CHAPTER 5

OPEN CHANNEL HYDROLOGY

5.10 Gradually Varied Flow – Example Problems

5.10.1 Example 1 – Direct Step Method

Using the direct step method (Section 5.9.2) to compute a water surface profile for a trapezoidal channel using the following data:

Q	= 400 cfs	B	= 20 ft
z	= 2	S	= 0.0016 ft/ft
n	= 0.025	α	= 1.10

A dam backs up water to a depth of 5 ft immediately behind the dam. The upstream end of the profile is assumed to have a depth 1 percent greater than normal depth.

Results of calculations are reported in Table 5.10.1-1. Values in each column of the table are briefly explained below.

5.10.1.1 Depth of flow, in ft, arbitrarily assigned values ranging from 5 to 3.4 ft.

5.10.1.2 Water area in sq ft, corresponding to the depth, y, in column 1.

5.10.1.3 Hydraulic radius, in ft, corresponding to y in column 1.

5.10.1.4 Mean velocity, in ft/s, obtained by dividing 400 cfs by the water area in column 2.

5.10.1.5 Velocity head, in ft calculated using the mean velocity from column 4 and a value of 1.1.

5.10.1.6 Specific energy, E, in ft, obtained by adding the velocity head in column 5 to the depth of flow in column 1.

5.10.1.7 Change of specific energy, delta E, in ft, equal to the difference between the E value in column 6 and that of the previous step.

Table 5.10.1-1
Direct Step method Results For Example

y (1)	A (2)	R (3)	v (4)	$\alpha v^2/2g$ (5)	E (6)	ΔE (7)	S_f (8)	$\bar{S}_f$ (9)	$S_o - \bar{S}_f$ (10)	Δx (11)	x (12)
5.00	150.00	3.54	2.667	0.1217	5.1217	--	0.000370	--	--	--	--
4.80	142.08	3.43	2.819	0.1356	4.9356	0.1861	0.000433	0.000402	0.001198	155	155
4.60	134.32	3.31	2.979	0.1517	4.7517	0.1839	0.000507	0.000470	0.001130	163	318
4.40	126.72	3.19	3.156	0.1706	4.5706	0.1811	0.000598	0.000553	0.001047	173	491
4.20	119.28	3.08	3.354	0.1925	4.3925	0.1781	0.000705	0.000652	0.000948	188	679
4.00	112.00	2.96	3.572	0.2184	4.2184	0.1741	0.000850	0.000778	0.000822	212	891
3.80	104.88	2.84	3.814	0.2490	4.0490	0.1694	0.001020	0.000935	0.000665	255	1,146
3.70	101.38	2.77	3.948	0.2664	3.9664	0.0826	0.001132	0.001076	0.000524	158	1,304
3.60	97.92	2.71	4.085	0.2856	3.8856	0.0808	0.001244	0.001188	0.000412	196	1,500
3.55	96.21	2.68	4.158	0.2958	3.8458	0.0398	0.001310	0.001277	0.000323	123	1,623
3.50	94.50	2.65	4.233	0.3067	3.8067	0.0391	0.001382	0.001346	0.000254	154	1,777
3.47	93.48	2.63	4.278	0.3131	3.7831	0.0236	0.001427	0.001405	0.000195	121	1,898
3.44	92.45	2.61	4.326	0.3202	3.7602	0.0229	0.001471	0.001449	0.000151	152	2,050
3.42	91.80	2.60	4.357	0.3246	3.7446	0.0156	0.001500	0.001486	0.000114	137	2,187
3.40	91.12	2.59	4.388	0.3292	3.7292	0.0154	0.001535	0.001518	0.000082	188	2,375

Note: $Q = 400$ cfs $n = 0.025$ $S_o = 0.0016$ $\alpha = 1.10$ $y_c = 2.22$ ft $y_n = 3.36$ ft

Reference: Chow (1959).

5.10.1.8 Friction slope, S_f, computed by equation 5.15, with n = .0.25, v as given in column 4, and R as given in column 3.

5.10.1.9 Average friction slope between the steps, S_f, equal to the arithmetic mean of the friction slope computed in column 8 and that of the previous step.

5.10.1.10 Difference between the bottom slope, S_O, 0.0016 and the average fiction slope, S_f, in column 9.

5.10.1.11 Length of the reach, delta x, in ft, between the consecutive steps, computed by equation 55.9.2.9-1 or by dividing the value of delta E in column 7 by the value of S_O-S_f in column 10.

5.10.1.12 Distance from the section under consideration to the dam site. This is equal to the cumulative sum of the values in column 11 computed for previous steps.

5.10.2 Example 2 – Standard Step Method

Use the standard step method (see Section 5.9.3) to compute a water surface profile for the channel data and stations considered in the previous example. Assume the elevation at the dam site is 600 ft.

