ ft, L = 1.5 ft		
	p_1 = 0.125 ft	p_1 = 0.25 ft	$p_1 = \infty$	p_1 = 0.25 ft	p_1 = 0.5 ft	$p_1 = \infty$	p_1 = 0.25 ft	p_1 = 0.5 ft	$p_1 = \infty$
K_1	3.996	3.610	3.126	3.696	3.385	3.089	3.686	3.400	3.059
K_2	0	0	0	0.004	0	0	0	0	0
U	1.612	1.581	1.526	1.617	1.562	1.518	1.598	1.569	1.515
h_1, range	0.06 – 0.46	0.06 – 0.48	0.05 – 0.5	0.08 – 0.7	0.8 – 0.7	0.08 – 0.8	0.1 – 0.9	0.1 – 1.0	0.1 – 1.0
q, range	0.04 – 1.15	0.04 – 1.14	0.03 – 1.08	0.07 – 2.1	0.07 – 1.95	0.07 – 1.8	0.09 – 3.1	0.09 – 3.4	0.09 – 3.1
ΔH	0.04	0.06	0.19	0.06	0.10	0.26	0.07	0.11	0.67

Parameters	$1.5 \le b_c \le 3.0$ ft, L = 2.25 ft				$3.0 \le b_c \le 6.0$ ft, L = 3.0 ft			
	p_1 = 0.25 ft	p_1 = 0.5 ft	p_1 = 1.0 ft	$p_1 = \infty$	p_1 = 0.5 ft	p_1 = 1.0 ft	p_1 = 1.5 ft	$p_1 = \infty$
K_1	3.662	3.375	3.19	3.036	3.362	3.169	3.167	3.027
K_2	0.008	0.011	0.009	0	0.013	0.013	0	0
U	1.643	1.625	1.587	1.514	1.636	1.605	1.557	1.519
h_1, range	0.15 – 1.0	0.15 – 1.5	0.15 – 1.5	0.15 – 1.5	0.21 – 1.84	0.22 – 1.93	0.21 – 1.98	0.2 – 2.04
q, range	0.18 – 3.2	0.17 – 6.6	0.17 – 6.1	0.17 – 5.6	0.29 – 9.24	0.29 – 9.28	0.29 – 9.26	0.26 – 9.24
ΔH	0.07	0.13	0.2	0.5	0.13	0.22	0.29	0.63

Parameters	$b_c \ge 6.0$ ft, L = 4.0 ft			
	p_1 = 1.0 ft	p_1 = 1.5 ft	p_1 = 2.0 ft	$p_1 = \infty$
K_1	3.125	3.150	3.105	2.999
K_2	0.017	0.016	0	0
U	1.621	1.575	1.563	1.521
h_1, range	0.3 – 3.0	0.3 – 2.6	0.3 – 2.64	0.3 – 3.0
q, range	0.48 – 19	0.48 – 14.2	0.48 – 14.2	0.48 – 16
ΔH	0.25	0.33	0.40	0.85



$L_a = h_{1max}$ and L_b = 2 to 3 times p_1 and $L_a + L_b$ = 2 to 3 times h_{1max}
$\Delta H = 0.1H_1$, or value listed, whichever is greater, for flumes discharging into a rectangular tailwater channel of the same width as the crest, b_c
$\Delta H = 0.4H_1$, or value listed, whichever is greater, for flumes with an abrupt expansion into a tailwater channel wider than the crest width, b_c

Table 8-5. — Equation and flow range parameters for flat-crested, long-throated flumes in partially full circular conduits (K_1 and K_2 values are valid for units of feet and ft^3/s only).

p_1/D	L_a/D	L_b/D	L/D	K_1	K_2	U	range of h_1/D	range of $Q/D^{5/2}$	b_c/D
0.20	0.50	0.60	0.700	4.176	0.007	1.750	0.080 - 0.43	0.056 - 0.980	0.800
0.25	0.60	0.75	1.125	3.970	0.004	1.689	0.070 - 0.60	0.048 - 1.689	0.866
0.30	0.55	0.90	1.050	3.780	0	1.625	0.070 - 0.55	0.050 - 1.434	0.917
0.35	0.50	1.05	0.975	3.641	0	1.597	0.065 - 0.50	0.046 - 1.202	0.954
0.40	0.45	1.20	0.900	3.507	0	1.573	0.060 - 0.45	0.042 - 0.991	0.980
0.45	0.40	1.35	0.825	3.378	0	1.554	0.055 - 0.40	0.037 - 0.807	0.995
0.50	0.35	1.50	0.750	3.251	0	1.540	0.050 - 0.35	0.032 - 0.640	1.000

Pregage distance, $L_{pg} \geq h_{max}$
Approach, $L_a \geq h_{max}$
Converging, $L_{cv} = 3p_1$
Control, $L_c \geq 1.5D - p_1$

Sill height = p_1
Dimensionless sill height = p_1/D
$h_{min} = 0.07D$
$h_{max} = [0.85D - p_1]$

$$Q = D^{2.5} K_1 \left(\frac{h_1}{D} + K_2 \right)^U$$

$\Delta H = 0.1H_1$ for flumes with a 6:1 downstream transition
$\Delta H = 0.2H_1$ for flumes with a vertical drop downstream from the crest

Note: The length values shown are minimum lengths in direction of flow, and may be increased 30 percent with only a slight change in calibration.

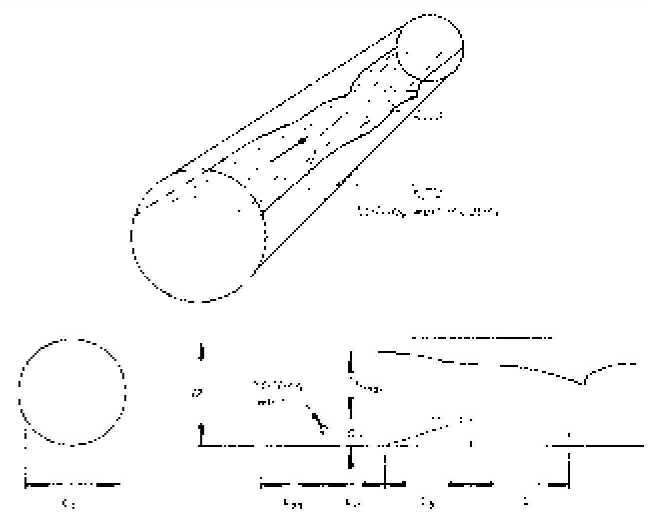


Figure 8-7.—Long-throated flume in a partially filled circular conduit.