Results of the calculations are reported in Table 5.10.2-1 Values in each column of the table are briefly explained below:

5.10.2.1 Section identified by station number such as "station 1 + 55." The locations of the stations are fixed at the distances determined in the previous example to compare the procedure with that of the direct step method.

5.10.2.2 Water surface elevation, z, at the station. A trial value is first entered in this column; this will be verified or rejected on the basis of the computations made in the remaining columns of the table. For the first step, this elevation must be given or assumed. Since the elevation of the dam site is 600 ft and the height of the dam is 5 ft, the first entry is 605.00 ft. When the trial value in the second step has been verified, it becomes the basis for the verification of the trial value in the next step, and the process continues.

5.10.2.3 Depth of flow, y, in ft, corresponding to the water surface elevation in column 2. For instance, the depth of flow at station 1 + 55 is equal to the water surface elevation minus the elevation at the dam site minus the distance from the dam site times bed slope. 605.048 – 600.00 – (155) (0.0016) = 4.80 ft.

5.10.2.4 Water area, A, in square ft, corresponding to y in column 3.

5.10.2.5 Hydraulic radius, R, in ft, corresponding to y in column 3.

5.10.2.6 Mean velocity, v, equal to the given discharge 400 cfs divided by the water area in column 4.

5.10.2.7 Velocity head, in ft, corresponding to the velocity in column 6 and a value of 1.1.

5.10.2.8 Total head, H, equal to the sum of z in column 2 and the velocity head in column 7.

Table 5.10.2-1
Standard Step Method Results For Example

Station	z	y	A	R	v	$\alpha v^2/2g$	H	S_f	$\bar{S}_f$	Δx	h_f	h_e	H
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
0 + 00	605.000	5.00	150.00	3.54	2.667	0.1217	605.122	0.000370	--	--	--	--	605.122
1 + 55	605.048	4.80	142.08	3.43	2.819	0.1356	605.184	0.000433	0.000402	155	0.062	0	605.184
3 + 18	605.109	4.60	134.32	3.31	2.979	0.1517	605.261	0.000507	0.000470	163	0.077	0	605.261
4 + 91	605.186	4.40	126.72	3.19	3.156	0.1706	605.357	0.000598	0.000553	173	0.096	0	605.357
6 + 79	605.286	4.20	119.28	3.08	3.354	0.1925	605.479	0.000705	0.000652	188	0.122	0	605.479
8 + 91	605.426	4.00	112.00	2.96	3.572	0.2184	605.644	0.000850	0.000778	212	0.165	0	605.644
11 + 46	605.633	3.80	104.88	2.84	3.814	0.2490	605.882	0.001020	0.000935	255	0.238	0	605.882
13 + 04	605.786	3.70	101.38	2.77	3.948	0.2664	606.052	0.001132	0.001076	158	0.170	0	606.052
15 + 00	605.999	3.60	97.92	2.71	4.085	0.2856	606.285	0.001244	0.001188	196	0.233	0	606.285
16 + 23	606.146	3.55	96.21	2.68	4.158	0.2958	606.442	0.001310	0.001277	123	0.157	0	606.442
17 + 77	606.343	3.50	94.50	2.65	4.233	0.3067	606.650	0.001382	0.001346	154	0.208	0	606.650
18 + 98	606.507	3.47	93.48	2.63	4.278	0.3131	606.820	0.001427	0.001405	121	0.170	0	606.820
20 + 50	606.720	3.44	92.45	2.61	4.326	0.3202	607.040	0.001471	0.001449	152	0.220	0	607.040
21 + 87	606.919	3.42	91.80	2.60	4.357	0.3246	607.244	0.001500	0.001486	137	0.204	0	607.244
23 + 75	607.201	3.40	91.12	2.59	4.388	0.3292	607.530	0.001535	0.001518	188	0.286	0	607.530

Note: Q = 400 cfs n = 0.025 S_o = 0.0016 α = 1.10 h_e = 0 y_c = 2.22 ft y_n = 3.36 ft

Reference: Chow (1959).

5.10.2.9 Friction slope, S_f, computed by equation 5.9.2.2-1, with n = 0.025, v from column 6, and R from column 5.

5.10.2.10 Average friction slope through the reach, S_f, between the sections in each step, approximately equal to the arithmetic mean of the friction slope just computed in column 9 and that of the previous step.

5.10.2.11 Length of the reach between the sections, delta x, equal to the difference in station numbers between the stations.

5.10.2.12 Friction loss in the reach, $h_{f,}$, equal to the product of the values in columns 10 and 11.

5.10.2.13 Eddy loss in the reach, h_e equal to zero.

5.10.2.14 Elevation of the total head, H, in ft, computed by adding the values of h_f and h_e in columns 12 and 13 to the elevation at the lower end of the reach, which is found in column 14 of the previous reach. If the value obtained does not agree closely with that entered in column 8, a new trial value of the water surface elevation is assumed until agreement is obtained. The value that leads to agreement is the correct water surface elevation. The computation may then proceed to the next step.

END OF SECTION 5.10